ASCII Supply Chain Intelligence Institute Austria

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Technical Background Report

Mapping of the global semiconductor supply chain - Embedding Austria in the global semiconductor inter-firm network

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Abstract

This report delves into Austria's role in the global semiconductor supply chain against the backdrop of significant global initiatives to incentivize the production of semiconductors, to secure availability for applications, to promote innovation and prepare for future chip supply crises. Leveraging a model of the stylized semiconductor value chain (SSVC) and employing large-scale data-mining techniques, the study classifies and maps over 20,000 semiconductor companies to their positions in the extended SSVC (chip production and application). The results reveal that the United States, China, Taiwan, Japan, and Korea are key players in various segments of the value chain. Austria emerges with a concentration in specific value chain segments and a well-diversified presence in a wide range of application domains. Austria has noteworthy capabilities in wafer fabrication, providing equipment and tools for core sub-processes such as lithography, deposition, and packaging. Regarding semiconductor applications, Austria focuses particularly on various industrial applications. It demonstrates proficiency in fields such as and sensors, encompassing security, RFID, and imaging applications, power electronics, design automation, high-performance design, mixed-signal circuits, wireless network applications, storage solutions, memory cards, and processor chips. Notably, Austria's strengths extend to applications within the automotive industry, where opportunities might arise with the shift to electric vehicles. Opportunities for Austria lie also in focusing on segments with increasing exclusivity and importance (such as advanced packaging) and combining low capital expenditure with high value add, particularly in chip design and equipment/tools segments. However, the report highlights potential weaknesses, such as dependencies on external segments and a lack of domestic production in certain areas. In conclusion, both the strategic role and potential opportunities for Austria's semiconductor industry lie in the linkage with related industries and its central role and strong capabilities in specific segments of the global semiconductor value chain.

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Executive Summary

The semiconductor industry, a cornerstone of contemporary technological infrastructure, embodies a multifaceted ecosystem shaped by regional specialization, evolving, and globally distributed inter-firm networks, and technological innovations. Our comprehensive analysis delves into these intricacies, to create insights into the semiconductor value chain, its regional embeddedness, and its connections to application domains.

We use a novel approach to perform a data-driven mapping of semiconductor companies. Based on established formal models for stylized value chains in the industry, we identify several hundred leading companies in specific segments. We then build a database of more than 20,000 semiconductor companies and extract their inter-firm networks from open web data, in which links signal collaboration, ownership or customer-buyer relationships. This allows us to embed the leading firms in their inter-firm networks, examine the regional extent of these networks and how they change over time. Furthermore, we enrich the analysis with semantic clustering approaches to link these companies to specific application areas and industries.

Key Findings:

Regional Specializations: Our research has confirmed the notion of distinct regional specializations within the semiconductor value chain. Specifically, Japan and South Korea dominate critical manufacturing domains such as wafer fabrication, while North America, Western, Central, and Northern European territories, alongside Australia and Singapore, excel across a diverse spectrum of application domains spanning various industries. The United States holds a crucial position, demonstrating expertise in various applications and manufacturing sectors at the same time.

Inter-Firm Network Dynamics: Over the past decade, the regional embeddedness of leading firms' inter-firm networks has remained relatively stable. However, there have been specific and regional changes in the underlying dynamics. More concrete, inter-firm networks in the EU, US and China have synchronously rewired towards prominent chip design firms. This highlights the growing importance of design capabilities in driving innovation and shaping industrial dynamics. Our approach also allows this analysis to be regionalized to individual countries to identify shifts in their global embeddedness.

Austrian Semiconductor Industry: Our study sheds light on the Austrian semiconductor industry. Like the rest of the EU, Austria has commendable strengths in specific application niches and specialized production paradigms. Our study shows that Austria has - especially relative to its size – a well-diversified semiconductor industry, with specific strengths in a wide range of industrial applications.

Opportunities and Implications:

Role of Advanced Packaging: Several recent studies identified advanced packaging is becoming increasingly important in modern semiconductor engineering. It combines multiple functions that are essential for driving technological progress, including performance optimization, system integration, miniaturization, and cost efficiency. Advanced packaging enables the integration of different technologies and the creation of small yet powerful semiconductor devices. This not only extends Moore's Law beyond mere nanometer-scale reductions but also promotes innovation across various industries. Our analysis identified a substantial shift in the inter-firm network of Austrian companies towards the leading companies in the related value chain segment.

Linkages to Automotive: Austria's ongoing push in automotive applications dovetails with several key areas, including investments in chip technologies, design innovation, energy-efficient paradigms, AI integration, high-performance computing capabilities and robust cybersecurity measures. These mutually beneficial connections provide Austria with promising opportunities to take advantage of emerging trends in the automotive and electric vehicle (EV) industries, promoting innovation and enhancing competitiveness.

Strategic Considerations: As the semiconductor industry evolves, it is important for stakeholders to understand the role of the semiconductor industry as an enabler for several of its core industries, ranging from automotive to security, sensors, and various other industrial applications. Potential product and process innovations need to be carefully assessed in terms of how they can contribute to further innovation and strengthening of these core industries considering current market trends but also geopolitical factors, thereby also increasing regional resilience.

In conclusion, our analysis provides valuable insights into the complex dynamics of the semiconductor industry, offering actionable recommendations for stakeholders to navigate the growing competition and changing demands. By utilizing regional strengths, fostering collaborations, and embracing innovation, stakeholders can strengthen their strategic position to succeed in a constantly evolving semiconductor sector.

1. Introduction

The global half-trillion-dollar semiconductor industry stands as a linchpin in the contemporary technological landscape, furnishing the foundational components for an extensive range of electronic devices. From the microprocessors powering computers to the sensors embedded in smart devices, the semiconductor supply chain intricately weaves across international boundaries. Unraveling this complex network holds critical importance for diverse stakeholders, spanning from manufacturers to policymakers, given its profound influence on global technological progress and economic stability.

The semiconductor manufacturing process, see Figure 1, unfolds through a series of intricate steps, each contributing to the creation of electronic components. Beginning with the chip design phase, the fabrication process encompasses among others photolithography, deposition of materials, doping, and etching to create transistors and interconnections on silicon wafers. Rigorous testing and quality control measures follow to eliminate defects and ensure reliability. The final steps involve the packaging and assembly of semiconductor devices, culminating in their distribution of finished chips to end-users. End-users of chips are manifold, and applications can be found in all industry segments. Therefore, end-users of chips are subsumed under different industry applications in figure 1.

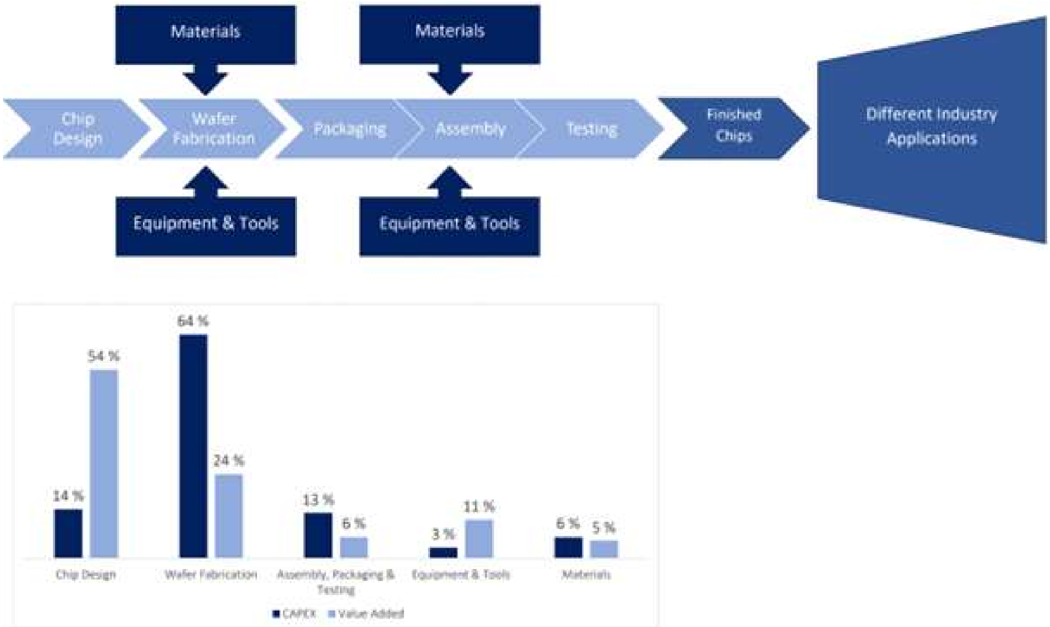

Figure 1: Main value-adding steps of the semiconductor supply chain[1]

Several key players dominate the semiconductor landscape, driving advancements in chip technology. Notable manufacturers include Intel, Samsung, TSMC, and GlobalFoundries. The United States, Taiwan, South Korea, and China emerge as pivotal countries in the supply chain. The U.S. excels in semiconductor design and research, Taiwan, and South Korea lead in fabrication, while China rapidly ascends as a major player, focusing on raw materials as well as production and consumption. The National Semiconductor Economic Roadmap 2022 published by BCG and the Arizona Commerce

[1] Graphic based on Varas, A., Varadarajan, R., & Goodrich, Jimmy, Yinug, Falan. (April 2021). Strengthening The Global Semiconductor Value Chain april-2021. Boston Consulting Group x SIA.

Authority highlights the particularly strong position of the USA (electronic design automation, design, and equipment) and China (raw materials), see Figure 2.

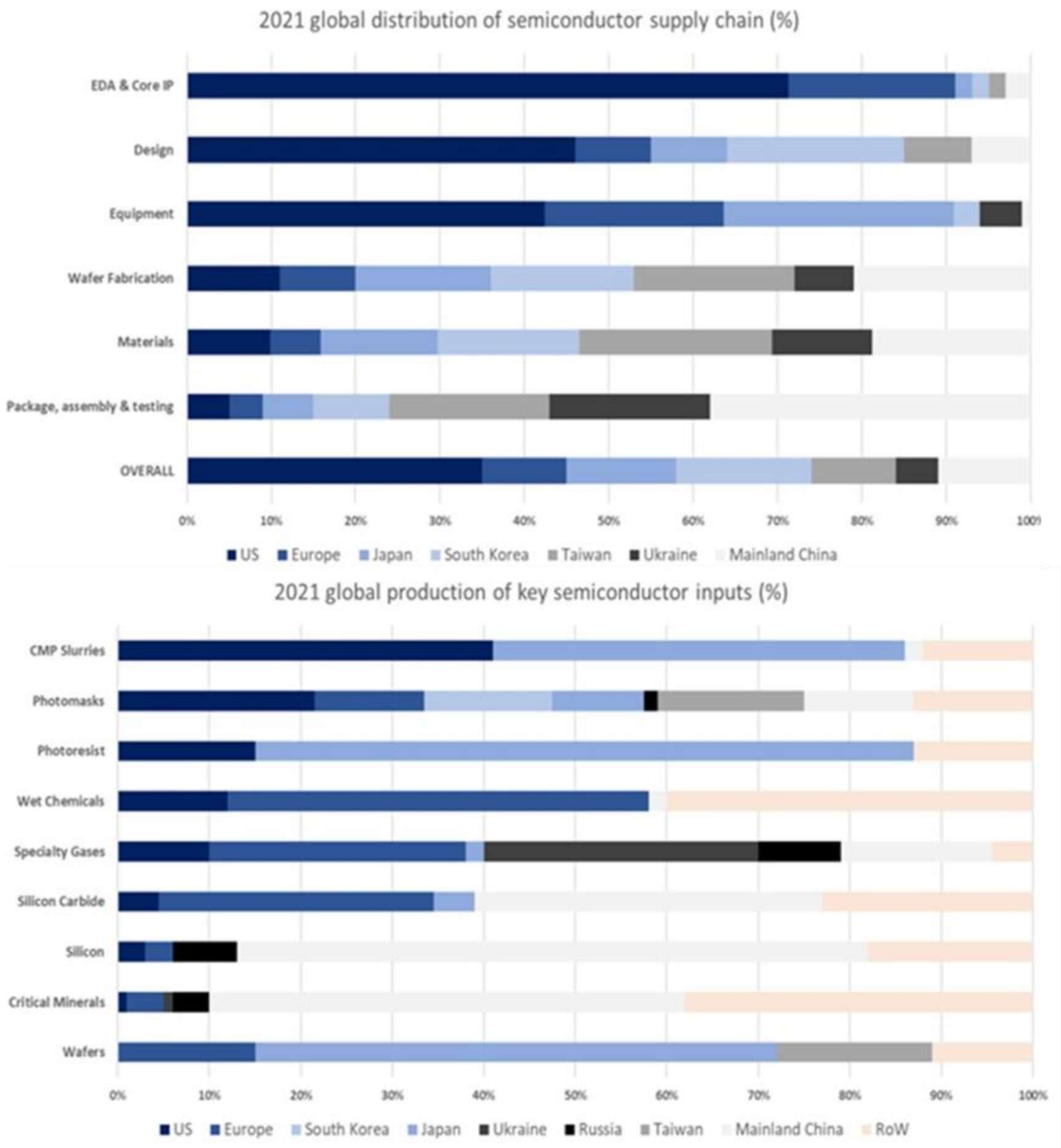

Figure 2: The global semiconductor landscape[2]

The semiconductor supply chain's complexity arises from its multifaceted nature, involving intricate manufacturing processes, continual technological evolution, and global interdependencies. Specialized skills and resources are demanded at each step, contributing to the industry's overall intricacy.

While industry giants such as Intel, Samsung, TSMC, and GlobalFoundries dominate the actual semiconductor arena, it is crucial to recognize the myriad smaller semiconductor manufacturing companies contributing highly specialized products, processes, or materials. Additionally, highly specialized companies apply finished chips in their products – being market leaders themselves in their respective industry. These firms, often

[2] Graphic based on NATIONAL SEMICONDUCTOR ECONOMIC ROADMAP, 2022, p. 21-22. www.azcommerce.com/media/1uubpnti/national-semiconductor-economic-roadmap-final.pdf, accessed 03/21/2024

operating in niche domains, play integral roles within the global semiconductor supply network. Despite their significance, the intricacies of their functions and their nuanced impact on the broader supply chain remain relatively little understood. Hence, a thorough understanding of the roles and capabilities of these specialized manufacturers becomes crucial for stakeholders aiming to comprehend the industry's holistic dynamics and to better understand inherent opportunities for strategic positioning.

In general, the semiconductor industry is an industry that is particularly concerned with the protection of trade secrets and new technologies. The competitive advantage of many supply chain actors lies in a deliberate lack of transparency. Global players such as Amazon Web Services or Microsoft develop and manufacture semiconductors exclusively for their own purposes and largely undisturbed by the actual semiconductor supply chain. Until a few years ago, the production of semiconductors intended for military purposes was largely decoupled from the production of commercial chips. These boundaries are becoming increasingly blurred and in turn contribute to secrecy in the industry.

Global political powers and actors aim to control the global semiconductor supply chain, figure 3 contributes to a thorough understanding of the interdependencies in the semiconductor supply chain. Figure 3 shows Europe’s dependence in the global semiconductor supply chain as approximately 20% of the final use occurs in Europe but only 10% of the production takes place here. The European Chips Act might be a useful instrument to improve Europe’s strategic position. However, Europe's successful long-term positioning within the value chain requires more than adequate capital investment. It is essential to determine the most promising positions along the value chain for Europe, considering its strengths and capabilities. It is also essential to consider the structure of the individual markets involved in the value chain. This raises the question about market concentration and the global distribution of value creation. Such an approach would ensure a cost-effective and efficient allocation of (public) financial resources. ASCII aims to identify and operationalize suitable measures, including Key-Performance-Indicators (KPIs) such as market-shares.

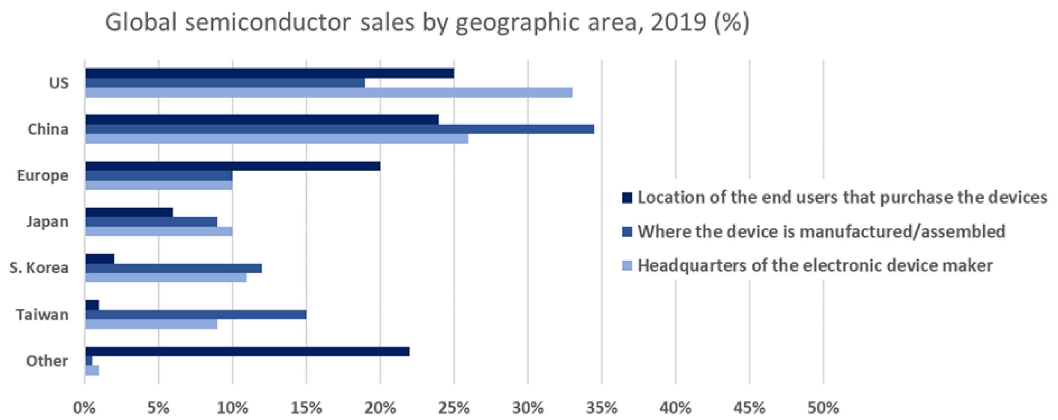

Figure 3: Bird's eye view on global power and dependence in the semiconductor supply chain[3]

[3] Graphic based on Varas, A., Varadarajan, R., & Goodrich, Jimmy, Yinug, Falan. (April 2021). Strengthening The Global Semiconductor Value Chain april-2021. Boston Consulting Group x SIA.

2. Our approach

In brief, our methodological approach consists of the following steps:

- Construct a stylized value chain model of the global semiconductor industry (2.1) and identify lead firms in each segment (2.2).
- Mapping the company ecosystem of these lead companies through an inter-firm hyperlink network to quantify regional strengths and weaknesses in value chain segments (2.3).
- Measure the intensity of the semiconductor value chain (2.4).
- Extend the semiconductor value chain - Conduct natural language processing analysis based on topic modeling to identify application areas (including industries and semiconductor-related products) for each region (2.5).

2.1. Constructing a stylized value chain model

Modeling the semiconductor supply chain is challenging and becomes even more difficult when attempting to model the entire supply chain end-to-end. The major players in the industry, based on revenue or number of employees, are publicly available on the World Wide Web and can be identified as described in the section "Identification of Lead Companies". Various commercial databases, such as Bloomberg SPLC or the ORBIS database (from Bureau Van Dyke), provide insight into company descriptions, country information, and links between companies. Using this data, it is possible to map the semiconductor supply chain at the company level, at least in part. The resulting supply chain graph consists of various nodes and connections between these nodes, with each node representing a company. However, while this graph is an initial result, it also highlights the first limitation: the level of granularity in mapping the supply chain. Representing one node for one company in the semiconductor network is a simplification and does not consider the fact that different companies operate in different locations, which in turn may work on different product lines. The problem becomes even more complex when you consider that some companies have subsidiaries that operate under a different name but work closely with the parent company. As a result, the issue becomes even more intense when considering the actual transportation routes, logistics facilities, and logistics service providers responsible for the shipments.

To outline a stylized value chain, we first delineate the primary processes that contribute value to the production of a finished chip. In addition, we include materials along with equipment and tools, recognizing their critical role as inputs at various stages of semiconductor manufacturing. To provide a comprehensive analysis of the semiconductor value chain, we delve deeper and include sub-processes based on publicly available industry reports. These processes are categorized as Chip Design, Wafer Fabrication (Oxidation & Coating, Lithography, Etching & Cleaning, Doping, Deposition, Chemical Mechanical Planarization, Metrology & Inspection), Assembly, Packaging & Test (Wafer Slicing/Dicing, Packaging, Testing), based on the classifications specified in the European Chips Act and the SIA report (see Figure 1).

Finally, as shown in Figure 1, we extend the stylized value chain to include industrial applications and end products. Introducing the applications side means creating a loop within the supply chain, as various equipment and machines used in semiconductor manufacturing rely on semiconductors themselves. However, this endeavor requires detailed insights into each company's customer base and their respective industry associations. Our discussions with industry experts unanimously highlighted the complexity and interdependencies inherent in the semiconductor supply chain. In addition, they emphasized the deliberate lack of transparency maintained by players within the supply chain. As a result, it was concluded that it is not feasible to map the supply chain in detail in the traditional sense, from raw material to end use.

Many of these challenges stem from data availability. Large Language Models and Natural Language Processing provide a novel approach to extracting data from the World Wide Web. However, they also have limitations in identifying the necessary information. For example, determining the nature of the relationship between companies is difficult. If a company's Web page doesn't clarify the connection between two companies, it is captured as an undirected connection. Similarly, it's not always easy to distinguish between a one-time connection and a long-term buyer-supplier relationship. In addition, some companies choose not to disclose their customer and supplier relationships, maintaining secrecy through contractual agreements.

2.2. Identifying lead companies

Lead companies are companies with high market shares and revenues for a given value chain. The top 10 publicly traded companies in each segment (see figure 1) served as the starting point for our research. Using commercial databases such as Bloomberg and ORBIS, we gathered additional information about the supply chains of these top listed companies for each value chain – i.e. relationships to suppliers and customers. Bloomberg provides information on supply chain links between publicly traded companies, as well as possible competitors of a company. Therefore, a search using the company names of the top companies (industry leaders) in Bloomberg provided additional input. Similarly, ORBIS provides an extensive list of companies, including company descriptions. Based on defined search terms such as "foundry" or "chip design", additional company names were collected. This approach has resulted in a list of more than 300 lead companies. Lead companies can be involved in one or more value-adding activities to produce semiconductors (chip design, wafer fabrication, assembly, packaging & testing).

2.3. Mapping inter-firm networks

A firm's position within a network of relationships with other firms plays a crucial role in shaping its activities and access to knowledge.[4] According to the theory of social capital, a firm's position in such networks determines its ability to access information resources.[5] Firms embedded in inter-firm networks are exposed to signals from their network

[4] Dahlke, J., Beck, M., Kinne, J., Lenz, D., Dehghan, R., Wörter, M., & Ebersberger, B. (2024). Epidemic effects in the diffusion of emerging digital technologies: evidence from artificial intelligence adoption. Research Policy, 53(2), 104917.
[5] Lin, N. (2002). Social capital: A theory of social structure and action (Vol. 19). Cambridge university press.

neighbors. Exposure to similar signals can influence the firm's decision making and adoption behavior. Firms in central positions within networks - lead firms - can act as knowledge diffusers, bridging different communities and facilitating knowledge transfer. Thus, a firm's ability to innovate and adopt new production processes is influenced not only by its access to knowledge, but also by its network position.

Inter-firm networks can be effectively measured by analyzing the hyperlinks associated with their websites, as these links provide valuable insight into how they relate and connect to other companies.[6] These hyperlinks serve as digital indicators of organizations' external relationships, collaborations, and knowledge sharing activities with other organizations. In our approach, we extract company websites from the Orbis database and extract all URLs associated with the company's host name from various editions of the Common Crawl corpus. This corpus contains monthly extracts of billions of web pages going back to 2007. For this report, we focus on three crawls conducted in 2023 and around 2013, respectively, to measure temporal changes in the inter-firm network. We extract all hyperlinks from websites associated with a firm to websites associated with any other firm in our database. The inter-firm networks for 2013 and 2023 are then represented as undirected and unweighted networks, where nodes are firms and links indicate the existence of at least one hyperlink between the firms' websites.

2.4. Measuring Value Chain Intensity

Our basic assumption for the intensity (at company, segment, and country level) in the semiconductor value chain is the following: The closer companies are directly or indirectly linked to leading companies in value chain segments through various relationships (buyer-supplier relationships, ownership, cooperation, ...), the higher their interdependence. The more companies there are in a region with high interdependence (compared to companies from other countries), the higher the country's intensity. In a revenue-weighted version of the intensity, firms receive weights that are proportional to their logarithmic operating revenue. We further examine total and relative versions of these intensity scores. Total intensity refers to the *sum* of all dependencies of a country's firms to leading companies of a given value chain segment. Relative intensity refers to their *average*. Thus, total intensity is partially driven by the overall number of firms in a country and is thus its confounded by its size, whereas relative intensity measures allow comparisons between countries independent of their size and number of firms.

For each firm and value chain segment, we measure its proximity to the lead firms in the inter-firm network. More specifically, for each firm i and value chain segment s we measure the length $d(i,s)$ of the shortest path (geodesic path) to any lead firm of a given value chain segment. Closeness of the company to this segment is then measured as $0.25^{d(i,s)}$. To compute the value chain intensity for a country c and value chain segment s, we sum these closeness values over all companies i from country c. The *normalized* value chain intensity is obtained by taking the average of the closeness values instead of their sum, which means that country size effects are eliminated. Finally, in the revenue-

[6] Krüger, M., Kinne, J., Lenz, D., & Resch, B. (2020). The Digital Layer: How innovative firms relate on the Web. ZEW-Centre for European Economic Research Discussion Paper, (20-003).

weighted value chain intensity, the closeness values are multiplied by the logarithm of the operating company's revenue before being summed or averaged.

2.5. Extending the semiconductor value chain to applications - Topic modelling

Topic modeling is a powerful technique used in natural language processing to discover hidden themes or topics within a collection of text. A popular method for topic modeling is Latent Dirichlet Allocation (LDA), which has gained widespread use due to its effectiveness and interpretability.[7]

LDA is typically used to analyze a large collection of documents, such as articles, blog posts, or company descriptions, to understand the main ideas or topics discussed in these texts. LDA assumes that each document is a mixture of a few topics, and that each word in a document can be assigned to one of these topics.

In short, LDA works as follows. First, you choose the number of topics you want the model to identify. Then, the model goes through each document and assesses which words are most likely to belong to which topics. It does this by iteratively assigning words to topics and adjusting these assignments to maximize the probability of observing the given documents.

The key idea behind LDA is that each topic is characterized by a distribution of words. For example, the description of a company involved in "mixed-signal circuits" might contain words like "digital," "analog," and "circuit," while a topic about "sensors" might contain words like "camera," "RFID," and "image. By examining these word distributions, one can interpret the topics discovered by the model.

Overall, Latent Dirichlet Allocation is a valuable tool for uncovering hidden structure in textual data, providing insights that can drive further exploration and understanding. In the present analysis, we apply this approach to the company description provided by the Orbis database to obtain a deeper classification of the companies and to identify the products or application areas in which these companies are active.

[7] Blei, D. M., Ng, A. Y., & Jordan, M. I. (2003). Latent dirichlet allocation. Journal of machine Learning research, 3(Jan), 993-1022.

3. Results

3.1. The global semiconductor value chain

Our search strategy identified 21,245 semiconductor-related companies. Most of these companies (9,356) are located in China, followed by the US (2,206), Japan (1,266), Korea (1,168), Taiwan (1,142) and Germany (774), see Figure 4(A). Information on the number of employees is available for 64% (13,699) and information on operating revenue is available for 85% (17,991). In total, these 21,245 companies employ 9.1 million people and have a combined operating income of USD 5,200 billion, see Figure 4(B,C).

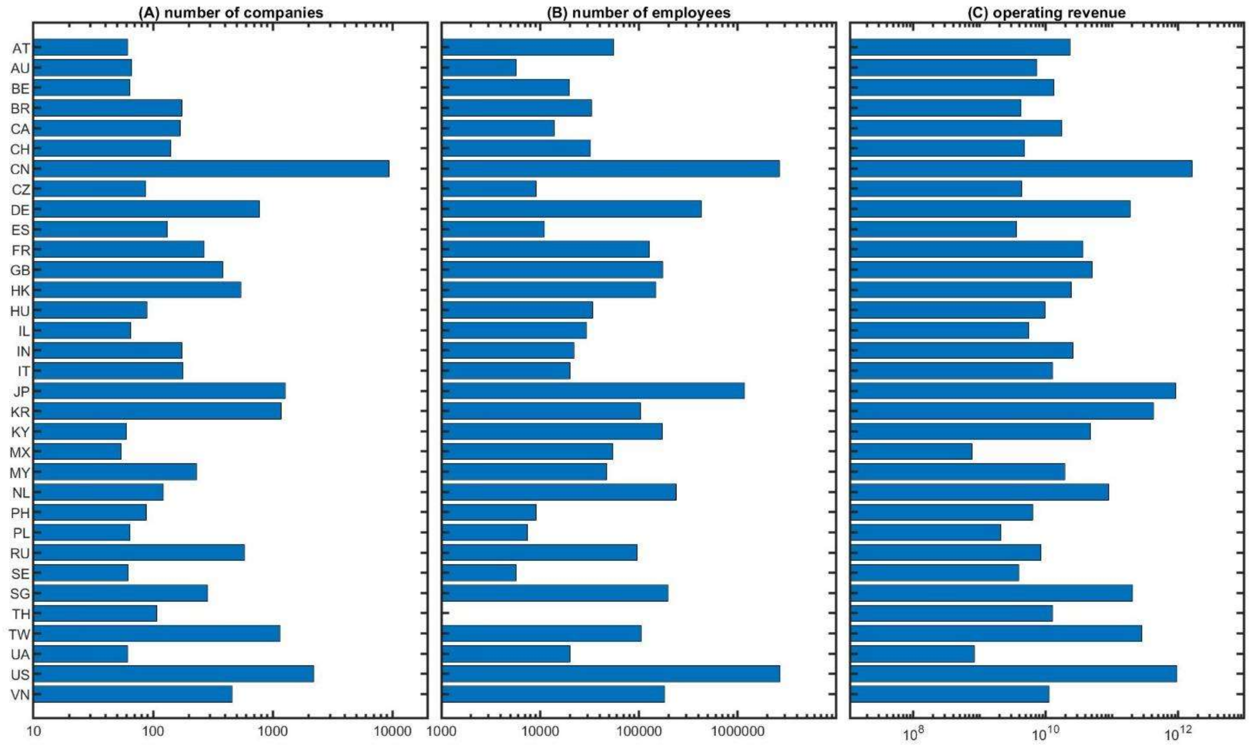

Figure 4: Descriptive overview of semiconductor companies. The number of companies in each country with more than 50 companies is shown (A) along with their combined number of employees (B) and operating revenue (C).

We study the network embeddedness of these firms by extracting their inter-firm hyperlink network, see Figure 5 for the network extracted for 2023. In this network, firms are shown as nodes in a network with a colour indicating their world region, except for lead firms, which are highlighted in black. Node size indicates node degree. Node degree is a graph-theoretic network measure that quantifies the number of direct relationships a company has. The higher the number of customer and supplier relationships, the higher the node degree of the company. Links indicate that the two companies are connected by at least one hyperlink.

The network shown in Figure 5 reveals several interesting properties upon inspection. First, although most of the lead firms (black nodes) have a relatively high degree (as indicated by the node size), there are few low degree lead firms for which our approach found a smaller number of links. It can also be seen that most of these low degree lead firms are in Asia, suggesting that the hyperlinked inter-firm networks are mainly observed between US and European firms. Nevertheless, many Asian lead firms were successfully embedded in their inter-firm networks.

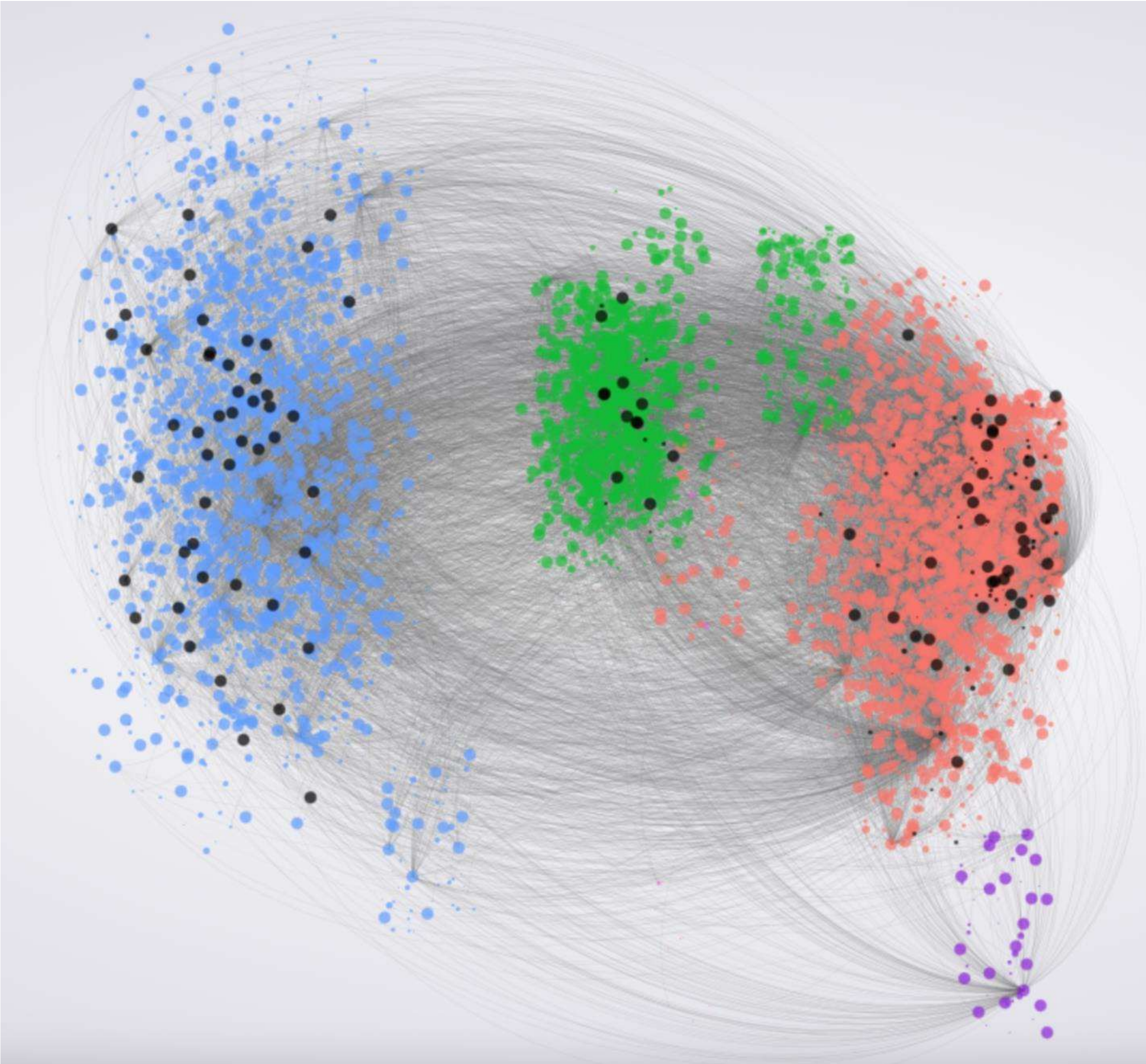

Figure 5: Inter-firm network for 2023. Nodes correspond to semiconductor-related companies with colours indicating their world region (blue for the Americas, green for Europe, red for Asia, pink for Africa and purple for Australia) except for lead companies, which are highlighted as black nodes. Node size is proportional to node degree. Links indicate the existence of at least one hyperlink between the websites of the linked companies. Node positions are randomly assigned by world region.

Figure 6 shows the sum over the closeness values of all companies in each country (row) to the lead companies in a value chain segment (column), referred to as value chain intensity, for (A) 2023 and (B) 2013. By construction, this statistic is strongly driven by the number of companies within a region. It is therefore somewhat surprising that most value chain segments are dominated by US companies, along with Japan and Korea, as opposed to China, despite the large number of Chinese companies. Overall, there are few major changes in value chain intensities between 2013 and 2023, suggesting that the overall regional distribution of capabilities across value chain segments has remained relatively stable over the past decade.

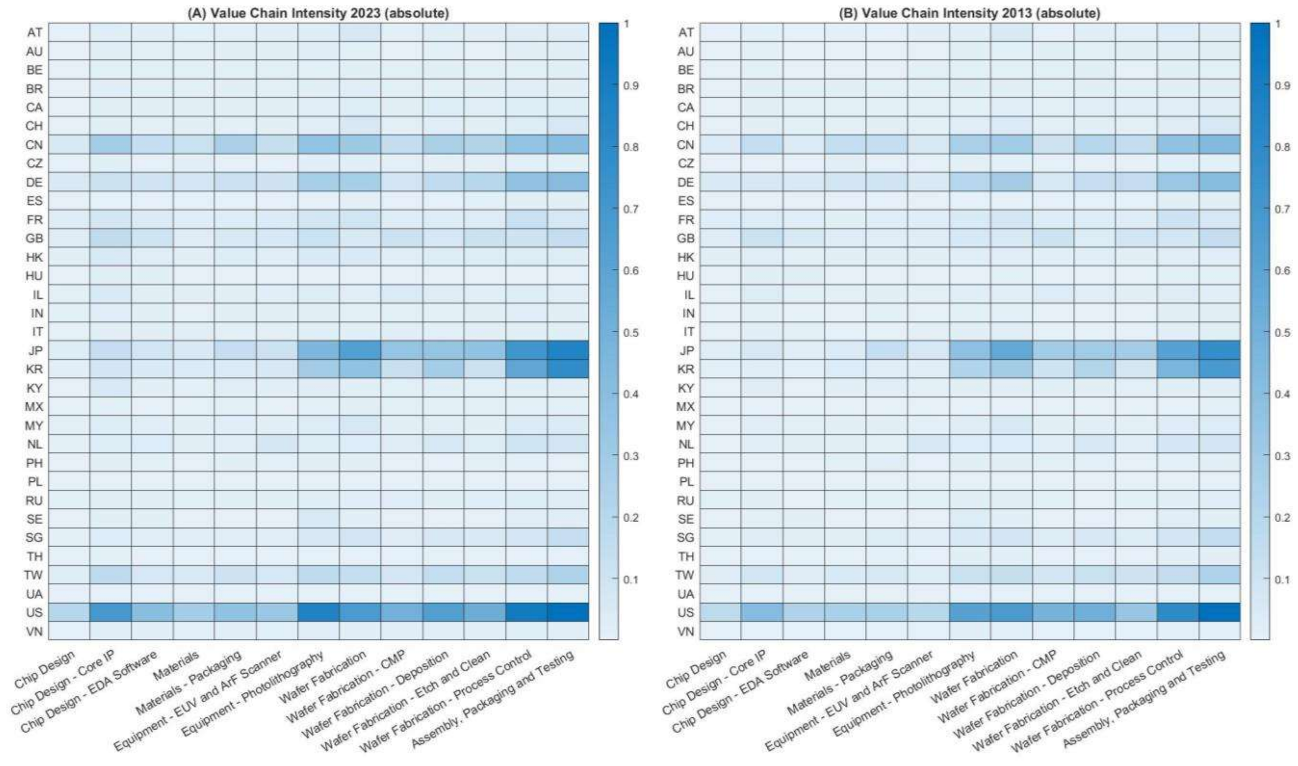

Figure 6: Results for absolute value chain intensity in (A) 2023 and (B) 2013. For each value chain segment (column), we evaluate how many companies in each country are in close network proximity to the leading companies in the segment.

In Figure 7, we show the results for value chain intensity in a normalized way. This means that size effects (number of companies per country) are scaled out, and instead we see whether companies in a country tend to be closer to the leaders in a particular value chain segment. This paints a very different picture.

First, we see that US firms are more evenly distributed across almost all segments of the value chain, suggesting a balanced degree of diversification among US firms. However, there is a slight tendency for US firms to concentrate on chip design. Other countries show more pronounced patterns of specialization. Some value chain segments are specific to a single country. This includes the Netherlands for EUV and ArF scanners, which of course reflects the unique position of ASML. Sweden is the only country where companies are clearly focused on photolithography equipment, possibly related to companies such as Obducat.

Companies from Japan and Korea are partnered with leaders in specific manufacturing steps, including chemical mechanical planarization, process control, deposition, etch and clean, wafer fabrication and assembly, packaging, and test.

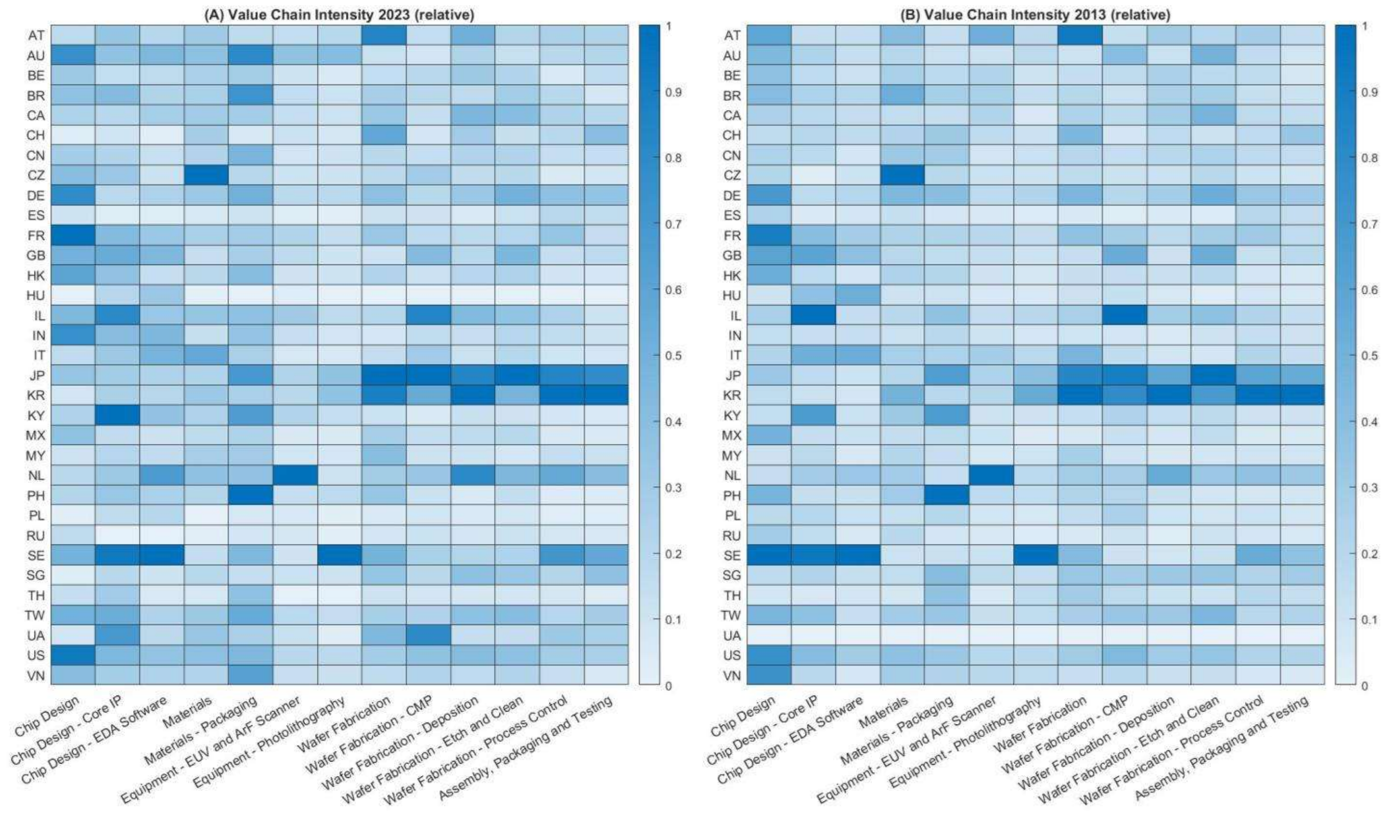

Figure 7: Same as Figure 6, but now for the relative intensity. For each value chain segment (column) and country (row), we evaluate how close its companies are, on average, to the leaders in the given segment.

Most of the relationships described above remained relatively stable between 2023 and 2013, again suggesting that the main areas of specialization remained robust throughout the study period. This comprehensive mapping of the semiconductor supply chain provides an initial overview that can be followed by numerous detailed analyses.

Figure 8: Revenue-weighted intensity scales the proximity of a given company to a leader by its revenue. Results are shown (A) in absolute terms, where they are driven by the number of high revenue companies in shows the revenue-weighted intensity in (A) absolute terms and (B) relative to the total revenue of all semiconductor-related companies identified by our approach in each country. This analysis places more weight on the closeness of high-revenue companies (weights are given by the logarithm of operating revenue). Despite these methodological differences, we still find similar patterns of specialization across regions and value chain segments, meaning that these trends are robust regardless of whether we look at the entire population of companies in a country or just the highest-revenue companies - supporting our approach of mapping the ecosystem of lead companies in more detail.

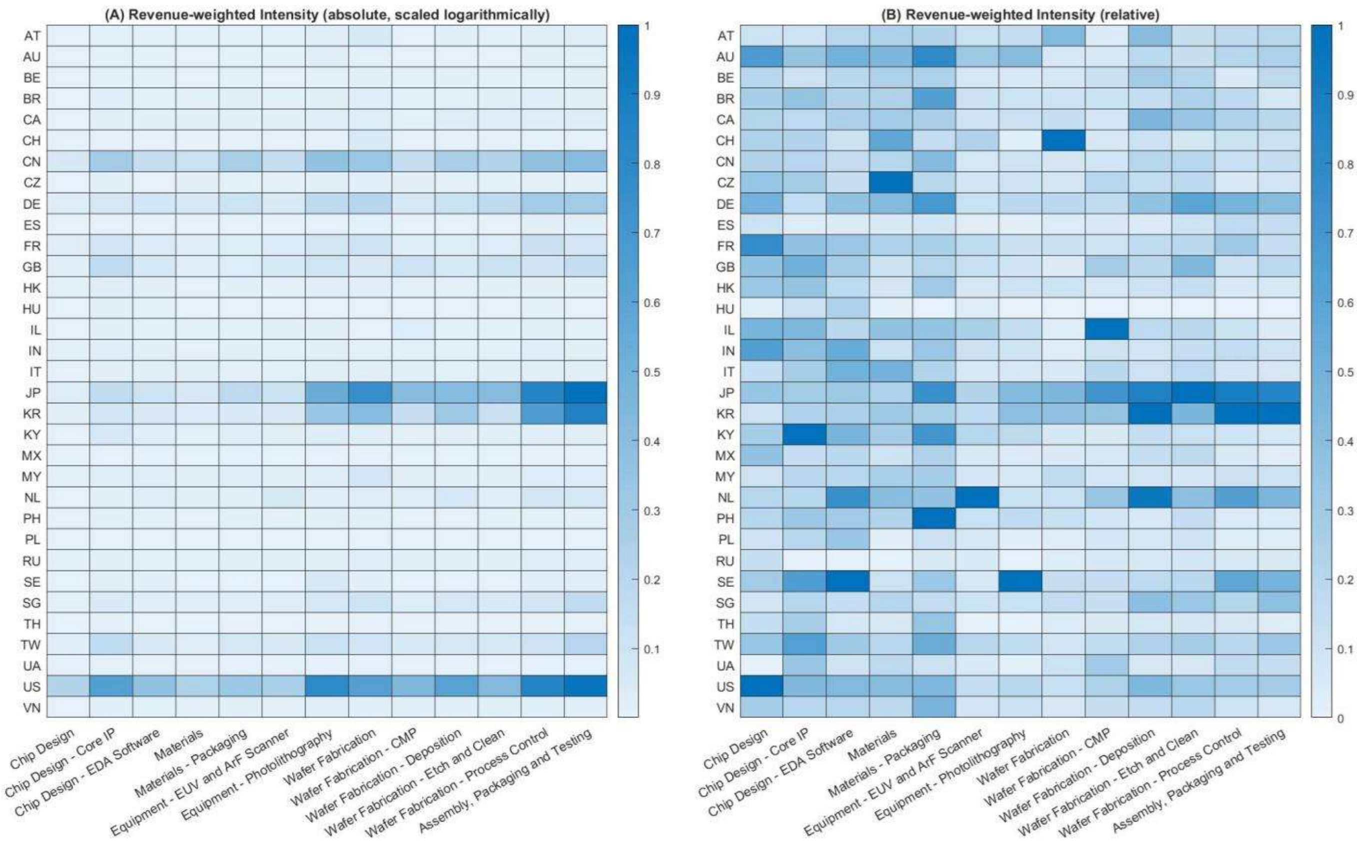

Figure 8: Revenue-weighted intensity scales the proximity of a given company to a leader by its revenue. Results are shown (A) in absolute terms, where they are driven by the number of high revenue companies in a region, and (B) relative to the total revenue of all companies in a region.

To take a closer look at changes over time, Figure 9 provides an overview of regional changes in value chain intensity between 2023 and 2013, expressed as percentage changes relative to 2013. Results are shown for (A) EU countries, (B) the US, and (C) China. Several segments show consistent trends across all regions, notably increasing value chain intensities in core IP; electronic design automation software; deposition, etching, and cleaning; photolithography; packaging materials. This means that in all these regions, the activities of individual companies tend to be more closely linked to the leading companies within these segments. Or, to put it another way, the respective leading companies are becoming more central in the inter-firm networks in all these regions, suggesting increased specificity in these production steps and thus an increased need for firms to share knowledge and collaborate.

There are also regional differences. Wafer fabrication shows a reduced role in the EU compared to the US and China. The US shows little movement in chemical mechanical planarization (CMP) and assembly, packaging, and test, while the EU and China show a significant increase in the former and a decrease in the latter.

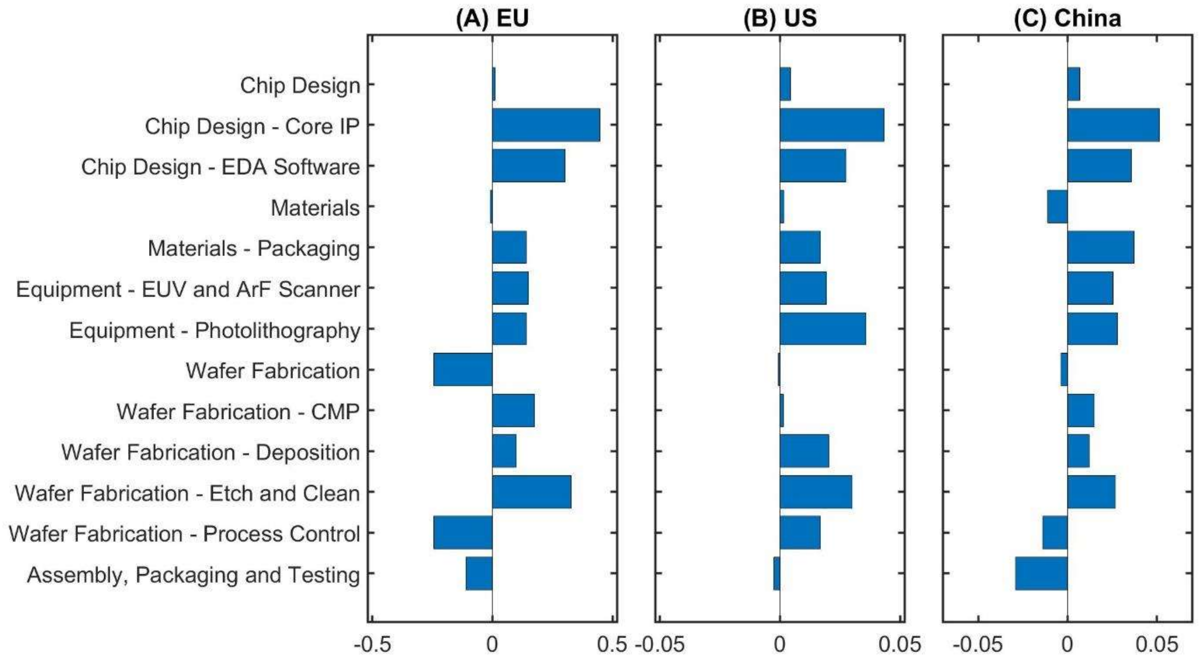

Figure 9: Percentage change in value chain intensity between 2013 and 2023 in (A) the EU, (B) the US, and (C) China.

Our approach also allows us to map the restructuring of the inter-firm network from 2013 to 2023 from a regional perspective, see Figure 10. The EU has reoriented its links, notably away from Japan and towards Singapore, the UK and Ukraine. The US has moved closer to China and Russia and away from Brazil. China's links have been mainly with the US, Taiwan, and Russia, while they have been separated from Hong Kong.

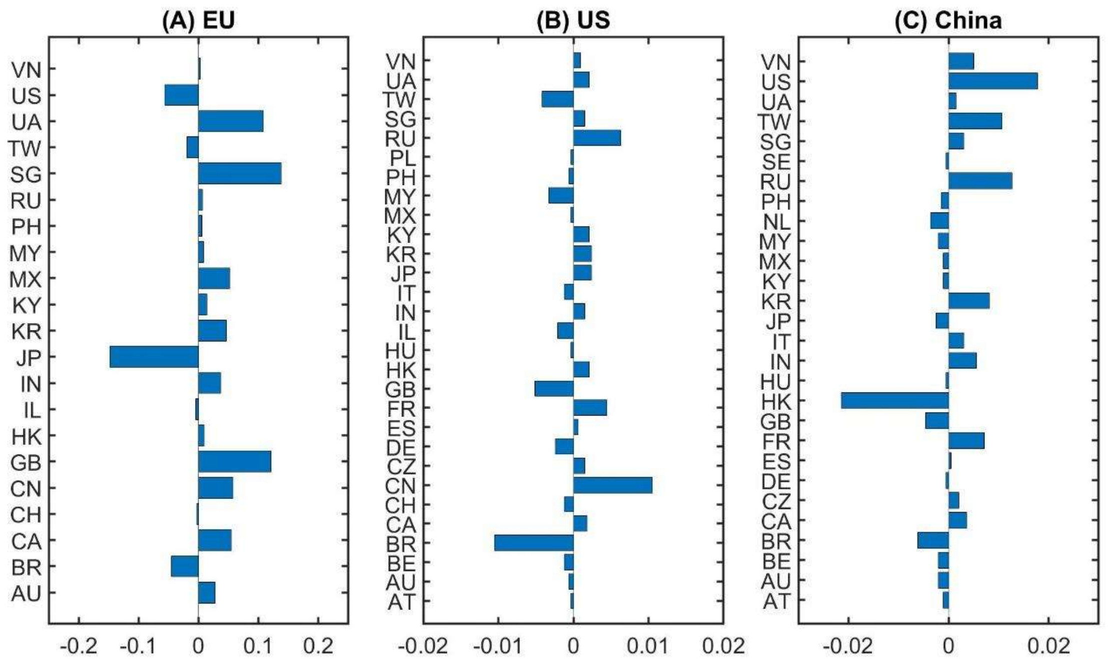

Figure 10: Rewiring of the inter-firm network from 2013 to 2023 for (A) the EU, (B) the US, and (C) China. The percentage change in the probability of links from a firm in these regions to another country (column) is shown. Positive (negative) values indicate a higher (lower) proportion of such links in 2023 compared to 2013.

3.2. Extending the semiconductor value chain - Mapping applications and products

Compared to the diverse applications of semiconductors, the actual production process of semiconductors is relatively straightforward and manageable. We use topic modeling as a method to logically extend the semiconductor value chain to include both application areas and semiconductor-related products of individual companies. The LDA model identified an optimal set of 80 topics that describe the business activities of the 21,245 semiconductor-related companies in this study. These themes were screened to identify those that could be clearly identified with either application areas or specific types of semiconductor-related products.

In total we identified 13 such topics, see Figure 11. The topics are ordered by their frequency within the companies, from left to right and from top to bottom. The most common topic is discrete analog and other semiconductors, including transistors, diodes, or rectifiers. In second place are various industrial applications, including automotive, aerospace, and defense. High-performance design ranks third, followed by power electronics, design automation, mixed-signal circuits, storage and wireless networking solutions, LCD panels, imaging, and other sensors (including RFID and security applications), wafer-based solar cells, memory cards, processor chips, and various accessories. The three least common topics include the automotive industry with respect to electric vehicles, memory cards, and processor chips. The most common topics are relevant to 3% of the companies, while the least common topics are relevant to approximately 0.5% of the companies. Please note that a company and its business activities can be linked to several topics.

Figure 11: Word clouds for application-relevant topics identified by the LDA model. Each word cloud corresponds to a topic, where the word size is proportional to the relevance of the term to the corresponding topic. The distribution of topic probabilities gives the probability for each company to be related to one of these topics.

ASCII

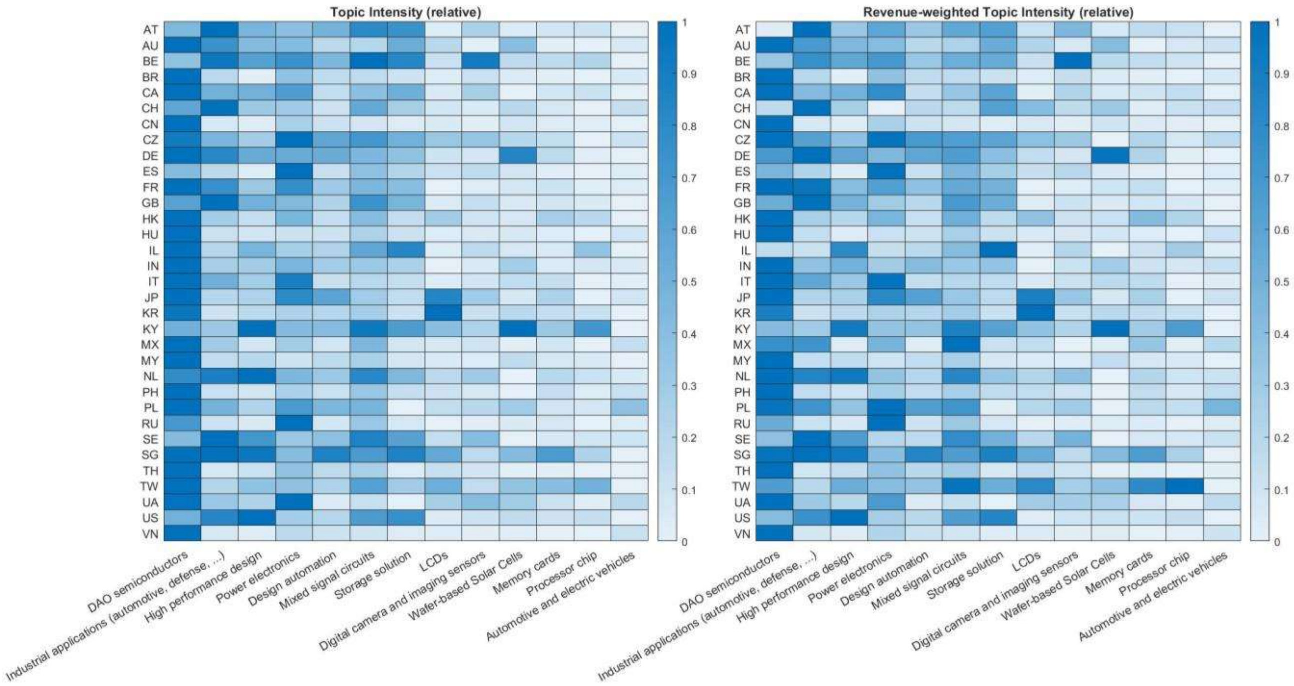

Figure 12: Intensity of LDA topics across companies in different countries. Topics are ranked from left to right according to their overall frequency. To obtain the topic intensity, the relative frequency of each topic across all companies in each country is calculated. For revenue-weighted intensity, companies are additionally weighted by their log operating revenue.

Figure 12 shows the intensity of these LDA topics across countries. To obtain the topic intensity, the relative frequency of each topic across all companies in a country is calculated. For the revenue-weighted topic intensity, companies are additionally weighted by their logarithmic operating revenue. Topics are ranked from left to right according to their overall frequency.

Figure 12 reveals some interesting patterns across countries. There are several countries where companies focus on the most common topic of DAO semiconductors, such as Brazil, China, Hong Kong, Hungary, India, Mexico, Malaysia, Philippines, Poland, Russia, Taiwan, Thailand, Ukraine, or Vietnam. However, most other topics are much less common.

There is a second category of countries that cover DAO semiconductors to a lesser extent, but are much more focused on applications such as industrial applications in automotive or defense, high performance computing, or power electronics. These countries include Austria, Australia, Belgium, Canada, France, Germany, the Netherlands, Singapore, Sweden, and the United States, basically Western, Central, and Northern European countries, North America, and Singapore. In terms of revenue, companies from these countries invest significantly more in applications than in DAO semiconductors.

4. Austria's strengths, weaknesses, and opportunities

From a national perspective; Austria has clear strengths in the application areas of the semiconductor value chain. In the actual production of semiconductors, Austrian companies are close to the leaders in the wafer fabrication segment. Figure 13 summarizes the results of the value chain and LDA topic analysis for Austria. Intensity values are shown by calculating the quotient of Austria's values with the world average. A value of 1 means that Austria's intensity values are equal to the world average, values above 1 indicate that Austria has a higher value chain intensity in this topic compared to the rest of the world.

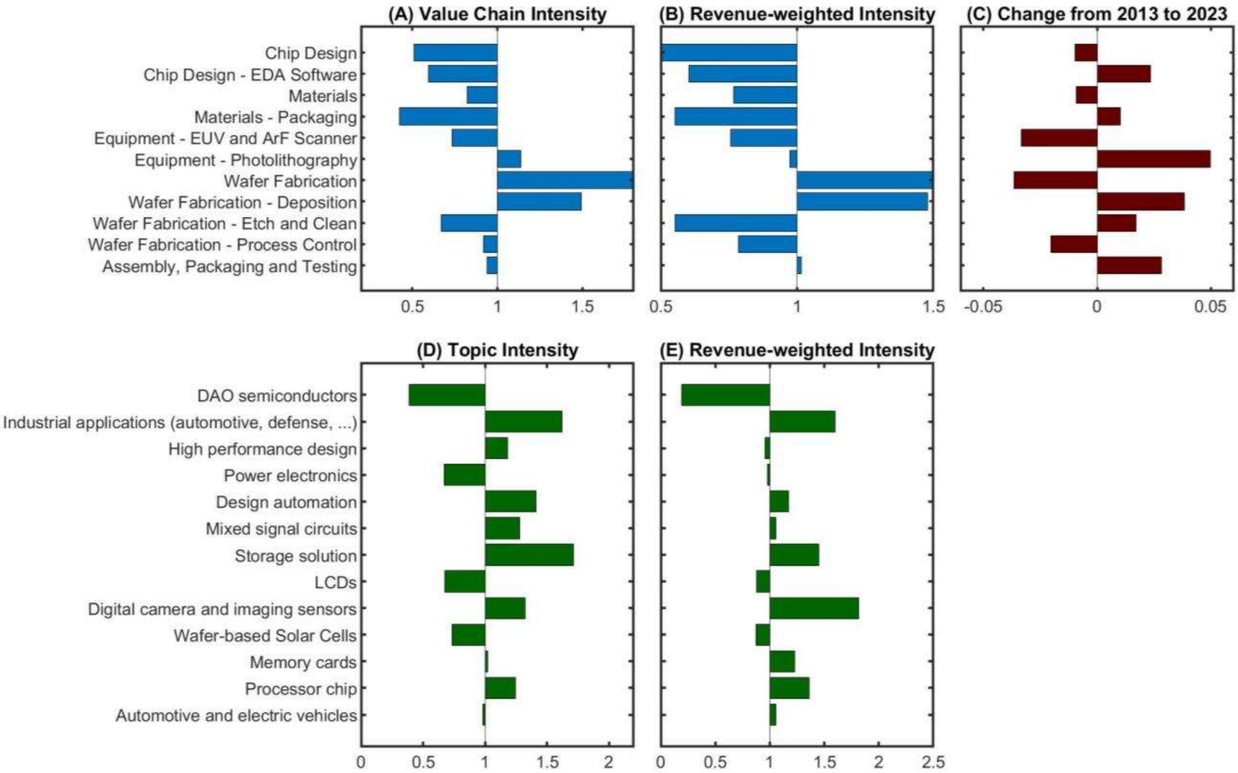

Figure 13: Overview of the results of the value chain and LDA topic analysis for Austria. The value chain (A) and topic intensity (D), as well as their revenue-weighted versions (B,E), show the values for Austria relative to the average values observed in other countries. The percentage change from 2013 to 2023 of the value chain intensity is also shown (C), as in Figure 9 for different world regions.

Our research shows that Austria follows the same pattern as the EU, focusing primarily on specific application areas and being rather specialized in terms of production steps. However, this does not exclude the existence of hidden champions in certain segments of the value chain, which reflect the special capabilities of individual companies rather than trends in the regional industry. Austrian companies are known to be market leaders in the production of photomasks, which are required for cutting-edge and advanced chip manufacturing. Some analysts even speak of "silent" monopolies in certain segments.[8] IMS Nanofabrication was recently estimated to have over 95% market share in the production of multi-beam mask writers in the sub-7 nanometer range, a critical input for

[8] https://www.semianalysis.com/p/austrias-silent-monopolies-on-advanced, accessed 03/21/2024

the manufacture of advanced logic gates, DRAM, and image sensor applications. EV Group has an estimated 82% market share of wafer bonding tools, a critical input for CMOS image sensors.

In terms of the value chain aspects, Austrian companies are close to the leading companies in the segment of wafer fabrication as shown in Figure 7. This could be explained by the fact that 19 of the 45 identified Austrian companies active in the semiconductor industry were classified as equipment manufacturers. Since the equipment serves as input for the foundry companies this connection seems plausible. A closer look at the company descriptions of these 19 companies reveals, that they offer equipment and tools for the sub-processes listed in section 2.1 (such as lithography, deposition, and packaging). For example, important Austrian companies offer advanced photomasks and wafer bonding tools.

While Austria exhibits different strength fields in connection to the semiconductor manufacturing such as semiconductor equipment, packaging, assembly and testing as well as chip design, we identified an even stronger affinity on the application side, as depicted in Figure 13. The graphic underlines Austrias relative strength in the field of industrial applications (more precisely applications in the automotive industry) compared to the other countries.

The importance of semiconductors in the automotive industry becomes apparent when considering the shift from traditional combustion engine to electric vehicles. While the average diesel-powered car requires about 1500 semiconductors, electric vehicles require twice as much, and they are not interchangeable.[9] According to a McKinsey Report topics like autonomous driving, connectivity, and electrification will drive most of the automotive semiconductor demand.[10] Applications of semiconductors in electric vehicles range from advanced driver assistance systems (ADAS) and infotainment systems to battery management systems and power distribution.[11] To make these features and components work, a variety of semiconductors like high-voltage controller chips, battery sensors, insulated gate bipolar transistors (IGBTs) and metal-oxide-semiconductor field-effect transistors (MOSFETs) is required.[12] The overlap between the automotive industry and the semiconductor value chain, particularly focusing on Austria's current strengths and potential future opportunities, warrants a deeper investigation.

We have further identified six Austrian companies positioned in the chip design segment, offering design services for a wide range of chips, covering a multitude of industrial applications such as Power-management, RFID, Automotive Electronics and NFC. A third

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[9] https://www.scmr.com/article/EV-semiconductor-supply-chain-concerns-grow#:~:text=Adding%20to%20the%20complexity%2C%20Cavallaro,%E2%80%9Cthey%20are%20not%20interchangeable.%E2%80%9D, accessed 03/21/2024

[10] https://www.mckinsey.com/industries/industrials-and-electronics/our-insights/will-the-supply-demand-mismatch-persist-for-automotive-semiconductors#/, accessed 03/21/2024

[11] https://polarsemi.com/blog/blog-semiconductor-chips-in-a-car/#:~:text=In%20electric%20and%20hybrid%20vehicles,Di%20for%20AC%2FDC%20converters, accessed 03/21/2024

[12] https://www.idtechex.com/en/research-article/electric-vehicle-bms-drives-a-third-of-silicon-demand/29066
https://www.eetimes.com/revolutionizing-high-voltage-controller-chips-for-electric-vehicles/
https://techovedas.com/evs-needs-twice-as-semiconductors-as-traditional-cars/
https://polarsemi.com/blog/blog-5-innovations-of-semiconductors-for-electric-cars/, accessed 03/21/2024

category worth mentioning in an Austrian context is Assembly, Packaging & Testing (see also Figure 13 C) here we can see a positive development between 2013 and 2023. This result matches with identified Austrian companies that operate in this field. This positive development is in line with global developments. A current McKinsey report highlights the growing importance of advanced packaging – predicting sales growth from 2.42 billion USD in 2020 to 8.69 billion USD in 2026.[13]

Figure 13 illustrates significant developments and changes of priorities from 2013 to 2023, shedding light on one major shortcoming of the current study design. All findings are derived from historical data obtained from publicly available sources. Consequently, the conclusions drawn are limited by the retrospective nature of the data, prohibiting the estimation of future trends and shifts in importance. Moving forward, preliminary findings from this study must be deliberated with industry experts, and strategies for integrating current and potential future developments into the analysis need to be devised.

[13] https://www.mckinsey.com/industries/semiconductors/our-insights/advanced-chip-packaging-how-manufacturers-can-play-to-win, accessed 03/21/2024

5. Discussion and conclusions

Here, we have constructed an extensive firm-level dataset of the semiconductor value chain, identified leading firms in different segments of the value chain, and examined the evolution of the inter-firm network in relation to these leading firms over the last decade. This analysis is combined with a topic modeling approach to further extract information on application areas and semiconductor-related products. This combination allows us to analyze the semiconductor industry from two perspectives, one focused on the semiconductor manufacturing process and the other on application and product classes.

We find that these two perspectives lead to very different results. Many manufacturing steps, such as wafer fabrication, are concentrated in Asian countries such as Japan and South Korea. However, these countries are typically not as strong in the applications where many North American, Western, Central and Northern European countries, Australia and Singapore are strong. The United States plays a special role from a global perspective, occupying both multiple applications and manufacturing steps.

At the global level, companies in the EU, US, and China have shifted over the past decade toward chip design leaders, namely core IP and electronic design automation software. This is not surprising, since design is the segment of the value chain that combines high value added with relatively modest capital expenditures.

Over the past decade, U.S. and Chinese companies have grown closer to each other in the inter-firm network. At first glance, this may seem surprising given the current US-China chip rivalry. However, U.S. semiconductor exports to China have quadrupled from 2013 to 2021[14]. Starting in late 2022, the US revised and dramatically tightened its export controls to curb China's push toward autonomous production of high-end chips[15]. Thus, our results reflect the stronger integration of US and Chinese semiconductor firms before the US tightened export controls. In future studies, it will be interesting to examine how the recent US-China chip war has affected the inter-firm network more recently.

One of the main drivers of recent U.S. export controls is a push for strategic autonomy in chip manufacturing, particularly with respect to advanced and cutting-edge chips and their use for military purposes. Our results support the notion that this form of strategic autonomy may be less relevant for the EU with its focus on industrial and other applications. Most of these industrial applications require so-called legacy chips, produced with older but still evolving processes. The US Chips and Science Act defines such legacy chips as those manufactured using 28-nanometer or larger technology, while cutting-edge chips are typically considered to be below 5 nanometers. Most chips used in the automotive, aerospace, defense and communications industries are legacy chips. In fact, the chip shortage during the COVID pandemics was essentially a shortage of legacy chips. Areas of application for cutting-edge and advanced chips (between legacy and cutting-edge), such as chips needed to train large AI models or high-end smartphone processors, are typically outside the specialization of most EU companies. Therefore, the EU's strategic interests lie more in industrial and other types of applications that do not necessarily require cutting-edge production processes.

In conclusion, our analysis illuminates the multifaceted landscape of the semiconductor industry, revealing regional specializations, inter-firm network dynamics, and

[14] https://www.apricitas.io/p/the-semiconductor-trade-war, accessed 03/21/2024

[15] https://www.csis.org/analysis/balancing-ledger-export-controls-us-chip-technology-china, accessed 03/21/2024

opportunities for innovation and growth. By employing a novel approach to mapping semiconductor companies and analyzing their interconnections, we have gained valuable insights into the sector's complexities. Our findings underscore the significance of regional strengths, particularly in key manufacturing domains and application niches, while also highlighting the evolving nature of inter-firm networks and the pivotal role of design capabilities in driving innovation. Moreover, our examination of the Austrian semiconductor industry showcases its commendable strengths and niche capabilities within the global value chain. Looking ahead, strategic considerations must guide stakeholders in leveraging regional strengths, fostering collaborations, and embracing innovation to navigate competition and capitalize on emerging opportunities. Ultimately, our analysis offers actionable recommendations to stakeholders seeking to strengthen their strategic position in the dynamic semiconductor sector, ensuring sustained success amidst evolving market dynamics.

Appendix 1 – Datasets

ETO Advanced Semiconductor Supply Chain Dataset

A categorization of semiconductor supply chain segments as provided by the Center for Security and Emerging Technology within Georgetown University was used as a starting point for the construction of the value chain used in the current report. The supply chain was segmented into seven main steps, namely (1) Design, (2) Fabrication, (3) Assembly, Testing and Packaging, (4) Electronic Design Automation and Core IP, (5) Semiconductor Manufacturing Equipment, (6) Materials and (7) Research and Development. These categories can be further split up into subcategories, yielding in total 79 different supply chain segments.

Each of these segments is provided along with a text description in the ETO Advanced Semiconductor Supply Chain Dataset. [16] Furthermore, segments are linked by different types of relationship. For instance, a subcategory of manufacturing equipment is advanced photolithography equipment. The segments belonging to EUV and ArF scanners are examples of such an equipment and hence linked to the photolithography equipment segment by an “is type of” relationship. Photolithography equipment is clearly a required input to perform photolithography as a manufacturing process. Hence, the segment of “photolithography equipment” links by a “goes into“ relation into the “photolithography” process, and so forth. In total, the dataset contains 94 such relations of either type, see Figure 14.

[16] https://github.com/georgetown-cset/eto-supply-chain/tree/main/data (accessed 06/12/2023)

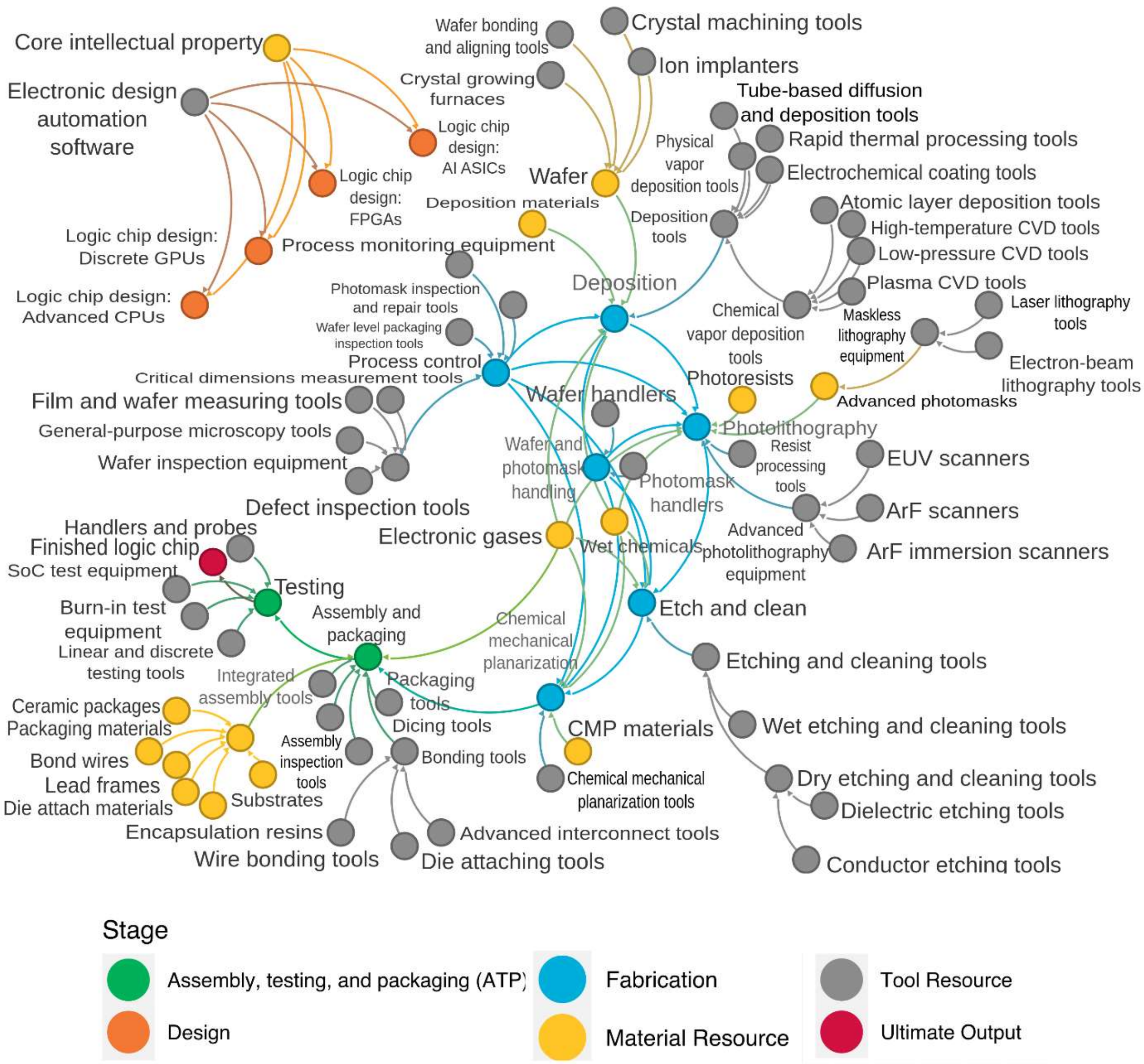

Figure 14: Network visualization of the stylized semiconductor value chain as constructed from the ETO Advanced Semiconductor Supply Chain Dataset. Each node corresponds to a segment of the supply chain with links indicating “goes into” (green) or “is type of” (grays) relations.

Abachy Semiconductor Materials and Equipment Directory

The Abachy Semiconductor Materials and Equipment Directory lists more than 2,000 manufacturers and suppliers of materials and equipment for semiconductor research and production. [17] The data is collected with the intention of providing buyers with a directory to identify providers of specific inputs to produce semiconductors. The directory contains a custom categorization of the materials and equipment types that these companies provide, which was linked by us to the categories of the ETO Advanced Semiconductor Supply Chain Dataset.

[17] https://abachy.com/ (accessed 06/12/2023)

Extracting Private Semiconductor Company Data

A dataset on 462 million companies worldwide is used, 45 million of which have financial information, the Orbis dataset. [18] Companies listed in the two industry-specific datasets (ETO and Abachy) were identified in Orbis, yielding a linkage of approximately 700 companies.

In the next step we sought to extract all companies from Orbis that can be assigned to the semiconductor industry. For the linked companies from ETO and Abachy, we identified their sectorial classification from Orbis, provided as 4-digit NACE codes (primary and secondary classifications). We then extracted all NACE codes that occurred ten or more times and extracted all companies from Orbis being assigned any of these codes, resulting in more than 800,000 potential semiconductor companies. Within these companies we extracted all entries that contained one of the following keywords in the textual description: “semiconductor”, “wafer”, “lithography”, “integrated circuit”, and “photomask”. This resulted in a list of 21,245 companies that served as the basis for this analysis.

In these extraction steps we do not include companies without text information. These texts particularly refer to Orbis data entries providing a description of the primary business line, products and services, trades, and main activities of the company with a combined length of more than 500 characters. Note that for most of the larger companies such an information is available and one misses mostly smaller companies. From the more than 800,000 companies in potentially relevant sectors, only 26% of the total turnover was recorded on companies that lack text descriptions.

[18] https://www.bvdinfo.com/en-gb/our-products/data/international/orbis, accessed 06/12/2023