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The "Semiconductor Crisis" as a Result of the COVID-19 Pandemic and Impacts on the Automotive Industry and Its Supply Chains

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Abstract: In the first half of 2020, the coronavirus pandemic led to a drastic slump in the automotive industry, which was replaced by a surprisingly rapid growth in demand in the fall of 2020, and consequently led to the current shortages in microelectronic products. The prospect of an equally rapid economic recovery in the automotive industry is still threatened by supply bottlenecks for raw materials and key components, foremost for semiconductors. The so-called 'semiconductor crises' show exemplarily the overlapping of short-term supply chain disruptions with long-term structural features of the semiconductor industry. The combination of both is preventing that the supply situation in the automotive industry will improve quickly. First in this paper, the reasons for and respective effects of the crisis on the automotive industry are investigated by a quantitative market analysis. Second, specific strategic measures and options of automotive Original Equipment Manufacturers (OEM) and suppliers in Germany to cope with the situation and increase resilience in future supply chains are described by the means of qualitative expert interviews. By that, the paper helps in understanding the actual situation in the automotive industry, on the one hand, and contributes to the field of strategic supply chain and risk management with a focus on practical implications on the other hand. The results aim to support political stakeholders as well as small and medium sized enterprises to prepare themselves for future developments in the automotive market and changes in manufacturer–supplier relationships due to the transformation to new powertrain technologies and digitization.

Keywords: market development; automotive industry; strategy; semiconductor; supply chain; COVID-19

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1. Introduction

As a direct consequence of the coronavirus pandemic, both demand and sales in the global passenger car market collapsed. The COVID-19-related closures of production plants led to global production losses for automotive manufacturers; in the first and second quarters of 2020, automotive production fell by a total of around 9.6% (approx. 7.7 million vehicles) and OEMs reduced their capacity planning requirements for supplier parts accordingly, including electronic components and semiconductors [1]. At the end of 2020, however, demand rose again surprisingly quickly, driven, in particular, by a recovery of the Chinese automotive market and by the higher sales of electrified vehicles associated with the German innovation premium. By the end of the year, passenger car sales in China alone were around 500,000 vehicles higher than the figures forecast in the fall of 2020 [2].

At the same time, demand for consumer electronics (e.g., smartphones, game consoles, TVs) increased during the coronavirus pandemic, which led to a change in prioritization and a shift in capacity of semiconductor manufacturers towards IT and consumer electronics customers. As a consequence, bottlenecks in the production and supply of electronic components for the automotive industry occurred, first and foremost among suppliers in the fourth quarter of 2020. In the meantime, and still ongoing in 2022, however, it is not only the suppliers who are affected, but almost all automotive manufacturers, who have had to reduce or (temporarily) completely stop the production of vehicles due to a lack of components and parts.

The use of semiconductors in vehicles will continue to increase due to electromobility and autonomous driving. Therefore, the stability of the supply chain is of high strategic importance for both the German and the European automotive industries.

The goal of this paper is to analyze the reasons for the ongoing shortage in semiconductor supply in the automotive industry, its impacts on automotive OEMs and suppliers, as well as to show how automotive companies in Germany develop strategies to cope with the situation and increase resilience in future supply chains.

2. Methodology

The analyses described in this paper were conducted using a combination of quantitative market analysis to (1) illustrate the causes and impacts of the crisis on the automotive sector and its companies, on the one hand, and qualitative expert interviews to (2) derive short- and long-term strategies for dealing with the crisis and increasing the resilience of supply chains in the future, on the other hand.

For the former (1), particular reference was made to news articles in the automotive industry, production and industry data, as well as annual reports of the companies affected at all stages of the value chain (OEM, Tier 1, Tier 2, Tier 3). It builds on the findings of existing market studies and enhances them with a special focus on the automotive and semiconductor industry and its dependencies in Germany [3–11]. It is accompanied by a description of the specifics and peculiarities of supplier relationships and value chains in the German automotive industry.

For the latter (2), and complementary to the market analysis, the study is based on 26 guided expert interviews conducted between July 2020 and September 2021. The interviewees primarily hold executive positions (including CEOs, heads of purchasing, heads of logistics, plant managers, production, supplier management) in the German automotive and mechanical engineering industries and cover all relevant stages of value creation in the automotive sector. In total, the interviews covered 3 OEMs, 4 system suppliers (Tier 1), 6 Tier 2 suppliers, 6 Tier 3 suppliers, 3 service providers, as well as 2 associations and 2 trade unions. They were conducted by telephone or video call, recorded, transcribed, anonymized, summarized and relevant statements were clustered according to the structure of the interview guide. The interview guide consisted of 7 main sections covering all relevant topics to assess the effects of the semiconductor crisis in the respective institutions: 1. Impacts of COVID-19/lockdowns/shortages on the company; 2. impact on production sales and labor volume; 3. specific supply chain disruptions and causes; 4. measures to handle the specific disruptions; 5. options to avoid future disruptions; 6. changes in future purchasing/procurement strategies; 7. expectations regarding transformation and electrification of the powertrain.

Results on how companies dealt with the semiconductor shortages and how they will try to increase supply chain resilience in the future were processed and compared in anonymized form. These will be described in Section 4 for the areas of operational measures (short-term) and strategic options (long-term). By that, this paper contributes significantly to the field of strategic management of supply chain risks with a special focus on the current practical implementation of solutions using the example of the German automotive industry. These results are unique because comparable studies focusing on practical solutions and options in the German automotive industry based on in-depth interviews do not exist in the current literature.

3. Results

In this section, the main results of the market study on the reasons for the semiconductor crisis (Section 3.1) and impacts on the automotive industry (Section 3.2) will be described and subsequently supplemented by the results of the expert interviews on (Section 3.3) options and strategies for German automotive companies to cope with the crisis and increase resilience in future supply chains.

3.1. Reasons for the Semiconductor Crisis

Various factors have led to the current supply bottlenecks, with both acute incidents and longer-term conditions having an impact on production volumes and the availability of electronic components for the automotive industry. The incidents that had an acute impact at the beginning of the crisis include:

- A fire at a semiconductor factory owned by chipmaker AKM in Nobeoka City, Japan:

In October 2020, a fire at a semiconductor plant of the Japanese chip manufacturer AKM, a subsidiary of Asahi Kasei K.K., led to the complete closure of production lines at the plant in Nobeoka City for about 12 months [12]. The electronic components produced there are used, among others, in audio and navigation systems for the automotive industry.

- A cold snap in Austin, Texas, North America (USA):

In February 2021, an arctic winter storm led to the collapse of the power supply and the closure of semiconductor factories in the US state of Texas. Among others, plants of NXP Semiconductors N.V., one of the largest suppliers to the automotive industry, Samsung Group and Infineon Technologies AG were affected [13–15]. Production was restricted for approximately 1 to 1.5 months.

- A fire at a semiconductor plant owned by chipmaker Renesas in Naka, Japan:

In March 2021, a fire at a semiconductor plant of the Japanese chip manufacturer Renesas Electronics K.K. in Naka led to a halt in the production of wafer components in particular [16].

The longer-term factors are rooted in the structure of the semiconductor market and the semiconductor industry itself, as well as in complex, elaborate production processes for manufacturing the chips. These more structural conditions mean that the problem is difficult for the automotive industry to solve in the near future. They will be described in detail in the following.

3.1.1. Structure of the Semiconductor Market and Automotive Share

The current structure of the semiconductor market works against the possibilities of a short-term increase in production capacities for customers in the automotive industry, as it represents only a small share of sales compared with other segments (such as communications). In 2020, for example, they accounted for only around 11% of global sales, while the communications and data technology segments accounted for almost 65% of total sales, amounting to EUR 352 billion [3].

China is now the world's largest sales market for semiconductor applications, with a market share of 35% in 2020. The development of market shares for the world regions of China, the Americas, Europe and Asia/Pacific from the year 2000 is shown in the following Figure 1:

Europe and Japan have an overall market share for semiconductors of less than 10% worldwide, and furthermore, the demand is mainly automotive-driven: the automotive industry accounted for 37% of semiconductor sales in Europe and 28% in Japan in 2019. By comparison, other segments dominate demand in the USA (with 10% automotive share) and China (7%). In the USA, for example, the "Computers" segment is in the lead with a share of 38%, in China the "Communications" segment is in the lead with 42% [4].

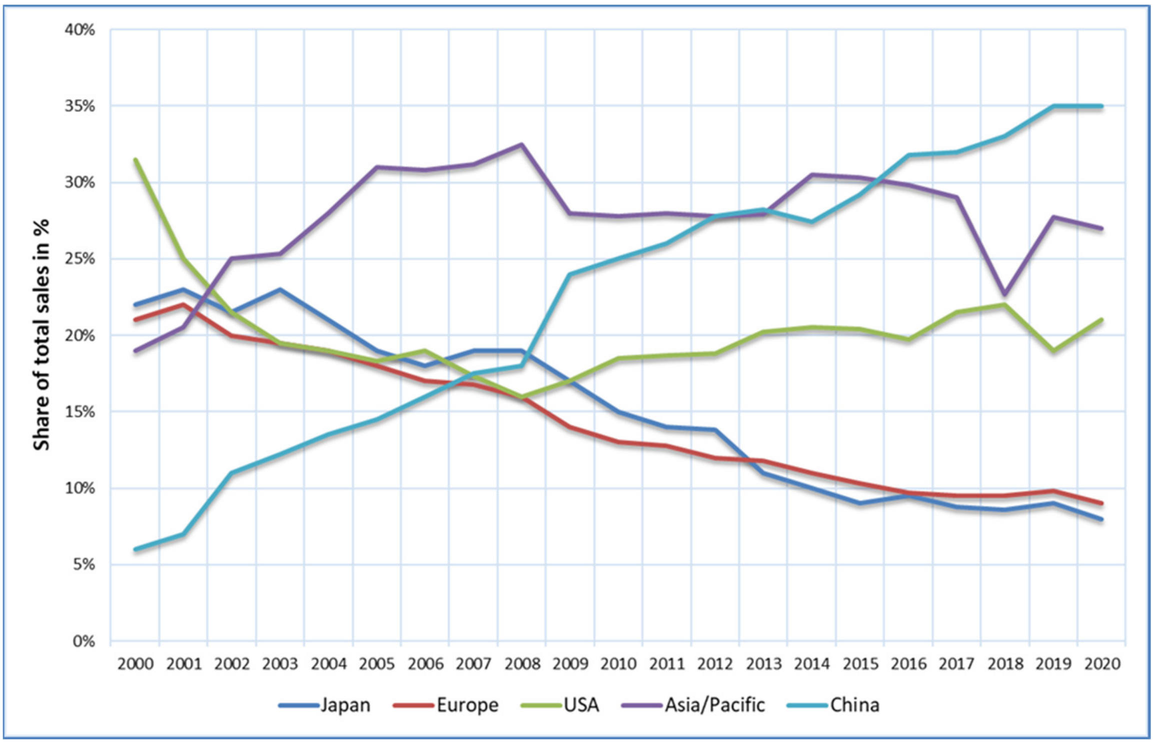

Figure 1. Development of market shares in semiconductor sales, 2000–2020 [3,4].

The shares of the individual segments in the total sales of the semiconductor market in comparison of the regions "World" and "Europe" are shown again graphically in the following Figure 2—the strong automotive focus for Europe (shown in purple) is clearly visible:

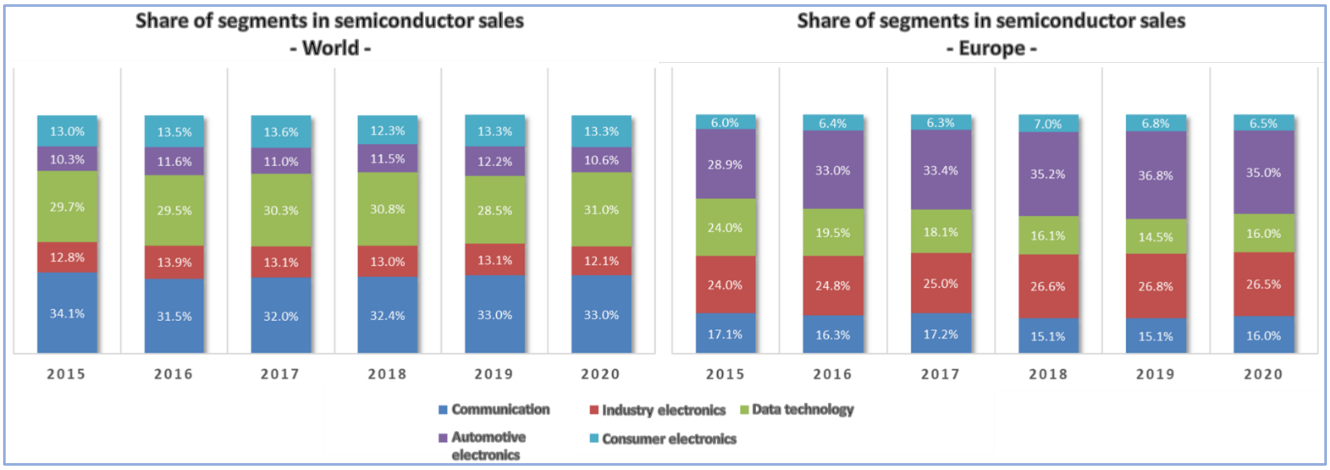

Figure 2. Share of individual segments in semiconductor sales in comparison with the world and Europe, 2015–2020 [3,4].

As an example, for eight of the largest semiconductor manufacturers, the respective relevance of the automotive business in terms of sales is shown below, whereby only NXP (44%), Infineon (42%) and Renesas (48%) have significant sales shares in the automotive sector. The other manufacturers, Texas Instruments (20%), Qualcomm (4%), AMD/ATI (1%) and NVIDIA (6%) primarily serve customers in the communications and consumer segments, which therefore buy much higher volumes overall and also provide chip manufacturers with greater profit margins. Even the world's largest chip manufacturer, TSMC

(Taiwan), has an automotive share of sales of only 3% (annual reports of NXP, Infineon, Renesas, Texas Instruments, Qualcomm, AMD, NVIDIA, TSMC, 2020). The market and negotiating position of the automotive industry for semiconductor products is correspondingly lower compared to other industries.

In the area of semiconductor components for automated and autonomous driving, the German manufacturers Audi, BMW, Mercedes and VW rely mainly on cooperation with the U.S. companies Qualcomm and Texas Instruments, and also in part on NVIDIA. In the case of electronic components for processing signal and information data, the German OEMs are supplied by Texas Instruments, BMW and Volkswagen, also by NXP (Netherlands), and Audi, also by Renesas (Japan). For the supply of power semiconductors for vehicle control, all German OEMs rely primarily on cooperation with Infineon (Germany) (Annual reports Audi, BMW, Infineon, Mercedes, NXP, Qualcomm, Renesas, Texas Instruments, VW, 2019).

3.1.2. Structure of the Semiconductor Industry and Production Capacities

The structure of the semiconductor industry itself, as well as the complex production process, also counteract any short-term easing of the supply situation in the automotive industry. Companies in the semiconductor industry can generally be divided into contract manufacturers with production capacities (so-called foundries) and companies without their own manufacturing and production facilities (so-called fabless) [5].

The latter focus their activities, in particular, on the areas of development of superior functions and designs (e.g., circuits), but not on the development and construction of investment-intensive production facilities. The so-called fabless companies include NVIDIA (USA), AMD/ATI (USA) and Qualcomm (USA), all of which—as described above—do not have a sales focus on the automotive business. Nevertheless, they also develop products that are a prerequisite for the realization of automated and autonomous driving functions. The main customer of these companies is TSMC in Taiwan, the world's leading company in terms of production capacity only in the 200 mm wafer sector [5]. However, TSMC also has a very small automotive share of sales in comparison.

The so-called foundries have their own production capacities for the manufacture of semiconductor products, which are characterized by high investment sums in the construction of highly automated production lines and can only operate economically competitively with large production volumes and quantities—often in three-shift operation and 24/7. The cost of setting up suitable production facilities amounts to several billion dollars [17]. The foundries include manufacturers such as TSMC (Taiwan), Texas Instruments (USA), Infineon (Germany), NXP (Netherlands) and Renesas (Japan). These producers focus mainly on the manufacture of chips for processing signal and information data (e.g., network controllers and navigation) or for vehicle control. Most of the other producing companies are located in Asia, e.g., Samsung (Korea), UMC (Taiwan), SMIC (China), TowerJazz Panasonic Semiconductor (Japan), VIS (Taiwan), PSMC (Taiwan), Hua Hong (China) and DB HiTek (Korea).

Production facilities at Chinese locations are also leading in the production of so-called wafers (the basic material of electronic components, primarily made of silicon) required for semiconductor components in a comparison of monthly production capacities of 200 mm variants: with approx. 5.6 million units and a share of 20%, ahead of Taiwan with approx. 5.3 million units (19%), South Korea and Japan with approx. 4.8 million units each (17%), the USA with 3.1 million units (11%) and Europe with 2.2 million units (8%). Fabs in these six world regions represent a total of 92% of global wafer production (approx. 28 million units per month). Experts expect this share to shift even further towards Chinese production facilities by 2024, with simultaneous growth in global output volume per year of approx. 5% to then approx. 36 million units per month [3].

In an analysis by headquarters of the leading semiconductor companies, however, U.S. manufacturers dominated the global market in 2019, with a 51% share of sales, followed by South Korea (19%), Europe and Japan (10% each), Taiwan (6%) and China (5%), as shown in Figure 3. Over a period of around 10 years, US companies have consistently accounted for a high share of sales (between 48% and 54%), similarly Europe and Taiwan with, however, much lower shares of sales (between 12% and 9% and 4% and 7%, respectively). Japan has seen a sharp decline over the same period since 2001, from 28% to just 10% in 2019, while at the same time South Korean companies increased their sales share from 6% to 24% in 2018. In 2019, however, this fell back to 19%. Chinese companies also increased their share of sales from 0% in 2001 to 5% in 2019 [3].

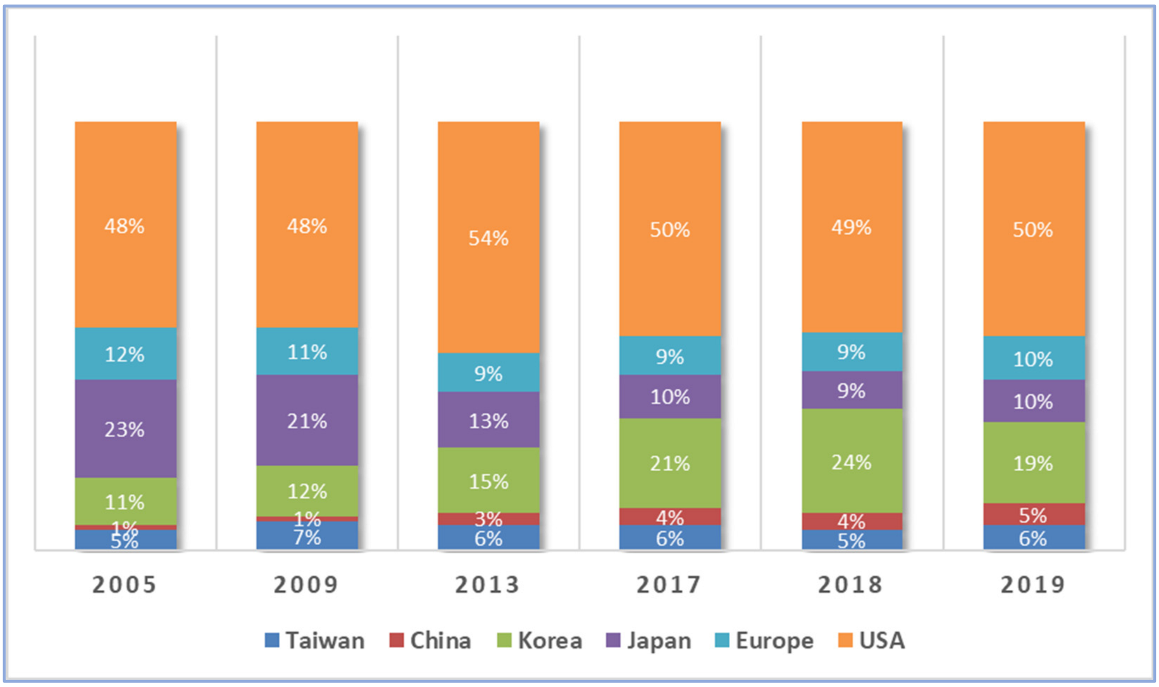

Figure 3. Development of market shares of sales by company headquarters [3].

3.1.3. Complex Production Processes and Supply Chains

The manufacture of semiconductor components is subject to a complex and elaborate production process, which also counteracts any rapid easing of the supply situation in the automotive industry. A total of around 5 to 8 months elapse between the order and the delivery of the component. The production of the wafer takes the most time, at around 3 months.

The raw material silicon required for this is separated from the quartz rock at high temperatures via a chemical reaction (so-called raw silicon) and freed from foreign substances (such as iron, aluminum, phosphorus). Subsequently, the arrangement of the atomic lattice structure is homogenized, and a so-called single crystal is produced from the silicon substrate or "pulled" from the silicon melt (so-called ingot).

These single-crystalline rods are processed into wafers in various steps, which are then coated and polished to form extremely flat surfaces, into which the circuit structures are burned on different levels in the nanometer range, for example using high-energy lasers (lithography). Finally, the individual chips are separated from the wafer, e.g., by sawing.

Wafers are produced in different sizes from 100 mm to 300 mm, whereby an increase in the diameter allows a higher production throughput and thus, lower production costs. By increasing the diameter from 200 mm to 300 mm, for example, the number of chips per wafer can be doubled. If the diameter is increased further (to 450 mm, for example), problems arise due to more complex processing steps and possible deformation.

The following Figure 4 schematically illustrates the production process and supply chain from ordering to delivery:

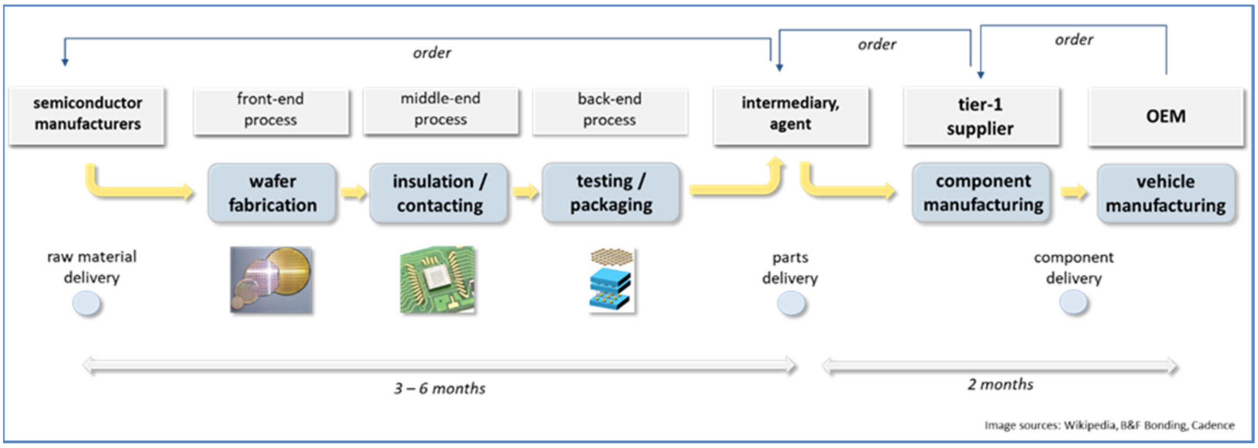

Figure 4. Production and supply chain for semiconductor components [18].

3.1.4. Increasing Importance of Microelectronics in the Automotive Industry

The demand and market for semiconductor elements will continue to grow in the automotive sector in the future. This is due to the higher requirements for digital and networked functions in the vehicle compared to today's conventionally powered vehicles, increasing levels of automation, the use of driver assistance systems and the electrification of the powertrain [6].

The value shares for semiconductor components thus increase from approx. EUR 330 to EUR 690 material value for plug-in hybrids or purely battery-electric vehicles against the background of electrified drive components alone. Automated and/or autonomous driving functions will require additional semiconductor elements with a pure material value of up to approx. EUR 1,030 [19]. According to Roland Berger, the cost of the semiconductor end products in a premium vehicle with a combustion engine is already around EUR 2,500 today and will rise to EUR 5,900 by 2025 in a passenger car with semi-autonomous driving functions [6]. The growing market for electrified and automated vehicles will further increase sales opportunities for semiconductors in the future. Semiconductor manufacturers are also responding to this by investing in the expansion of additional production capacities. As a rule, the construction phase for a semiconductor fab is expected to take around 3 years and cost up to EUR 20 billion (for state-of-the-art production in the 5 nm range).

3.2. Impacts on the Automotive Industry and its Supply Chains

In this section, the specifics of the supply chains in the automotive industry will be described in general, reaching from the extraction of raw materials to the delivery of products to end customers, before exemplary impacts of the semiconductor shortages on OEMs and their production capabilities are shown.

3.2.1. Characteristics of Automotive Supply Chains

The so-called "supplier–manufacturer–customer network" in the automotive industry extends around the entire world, especially for raw materials and for some intermediate products and components. To coordinate this network, OEMs and suppliers have established a supply chain management system to secure and optimize product, information and cash flows in a competitive environment. This supply chain management is defined as "the establishment and management of integrated logistics chains [...] across the entire value creation process, starting from the extraction of raw materials through the refinement stages to the end consumer" [20].

A distinction can be made between the so-called basic supply chain and the extended supply chain [21]. The former comprises the manufacturing company, its direct suppliers (Tier 1) and direct customers—in the automotive industry, this can be the retail trade, but in some cases, it can also be bulk buyers such as car rental companies or logistics companies, or direct sales to end customers. The extended supply chain expands the management of the supply chain to include additional value-added stages up to suppliers active in the fields of raw material processing. In the course of the change in value creation strategies of automotive manufacturers in the transformation to electrified powertrains, this concept is even being extended by OEMs to the level of raw material extraction.

Today's supply chain in the automotive industry consists of up to five internal and ten external stages [22]. Automotive manufacturers are integrators at the top of a hierarchical supplier system characterized by a division of labor between OEMs and suppliers, and by a high degree of modularity and flexibility in the selection and use of suppliers.

OEMs and Tier 1 suppliers influence the structure of their respective suppliers by limiting the number of direct suppliers. This structure, described by the image of the "supplier pyramid", is based on the fact that manufacturers and a few globally active suppliers are at the top, followed by development service providers, contract manufacturers, just-in-sequence and just-in-time suppliers, and logistics service providers as Tier 2 to Tier n suppliers, depending on the complexity of the input products and the share of product and process innovations. At the lowest level (e.g., Tier 3), highly standardized parts, e.g., screws, are usually manufactured, while at the next higher level (e.g., Tier 2), components such as rotors, stators, valves or cylinders are manufactured. At the highest level of system suppliers (e.g., Tier 1), components are integrated into modules and systems, e.g., battery modules, steering systems, and then delivered to the automaker for final assembly within the vehicle. The position in the supplier pyramid and the dependency on individual customers or OEMs decisively determines the dependency of the company and thus the scope of its own corporate strategy; with their buying power, OEMs hold central positions here [23]. The close interaction between OEMs and suppliers has emerged during a long phase of industry growth. It is considered an important element of the premium and quality strategy of German OEMs, has been maintained over the long term despite high cost and price pressure and can be described as a production knowledge-based innovation cluster [24].

The image of the supplier pyramid also describes a model gradation of suppliers according to the complexity of the preliminary product. Since the 1980s, suppliers in the automotive industry have been taking on ever larger shares of the value chain, including more complex tasks and parts. As a result, they also have greater obligations when it comes to financing upstream products and materials. For OEMs, reducing their own depth of value added and outsourcing to suppliers was and is a lever for maximizing earnings.

The internationalized value chain, which is based on a high division of labor, places high demands on companies to ensure trouble-free supply. Starting from the original purchasing or procurement, OEMs and Tier 1 suppliers have now established a supplier or supply chain management system for this purpose. Whereas the initial focus of supplier relationships was primarily on the question of whether primary products or components could be manufactured in-house or purchased more cheaply ("make or buy"), suppliers are now audited/certified by OEMs and production processes, approved, advised on optimizing production processes and supported financially or by other means in the event of threats to the supply chain.

OEMs have long been shifting value creation to their suppliers in order to be able to focus on global markets and the interfaces with their customers [22]. Due to their financial strength, they continue to maintain a central position and exert a strong influence on contract design with suppliers. Nevertheless, the image of a strictly hierarchical supply chain or supplier pyramid is changing; at least in part, value networks are emerging instead, in which companies can focus better on their core competencies and act more flexibly. Suppliers can improve their position in the value chain through more strategic partnerships with OEMs and Tier 1 suppliers. The shift to electromobility, with new supply relationships, and in some cases new suppliers, is accelerating these changes. However, this option is limited, on the one hand, by the fact that mastering complexity along global supply chains will continue to be a key challenge for OEMs and Tier 1 suppliers in the future. On the other hand, OEMs are taking back at least some of their production shares to compensate for the loss of value creation in electric vehicles.

3.2.2. Exemplary Impacts of the Semiconductor Shortages on the Automotive Industry

An exemplary overview of impacts of the semiconductor shortages on the automotive industry in terms of sales and production figures are shown below, with a special focus on the effects for single OEMs and suppliers [25]:

- Audi had to send part of its workforce to short-time work due to a shortage of electronic components at its Ingolstadt and Neckarsulm plants (A4 and A5).
- BMW suffered short-term production stoppages at its plants in Regensburg (1 Series, 2 Series, X1, X2), Leipzig (i3) and Oxford, England (Mini) due to a lack of parts deliveries.
- Daimler had to initiate a production stop at the Sindelfingen (E-Class), Bremen (C-Class, GLC) and Rastatt plants, as well as at the Kecskemet plant in Hungary (A-Class, B-Class, GLA); the respective employees were moved to part-time working for a limited period. The supply of electronic components is being managed in such a way that they can be used in high-margin models (such as the S-Class or EQS) on a prioritized basis and these can continue to be produced.
- Ford had to stop production at the Cologne plant for several weeks, affecting around 5000 of the 15,000 employees there. Production was also reduced or completely interrupted at the plants in Saarlouis (Focus), Gölcük in Turkey, Craiova in Romania, Valencia and other plants in the USA. The company expects the supply bottlenecks to reduce profits by USD 1 billion to USD 2.5 billion in 2021.
- Regarding Volkswagen, the plants in Wolfsburg (Golf), Emden (Passat), Mexico (Jetta, Tiguan) and Slovakia (Bratislava, mainly SUV models) have been affected. Across the Group, approximately 100,000 fewer vehicles could be produced in the first quarter of 2021 due to the semiconductor bottlenecks. As a consequence, Volkswagen is responding by establishing its own relationships with semiconductor producers in order to be able to negotiate capacities directly and manage them better. Inventories are also to be increased for special chips in the future.
- Furthermore, Opel, Tesla, Toyota, Nissan, Hyundai, Jaguar Land Rover, Peugeot and Renault, among others, also reported problems due to missing components and supply bottlenecks in 2021.

Overall, supply bottlenecks have led to a drastic reduction in production volumes in 2021 and even beyond. In May 2021, the management consultancy Alix Partners assumed that around 3.9 million fewer vehicles, worth about EUR 90 billion, were to be produced worldwide in 2021 [1]. Also, LMC Automotive expected that the lower availability of chips would lead to a drop in production of approx. 1.3 to 2.2 million passenger cars, which would correspond to a decline of approx. 1.5% to 2.5%, with an expected total volume of around 88 million units for 2021 [2]. In reality, the number of vehicles not produced because of the semiconductor crisis added up to about 9.7 million light-duty vehicles in 2021 alone [26]. Experts expect the supply shortage to continue in 2022 and beyond [27].

3.3. Strategies and Options to Cope with Shortages

In this section, company strategies to deal with the disruptions in supply chains will be analyzed and described in detail. With its high dependence on exports, and the structures of a diversified, internationalized division of labor in global value networks that have been created over decades, the German automotive industry appears to be particularly vulnerable to external disruptions in the supply chain. In the course of the study, this thesis was discussed in expert discussions and in-depth interviews. The aim was to identify the effects of the supply chain disruption on the affected companies in the automotive industry and to identify measures for overcoming them. The latter include both operational, rather short-term measures, arising directly from the COVID-19 crisis, as well as strategic options and consequences with a rather longer-term perspective. The latter are aimed at generally increasing resilience in relation to external disruptions to production and supply chains.

3.3.1. Operational Measures (Short-Term)

Short-term and operational measures to deal with the disruptions caused by the COVID-19 pandemic and the shortage in semiconductor components could be clustered into the following five topics: "Use of short-time work and closure of production plants", "Adjustment of production processes", "Adjustment of inventories", "Establishment of central emergency teams and task forces" and "Search for alternative suppliers". The mentions relating to "Short-time work" and "Adjustment of production processes" were the most frequent. In the case of multiple mentions, the area "Establishment of central emergency teams and task forces", in particular, was highlighted as a very relevant measure, both in relation to the company itself and in relation to the higher-level customer. The "Search for alternative suppliers" was mentioned only once.

Use of short-time work and closure of production plants: 66% of the interviewees were affected by the lockdown and the associated halt of production activities. They mainly used labor market policy instruments as a result of the lockdown, with part-time work in particular.

Adaptation of production processes: 53% adapted their production processes as a result of the pandemic, in particular to be able to implement safety measures to protect against infection. Where the minimum distance of 1.5 m could not be maintained (e.g., on production lines), plexiglass walls were built up, masks were made compulsory and disinfection facilities were installed. Overall, the implementation of these measures resulted in an increase in infection protection, but at the same time led to productivity losses for the companies. Unexpectedly, hygiene articles such as masks have turned out to be "critical goods" and have presented companies with procurement problems

Adjustment of inventories: 60% mentioned adjusting inventories as a tactical measure to deal with the pandemic and customers' often unclear demands and call-offs. In this context, inventory levels were both increased and decreased. On the one hand, in the early phase and before the (partial) lockdown, production was continued to a large extent despite unclear customer demand, or deliveries were accepted and inventories increased in order to be able to continue to deliver with high volumes and at short notice in the event of an improvement in the coronavirus situation. Secondly, in the later course of the crisis, existing inventories were reduced again in order to be able to manufacture and deliver the company's own products. This meant that the company was less dependent on upstream products that were no longer supplied or only supplied in small quantities. Adjustments to inventories were mainly made for products identified as "critical", such as electronic parts or cable harnesses.

Establishment of centralized emergency response teams and task forces: The establishment of task forces was named by 64% of the interviewees as a short-term operational measure for dealing with the crisis. In this context, the interviewees were referring, in particular, to difficulties in general communication with customers in terms of the reliability and predictability of requirements and orders. They emphasized that customers, in particular, were able to quickly set up task forces and establish them at the interfaces of the supply chain, which have their own central logistics in a strong position and a distinct, established supplier management. Reference was also made here to those companies that were affected by Fukushima in 2011, where they were able to gain experience in setting up emergency task forces.

In addition to the organizational establishment of centralized emergency response teams and task forces, digital technologies for the exchange of information and, in particular, the tracking of the flow of goods along the value chain were also mentioned by 23% of the interviewees. This includes blockchain technology, which is intended to ensure a secure flow of information and is being tested by the automotive industry in initial pilot projects. Here, however, it is questionable whether cross-company data exchange along the entire supply chain is actually feasible. On the one hand, the emerging data volume is currently unmanageable, and on the other hand, the companies must agree to the data transfer. It is hard to imagine the semiconductor industry granting what it considers an insignificant market share appropriate access here.

Search for alternative suppliers: Only one interviewee mentioned the search for alternative suppliers as an operational measure to deal with the crisis. The majority of the companies were able to maintain their own production capacities on the basis of existing supplier relationships and/or by reducing inventories until production was able to restart again.

3.3.2. Strategic Options (Long-Term)

In the first weeks of the lockdown, broken supply chains were discussed as the cause of the production halt in the automotive industry. To avoid and/or better manage this problem in the future, a greater return to local production was called for as a way to contain the pandemic and stabilize the economy, according to broader public discussion. However, in the expert interviews, the opposite position was stated for the automotive industry: there will be no fundamental change in international division of labor or associated global supply chains. Instead, a modification of purchasing strategies is more likely. Overall, four fields of action could be identified in the question of long-term strategic fields of action for stabilizing supply chains in crisis situations: “Increase stockholding for critical components”, “Strengthen dual sourcing and flexible shares”, “Support local supply chains” and “Monitoring of the reliability of political action”. The responses were equally distributed across all interviews. In the case of multiple mentions, the area “Reliability of political action” was identified as most relevant option.

Increase inventory levels for critical components: 40% of the interviewees named an increase in inventories for critical components as a reasonable strategic option. Vulnerability to disruptions was already evident in 2011 during the Fukushima crisis but affected not as many products there. The COVID-19 pandemic with its global impact endangered production in the entire supply industry. Therefore, in addition to the identification of critical components and suppliers, higher stock levels for single parts were set up. Since warehousing requires corresponding areas, systems and staff, activities always have to be weighed against disadvantages in cost and efficiency in the automotive industry. For this reason, larger warehousing—if at all—would only be practicable for individual components that are considered to be particularly critical.

Strengthen dual sourcing and flexible shares: Another 40% stated that strengthening dual sourcing and flexible shares with suppliers is being discussed as a strategic option for the future. Dependence on one supplier, especially a foreign supplier, has already revealed weaknesses in supply chains during Fukushima and even more so in the pandemic. In the interests of resilient supply chains, consideration is therefore being given to purchasing from two suppliers instead of one for selected components and to a limited extent. As a result of the global disruption, splitting with a low-cost supplier, e.g., in Asia, and a European or German supplier is being considered here. However, this will only lead to a small return of production, if at all. This is because, when split between the suppliers, the significantly larger volume would still be sourced from the lower-cost foreign countries; the experts cited proportions of 70 to 80% here.

Supporting local supply chains: 33% mentioned a stronger focus on local supply chains as a possible strategic option, and as critical for the resilience of future value networks. In many cases, it is not only supplier relationships in Germany that are rated as “geographically local”, but also European ones on a larger scale. As a result of the pandemic, the need to adapt purchasing strategies in the interests of greater stability is seen. Here, the company experts see an advantage in greater geographical proximity, and thus, a focus of the supply chains in the European countries or in the future also in the (North) African countries. At the same time, the experts have pointed out that sourcing components and parts from European locations is associated with higher costs compared with sourcing from Asian production. Therefore, the advantages of regionalized supply chains must be weighed against higher costs. This raises the question of how far the current impressions from the pandemic will extend into the future, or whether purchasing decisions will soon again be made primarily on the basis of cost efficiency.

Monitoring the reliability of political action: When asked about possible political action, the experts focused mainly on reliability, and thus, on maintaining social and economic stability. This topic was mentioned most frequently among the long-term measures (47%). Three levels of action should be distinguished here: the municipal level or that of the federal state, the national level and the pan-European level. With its decisions on how to deal with the pandemic, the political arena provides the essential framework conditions under which economic activity, such as the company's production, the purchase of inputs and the sale of its own products, is possible in the first place. Only the most effective possible limitation of the pandemic protects against restrictions on the company's own production. The interviewees certainly acknowledged the great difficulties that politicians faced with the first lockdown decision in German history. Nevertheless, it is helpful for companies at the local level to have reliable and comparable regulations across different counties and cities. This was not always the case in the first lockdown in March/April 2020. For companies in the automotive industry, which are heavily dependent on foreign trade, this demand for politically regulated stable framework conditions also applies to other states with which they maintain economic relations. After all, limiting the pandemic can protect against a lockdown there as well. However, this change in supply chains is associated with disadvantages in terms of cost efficiency and, depending on the corporate strategy, is not feasible for everyone. In return, companies expect stability within the European economic area and agreements on border crossings for business purposes. Here, however, the expectations of companies in the automotive industry and the machine tool industry differ: while the automotive industry was primarily concerned with the supply of components and parts from foreign production sites, for the machine tool industry, the greatest difficulty was primarily in the supply of machines and in the commissioning and repair of machines abroad.

4. Conclusions

Despite previous crises, the COVID-19 pandemic and the subsequent shortage in semiconductor components proved to be a shock to the economy and the automobile industry: for the first time the entire world and almost all economic sectors were affected, and supply chain disruptions will continue to negatively impact production capacities even in and beyond 2022. The production plant lockdowns and semiconductor shortages, however, were not the sole trigger of the slump in demand that has been evident in the automotive industry since 2019 and in mechanical engineering since 2018. Already in the summer of 2020—after the initial lockdown and improvement in the infection situation—the pandemic took a back seat to the demand crisis and questions of transformation toward new technologies of electrification and digitalization.

Our results contribute to the field of strategic management of supply chain risks, with a special focus on the current practical implementation of solutions using the example of the German automotive industry on the one hand and to the practical handling of supply chain risks in the German automotive industry based on the current semiconductor shortages on the other hand. Our findings are unique because comparable studies focusing on practical solutions and options in the German automotive industry based on in-depth interviews do not exist in the current literature.

They clearly show that the European and German automotive industries have little influence on the stability of semiconductor supply chains due to their small market share, but are heavily affected in terms of production capacities. In this respect, approaches for new purchasing and logistics strategies to make the supply chains more resistant to crises in the long term are being discussed in automotive companies. Operationally, increased warehousing and dual sourcing—especially for critical components—could become more important in the future [28]. Strengthening local (European) value networks for critical components is also being considered by OEMs and suppliers. However, both are described more as "incremental improvements" than as a fundamental change in strategy, and both lead to a more holistic view of supplier relationships in the sense of more systematic management of supply chains, product and supplier risks. Research limitations of our study are based on the quantity of expert interviews held and the quality of the statements therein. The research design of this study has therefore been selected in such a way that each stage of the value chain in the automotive industry (OEM tier 1, tier 2, tier 3) and different perspectives in the supplier–manufacturer alliance could be fully covered by the expert interviews conducted.

The implementation of these strategies, their impact and their potential to improve the handling of supply chain risks in the German automotive industry should be investigated in further research and also be compared to specifics in other world regions, such as France, the United States of America, Japan, South Korea and China. Building up on our findings, the aim of these studies could be to (1) identify best practice examples for dealing with potential shortages of critical materials and components on the basis of further analyses and (2) to expand the research scope and also include change potentials for value creation networks and supply chains resulting from the transformation of the automotive industry towards new powertrain technologies, digitalization and CO_2-neutrality.

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