Supply Chain Intelligence Institute Austria

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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 regional roles 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, combined with comprehensive trade data, and employing large-scale data-mining techniques, the study classifies and maps over 20,000 semiconductor companies to their positions in the extended value chain (chip production and application). The results reveal that the United States and China occupy almost complementary value chain segments while the EU's comparative strengths concentrate in semiconductor production equipment next to intermediate and final electronics for industrial applications. Austria emerges with a concentration in specific value chain segments and a diversified presence in a range of application domains. Austria has noteworthy capabilities in wafer fabrication, providing equipment and tools for core sub-processes such as lithography, etching, and packaging next to services such as design automation. Regarding semiconductor applications, Austria focuses particularly on various industrial applications such as sensors, encompassing security, RFID, and imaging applications, power electronics, or advanced product design. 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 on a European level, 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 significant 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 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 combined with extensive and comprehensive trade data. Based on established formal models for stylized value chains in the industry, we map comparative strengths in exports of semiconductor-related goods across regions over ten years. We further 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, China, Japan and South Korea dominate critical manufacturing domains such as wafer fabrication and consumer electronics, while North America and European territories, excel across a diverse spectrum of application domains spanning various industries next to equipment for wafer and semiconductor production.

Industry Dynamics: An analysis of comparative strengths over the last ten years shows that there has been minor change in EU strengths over time. China has gained comparative strengths in several segments of the value chain, while the US has lost strength in several categories. Further, 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. Austria has comparative strengths in several product categories related to equipment for semiconductor production, inputs required for intermediate electronics, as well as intermediate outputs for industrial use. According to trade statistics, these categories include, for instance, filtering equipment for semiconductor production, smart cards, resistors, diodes, transistors with a dissipation rate higher than 1W, or control and regulating instruments. Austrian companies cover a multitude of industrial applications such as power-management, RFID, automotive electronics, and NFC. Additionally, many relevant companies describe themselves via applications in automotive, consumer electronics, industrial applications, as well as communications and medical technology.

Opportunities and Implications:

Role of Advanced Packaging: Several recent studies identified that 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 core industries, ranging from automotive to security, sensors, and various other industrial applications. The potential of semiconductor innovations and their applications need to be carefully assessed based on their capacity to bolster future innovation. The focus should be to strengthen these core industries, within the context of the current market trends and geopolitical factors, thus increasing regional resilience.

In conclusion, our analysis provides valuable insights into the complex dynamics of the semiconductor industry, offering actionable recommendations to stakeholders for navigating 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 the 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.

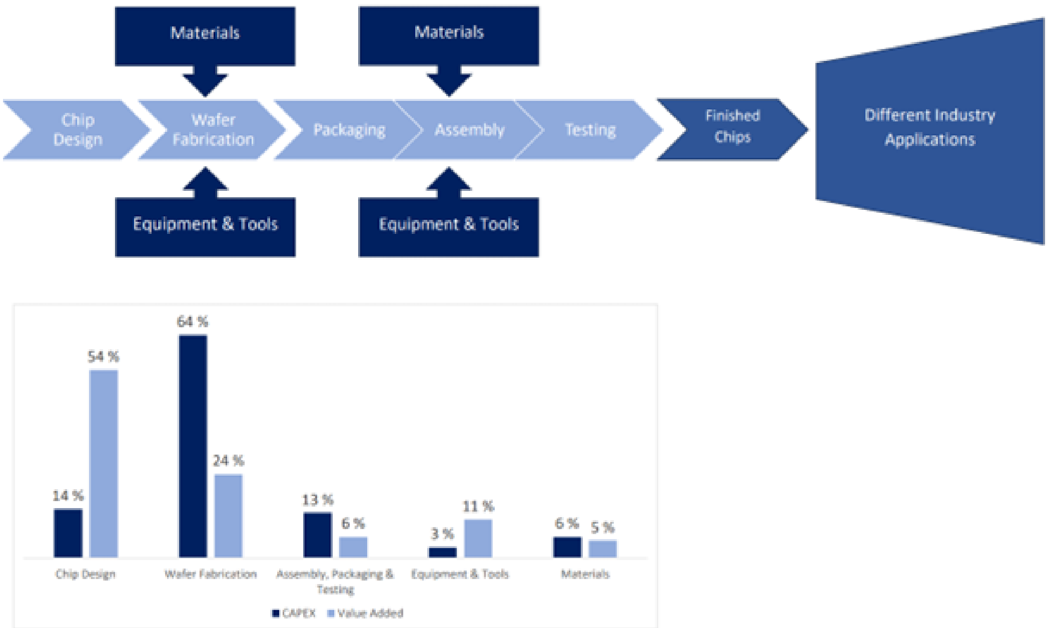

Figure 1: Main value-adding steps of the semiconductor supply chain[1]

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

[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.

Semiconductor Economic Roadmap 2022 published by BCG and the Arizona Commerce Authority highlights the particularly strong position of the US (electronic design automation, design, and equipment) and China (raw materials), see Figure 2.

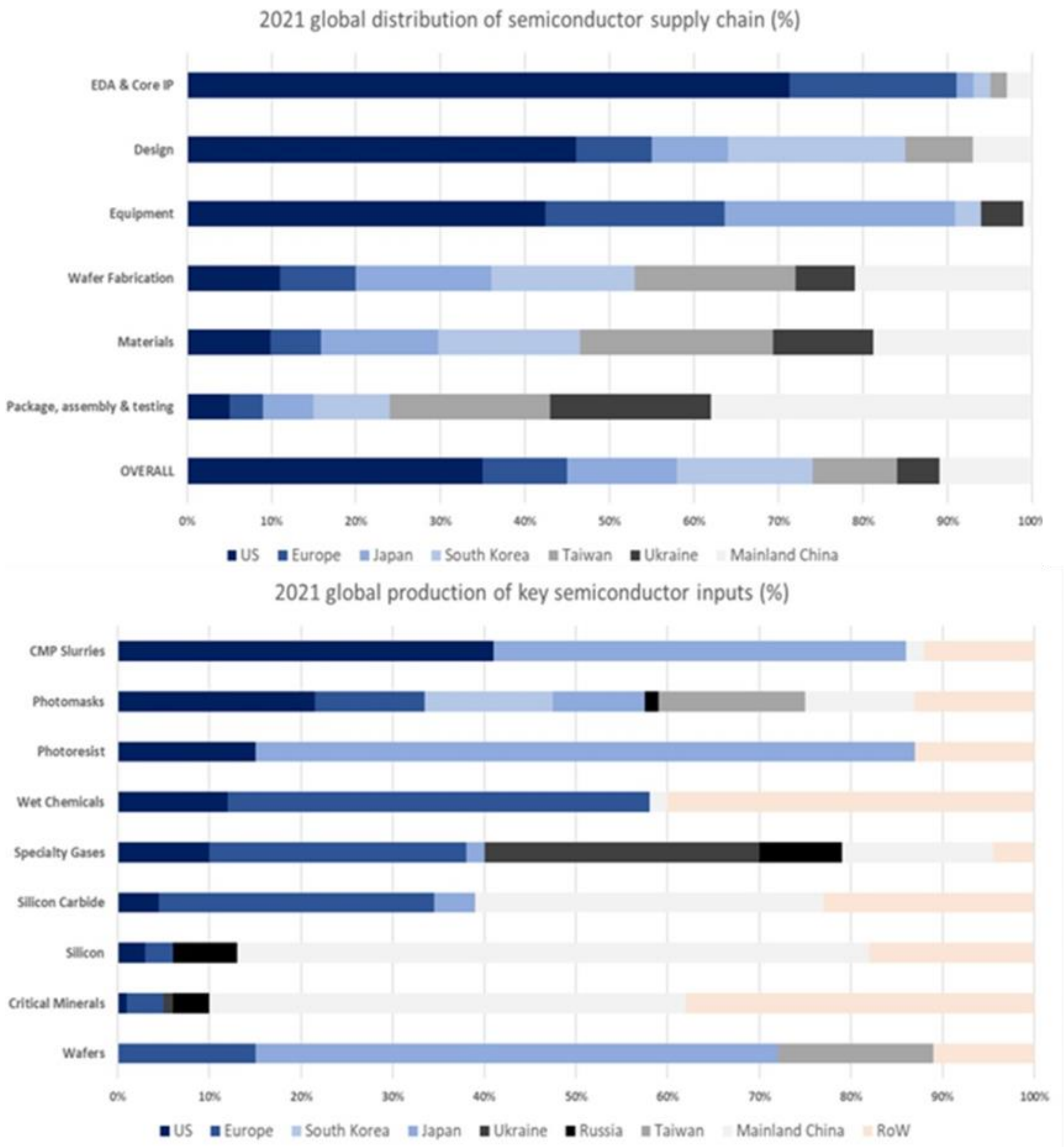

Figure 2: The global semiconductor landscape[2]

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 required 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 of smaller semiconductor companies contributing highly specialized products, processes, or materials. Additionally, highly specialized companies apply finished chips in their products – being market leaders

[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

themselves in their respective industry. These firms, often 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 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 innovative technologies. The competitive advantage of many supply chain actors lies in a deliberate lack of transparency. Hyperscale cloud service providers such as Amazon Web Services, Alphabet and Microsoft, can benefit from the commoditization of semiconductor manufacturing, as they develop microchips for their own needs. In the process, they have become major players in the semiconductor industry, as design providers. Until a few years ago, the production of semiconductors intended for military purposes was often 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 seek to control the global semiconductor supply chain. Figure 3 illustrates these relationships between end use, production locations and headquarters. Figure 3 illustrates Europe's dependency in the global semiconductor supply chain, as about 20% of end-use takes place in Europe, but only 10% of production takes place here. The European Chips Act could be a useful tool to improve Europe's strategic position. However, Europe's successful long-term positioning in the value chain requires more than adequate investment. It is essential to identify the most promising positions along the value chain for Europe, taking into account its strengths and capabilities. It is also important to consider the structure of the individual markets involved in the value chain. This raises the question of market concentration and the global distribution of value creation. Such an approach would ensure a cost-effective and efficient allocation of (public) financial resources.

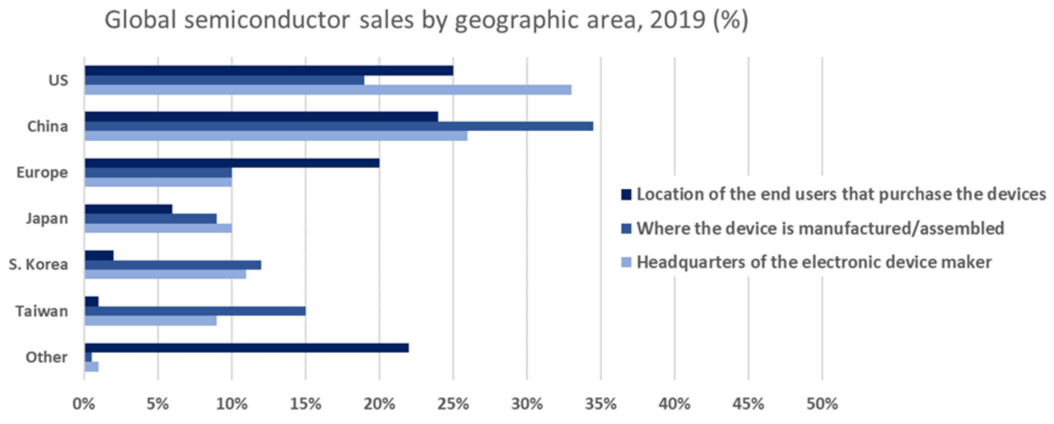

Figure 3: Bird's eye view on global power and dependence in the semiconductor supply chain[3]

[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. Methodological approach

Here we combine three methodological approaches to analyze the semiconductor value chain in terms of regional specialization from three different perspectives. First, we perform a comprehensive analysis of the value chain based on existing trade statistics focusing on goods trade. Second, we identify broader sets of semiconductor-related industrial activities by performing a topic modeling analysis of firm-level information. Third, we embed the identified semiconductor-related firms in an inter-firm network constructed through large-scale web data analysis to understand the structure of global inter-firm relationships. This multi-pronged approach is designed to provide a holistic understanding of the semiconductor value chain from perspectives ranging from trade in goods to relationships to industrial applications to interfirm relationships. Table 1 provides an overview of the methodological strengths and weaknesses of these three approaches.

Table 1: Methodological approaches in this study, their scope, strengths, and weaknesses.

Approach	Scope	Pros	Cons
Trade statistics	Captures flows of traded goods in a standardized customs tariff classification	- Based on reliable statistics - Global coverage	- Data only available until 2022 and on a country level - Captures only goods, no services, collaborations, IP, …
Topic Modelling	Map company activities based on NLP from unstructured (but mostly expert-curated) text information.	- Firm-level information - High coverage for OECD+EU countries (~90% in most countries)	- Information on business activities is unstructured - Provided information varies between companies (bias towards big players) - No history
Inter-firm network analysis	Mapping linkages beyond traded goods: collaborations, ownerships, …	- Firm-level information - Allows analysis data since 2007 up until a few weeks ago	- Emerging analytic approach - Requires further development of annotation procedures

Our methodological approach consists of the following steps:

- Construct a stylized value chain model of the global semiconductor industry (2.1) and map this model to product categories provided by the Harmonized System Classification.

- Evaluate regional competitive export strengths in individual value chain segments from trade statistics (2.2).
- Identify lead firms in each segment (2.3) and map the ecosystem of these lead companies through an inter-firm hyperlink network (2.4) to quantify regional strengths and weaknesses in a broader definition of value chain segments (2.5).
- Further extend the semiconductor value chain by means of natural language processing analysis based on topic modeling to identify application areas (including industries and semiconductor-related products) for each region (2.6).

More technical details on data and methods can be found in Annex 1.

2.1. Constructing a stylized value chain model

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 & Testing (Wafer Slicing/Dicing, Packaging, Testing), based on the classifications specified in the European Chips Act and the SIA report (see 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.

Some, but not all (e.g., activities such as R&D or design are not captured by trade in goods), value chain steps can be easily mapped to product classification systems. Here we adopt a previously proposed value chain model in which specific segments are mapped to Harmonized System codes, see also Annex 2. These segments are wafer and semiconductor manufacturing (i.e., distinct stages of semiconductor production) and their intermediate or final use by consumers or industry. For each of these stages, raw materials, inputs, equipment, and outputs have been identified and mapped to Harmonized System codes as follows: [4]

[4] OECD (2019-12-12), “Measuring distortions in international markets: The semiconductor value chain”, OECD Trade Policy Papers, No. 234, OECD Publishing, Paris. http://dx.doi.org/10.1787/8fe4491d-en

- **Wafer Production**:
    - **Raw material**: silicon
    - **Input**: photographic sheets
    - **Equipment**: machines for manufacture and measure of wafers
    - **Output**: silicon wafers
- **Semiconductor Production**:
    - **Raw material**: silicon wafers
    - **Input**: sheets, mirrors, and lenses
    - **Equipment**: fans, heat units, purifying machinery
    - **Output**: semiconductors
- **Intermediate Electronics**:
    - **Material**: semiconductors
    - **Input**: tubes and transistors
    - **Output (industry)**: parts of navigational instruments, automotive, etc.
    - **Output (consumer)**: sound, video or recording apparatus, etc.
- **Final Electronics**:
    - **Inputs (industry)**: intermediate industry electronics
    - **Inputs (consumer)**: intermediate consumer electronics
    - **Output (industry)**: calculating machines, data processing, etc.
    - **Output (consumer)**: smartphones, cameras, etc.

2.2. Measuring competitive export strength

The analysis is based on a dataset of bilateral trade flows for two hundred countries using the Harmonized System Classification system with six-digit codes.[5] Trade values by country and product are used to measure competitive export strengths using the Revealed Comparative Advantage (RCA) metric. A country *c* is said to have RCA in a product *p* if the ratio of its exports in *p* to its total exports of all products exceeds the same ratio for the world. Let $X_{c,p}(t)$ be the exports of country *c* in product *p* and year *t*, then its RCA is defined as $RCA_{c,p}(t) = \left(X_{c,p}(t) \big/ \sum_p X_{c,p}(t) \right) \Big/ \left(\sum_c X_{c,p}(t) \big/ \sum_{c,p} X_{c,p}(t) \right)$.

If a country has an RCA>1 for a product, it is said to be a competitive or significant exporter or producer of that product. The higher the RCA value, the higher its export strength.

Export strength typically means that countries have significant capabilities needed to produce the goods in question. These capabilities often allow countries to also produce closely related goods, a concept that is exploited in the so-called product space. This product space is typically represented as a network in which nodes correspond to

[5] Gaulier, G. and Zignago, S. (2010) BACI: International Trade Database at the Product-Level. The 1994-2007 Version. CEPII Working Paper, N°2010-23. http://www.cepii.fr/CEPII/en/bdd_modele/bdd_modele_item.asp?id=37.

products and links connect products that are typically exported together. More specifically, two products p and q are connected by a link in the product space if there is a significant correlation between countries with RCA>1 in *p* and *q* at the same time.

2.3. Identifying lead companies

Lead companies are companies with high market shares and revenues for a given value chain step. The top ten 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 – 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 three hundred leading companies. These companies can be involved in one or more value-adding activities to manufacture semiconductors (chip design, wafer fabrication, assembly, packaging & testing).

2.4. 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.[6] According to the theory of social capital, a firm's position in such networks determines its ability to access information resources.[7] Firms embedded in inter-firm networks are exposed to signals from their network neighbors. Exposure to similar signals can influence the firm's decision making and adoption behavior. Firms in central positions within networks - lead firms - can function 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.[8] 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

[6] 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.
[7] Lin, N. (2002). Social capital: A theory of social structure and action (Vol. 19). Cambridge university press.
[8] 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).

2023 and around 2013, respectively, to measure temporal changes in the inter-firm network. We extract all hyperlinks from websites associated with companies linked to 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.

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 the connections between them, 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 various locations, which in turn may work on different product lines. The problem becomes even more complex when one considers that some companies have subsidiaries that operate under a different name but collaborate closely with the parent company. Further layers of complexity appear when considering the actual transportation routes, logistics facilities, and logistics service providers responsible for the shipments.

Many of these challenges stem from data availability. For example, determining the nature of the relationship between companies is difficult. If a company's Web page does not clarify the connection between two companies, it is captured as an undirected connection. Similarly, it is 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.

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

2.6. 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.[9]

LDA is typically used to analyze an enormous 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, the number of topics the model should identify is chosen. Then, the model goes through each document and assesses which words are most likely to belong to which topics. It does so 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 structures 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.

[9] 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. Trade-data-based value chain analysis

The results for the exports in categories related to wafer and semiconductor fabrication are shown in Figure 4 combining trade information from 2020 to 2022. Within wafer fabrication, by far the largest exports are in the equipment category, which refers to various parts and accessories necessary for wafer fabrication. The USA and Japan have the highest exports in this category, but several European countries also play a role in this segment. The product-normalized results show the leading exporters for the other, smaller segments. Most of these categories are highly concentrated, with only a few countries dominating most world exports in each category. In terms of raw materials, Germany and the United States dominate trade in high-purity silicon, while China dominates trade in silicon carbide and germanium. Photographic plates and films mainly come from the EU (>225 mm side length) and Japan (<225 mm side length). Japan also dominates in photographic products, wafer fabrication machinery and wafer inspection and measurement instruments, while China dominates over gallium. Optical instruments for wafer inspection come mainly from Singapore and the USA. Exports of silicon wafers are distributed among several countries, including China, Japan and, to a lesser extent, Germany, the United Kingdom, Korea, Taiwan, and the United States.

Exports in semiconductor production exceed those in wafer production by an order of magnitude, with Taiwan being the largest exporter of integrated circuits. Looking at the individual segments, there is again a high concentration in most of them. Inputs such as wafers and lenses mostly come from Japan and/or China, while most exports of inspection tools or equipment come from the EU and/or US. China, on the other hand, is among the top exporters in all output categories, while other regions show strength in more specific output segments. In addition to integrated circuits, these include processors, controllers and microassemblies from Taiwan, passive elements from Japan, solid state storage devices and amplifiers from Malaysia, and memories and non-volatile storage devices from Korea. The EU also has visible export shares in passive electrical resistors, smart cards, solid state storage and processors and controllers at levels that are, however, smaller than Chinese exports.

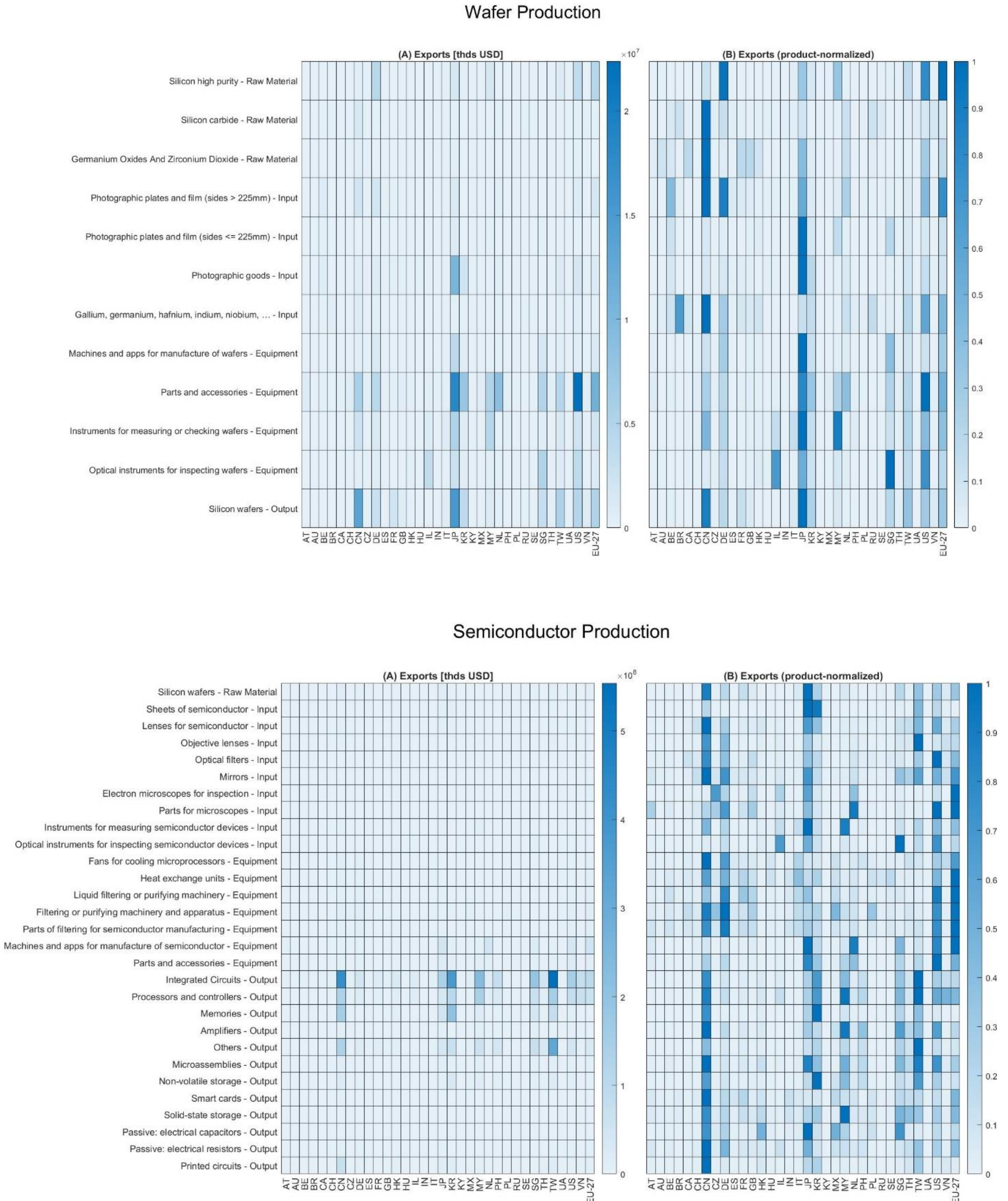

Figure 4: Exports in (top) wafer and (bottom) semiconductor production categories. Exports by country and category are shown in absolute values (in thousands USD, left) and normalized by product category (right) to identify leading exporters in each category.

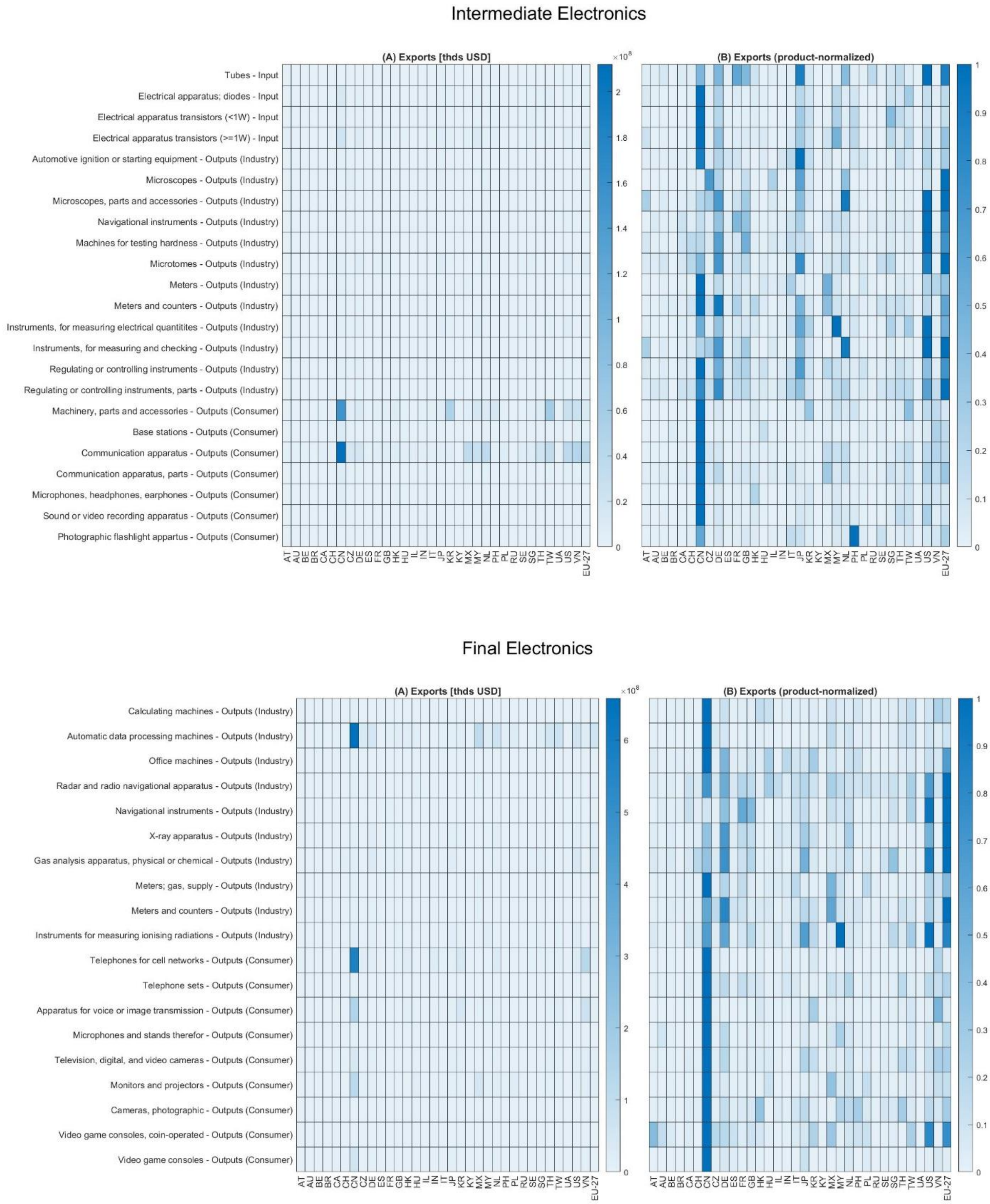

Figure 5: Exports in (top) intermediate and (bottom) final electronics. Exports by country and category are shown in absolute values (in thousands USD, left) and normalized by product category (right) to identify leading exporters in each category.

Total world exports of intermediate electronic products are dominated by Chinese exports of consumer electronics, Figure 5, particularly in the base stations and communication equipment categories. Apart from tubes (dominated by EU and US exports), all input categories are dominated by Chinese exports. On the output side, there is a clear split between industrial applications, dominated by the EU and US, and consumer applications, dominated by China. Exceptions to this general trend include electrical measuring instruments from the USA and Malaysia, photographic flashlights from the Philippines and ignition and starting equipment for motor vehicles from Japan. A similar picture emerges for exports of consumer electronics. Smartphones and computers from China dominate total exports. However, the EU dominates exports for most industrial applications considered (exception are gas measurement tools from China), in some categories shared with the US (physical or chemical gas analysis tools, navigational instruments, instruments for measuring ionizing radiation).

The above analysis provides an overview of the strongest exports in individual segments. These results are therefore biased towards larger countries. For a more fine-grained and regionalized analysis, we now consider the RCA metric. In this metric, for each country and segment, exports are measured relative to the country's total exports and compared to the segment's global export share. An RCA value of 2 (0.5) therefore means that the export share of the country and product in question is twice (half) that of an average country.

The distribution of RCA values across segments for China, the US and the EU is shown in Figure 6 as a box plot. The results confirm China's export strength in consumer electronics as intermediate and final goods, together with semiconductor production and other inputs for intermediate electronics. The United States is a significant exporter of wafer and semiconductor production equipment and has high RCA values for intermediate electronics for industrial applications and inputs for semiconductor production.

The EU is a significant exporter of many products used as semiconductor manufacturing equipment and in intermediate and final industrial applications. In most other categories, the majority of RCA values are less than one, indicating a lack of comparative strength.

For a more detailed view of comparative strength, we visualize the results in terms of a product space, see Figure 7. Nodes correspond to categories labelled by their Harmonized System code, see Appendix 2. The node colors indicate the value chain segment, the node symbol the type of category (raw material, equipment, input, output) and the node size the total exports in the category. We then visualize the product space for China, the US, and the EU, showing in black (grey) those categories in which the region has (does not have) comparative strength.

The analysis shows that China and the US focus their comparative strengths almost exclusively on complementary regions of the product space. For China, this is the upper region, which includes the output of consumer electronics and intermediate goods, as well as several input categories for these segments. The US has comparative strengths in the lower regions of the product space, including many equipment categories. Semiconductor manufacturing output is also split between the US and China. The Product Space shows a center-right region where wafer fabrication categories are clustered, particularly equipment categories. The US dominates these regions.

The EU shares several of its comparative strengths with the US. These include semiconductor manufacturing equipment and inputs and several categories of industrial electronics. Compared to the US, the EU has strengths in a wider range of such industrial applications but lacks strength in semiconductor production output categories. More results of RCA by country and category can be found in Annex 3.

The dynamics of comparative strength over ten years is shown for China (Figure 8), the US (Figure 9) and the EU (Figure 10). China has developed comparative strength in several categories in recent years, which can be seen as a view from blue (log. RCA<0) to red (log. RCA>0) over time. These categories include photographic plates and film (>225m), gallium, integrated circuits, microassemblies and control tools. In contrast, China only lost comparative strength in the category of tubes as input for intermediate electronics. The US has steadily lost strength in several categories, including wafer fabrication equipment, (electron) microscopes, cooling fans, integrated circuits, diodes, automotive ignition equipment, meters, and consumer communications equipment. The EU shows less change in its comparative strengths over time. There are slight but steady increases in high-purity silicon and industrial intermediate goods such as meters, counters, and control instruments.

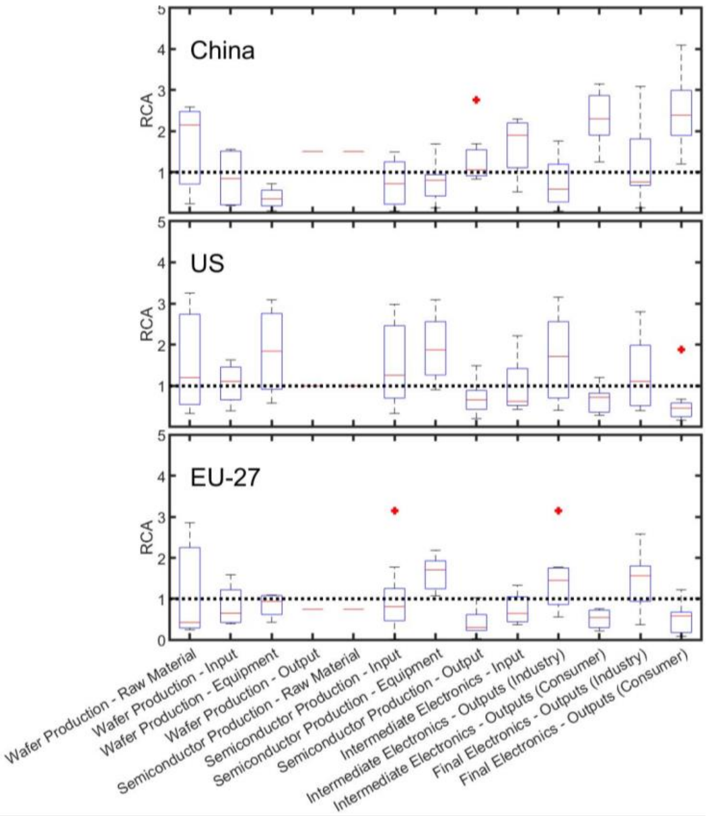

Figure 6: RCA by segment and region. The boxes show the distribution of RCA values across all product categories in the respective segments. The blue boxes range from the 25th to the 75th percentile, the red line indicates the median. Red dots indicate outlier categories, and the whiskers (dashed line) indicate the non-outlier minimum and maximum. Results are shown for China (top), the US (middle) and the EU (bottom).

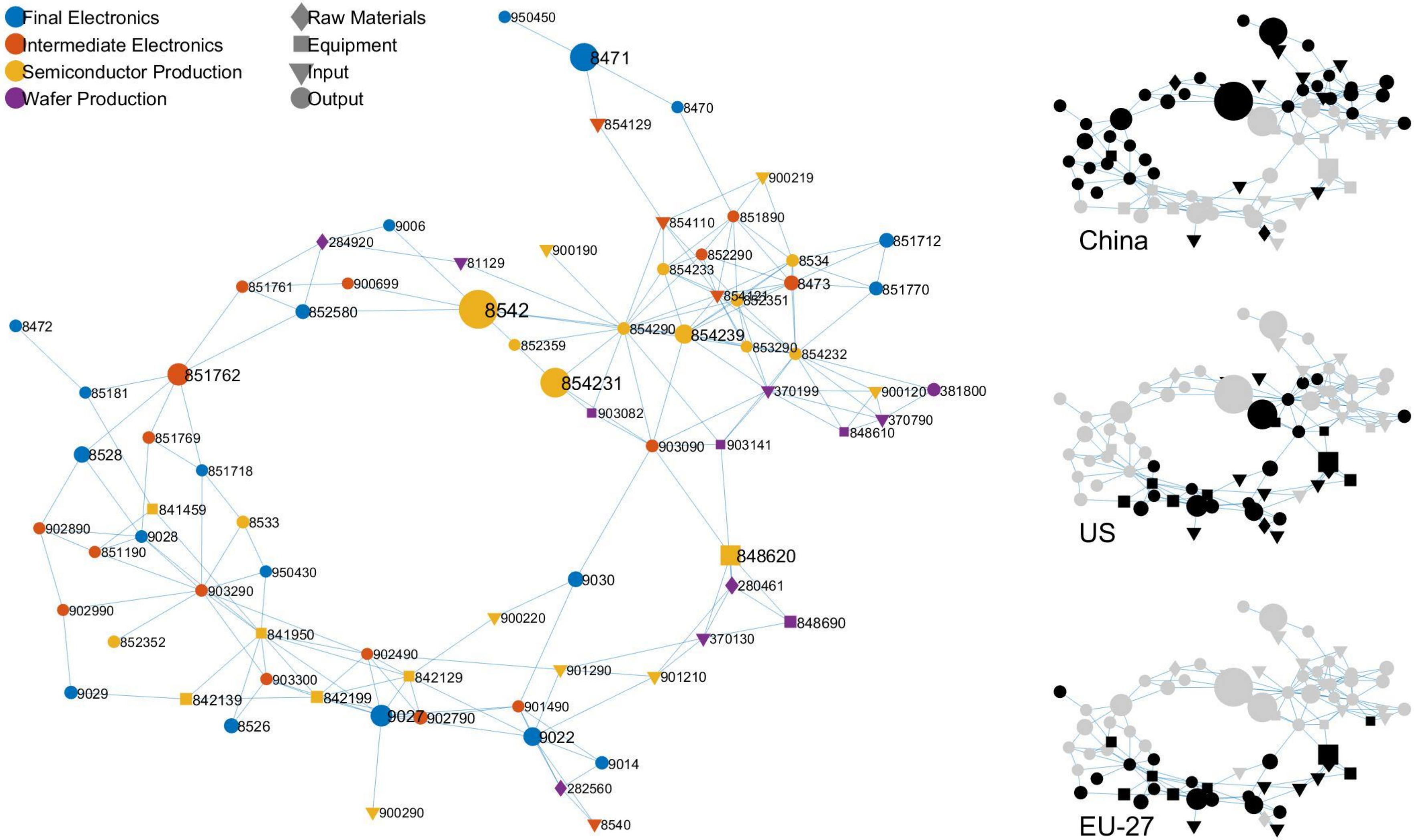

Figure 7: Product Space. The node colours indicate the value chain segment, the node symbol the type of category (raw material, equipment, input, output) and the node size the total exports in the category. The Product Space for China, the US and the EU shows in black (grey) categories in which the region has (does not have) comparative strength.

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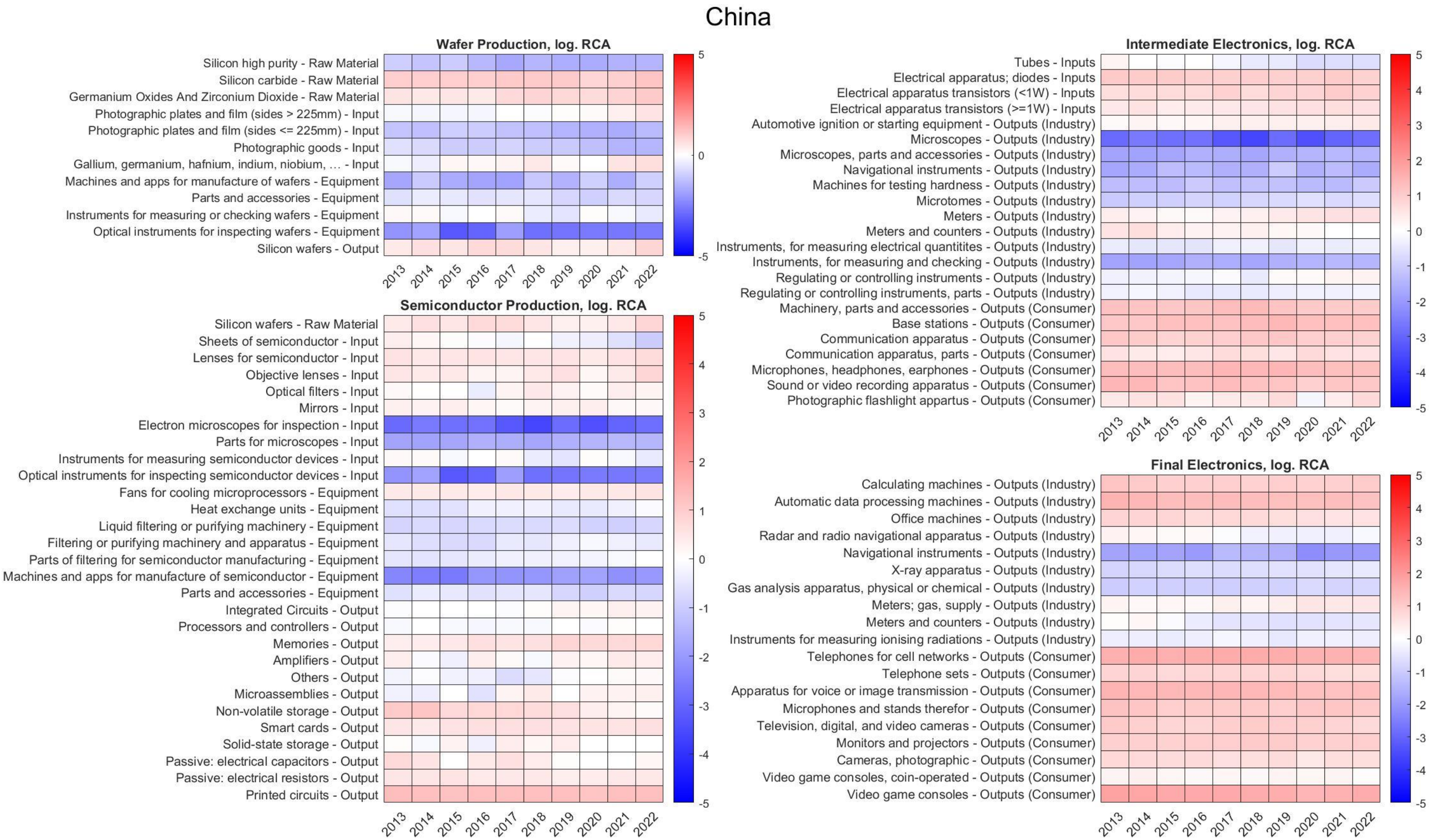

Figure 8: Dynamics of comparative strengths in China. For 2013 to 2022 the logarithmic RCA is shown for each category, where values above zero (red) indicate comparative strengths.

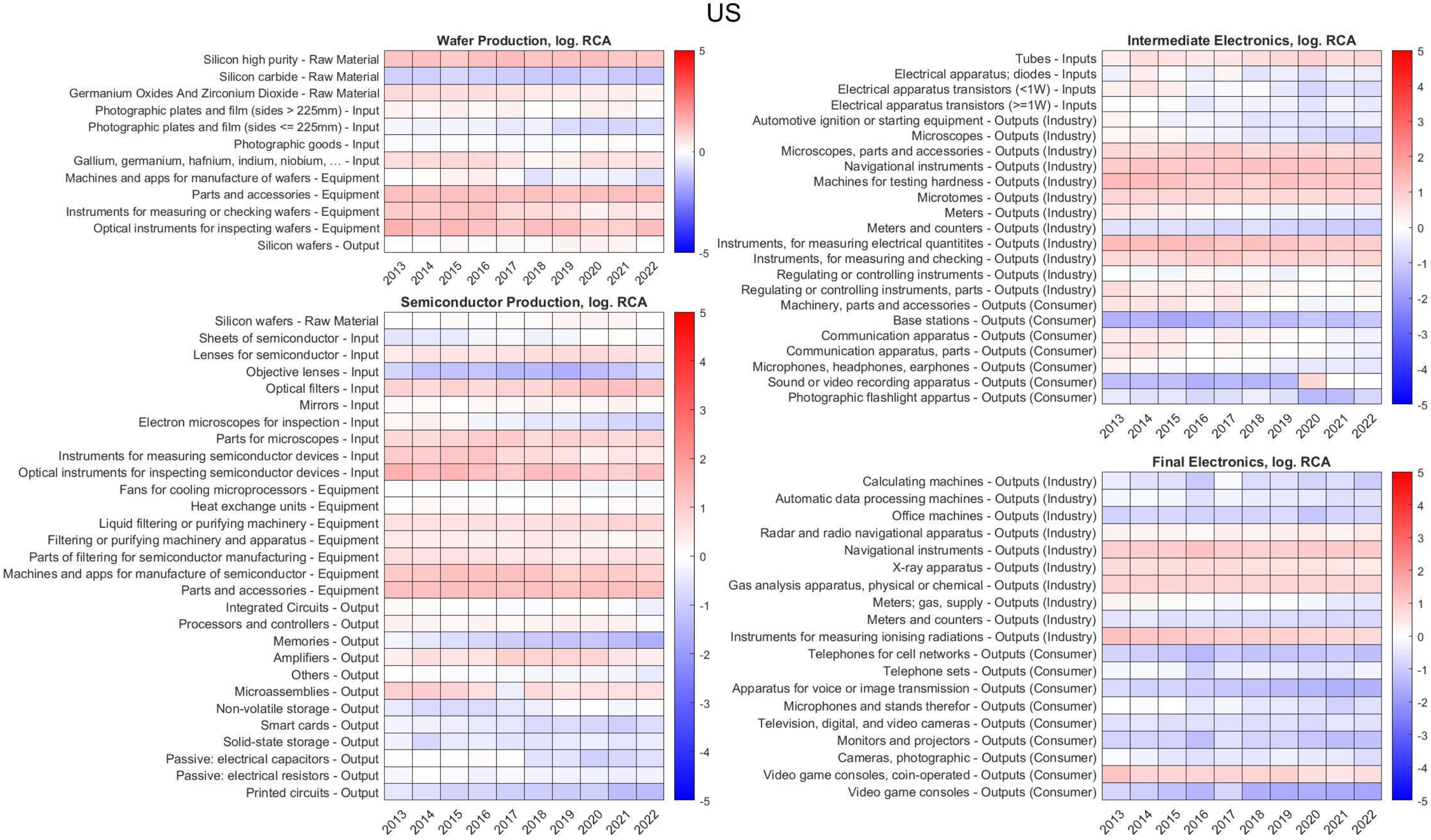

Figure 9: Dynamics of comparative strengths in the US. For 2013 to 2022 the logarithmic RCA is shown for each category, where values above zero (red) indicate comparative strengths.

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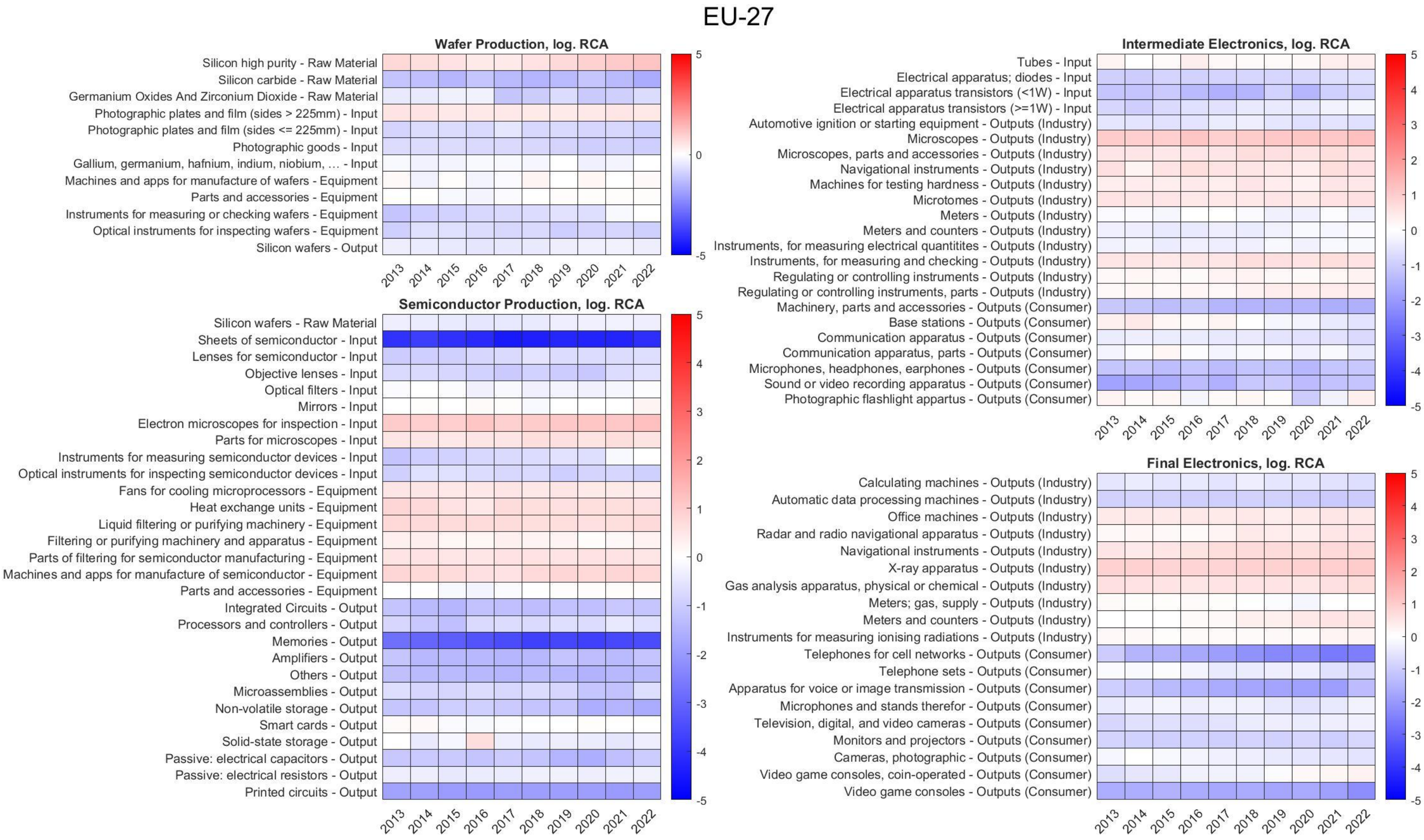

Figure 10: Dynamics of comparative strengths in the EU. For 2013 to 2022 the logarithmic RCA is shown for each category, where values above zero (red) indicate comparative strengths.

3.2. Mapping semiconductor companies

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 11(A), where we also show combined results of all EU member states (EU-27). 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 11(B,C).

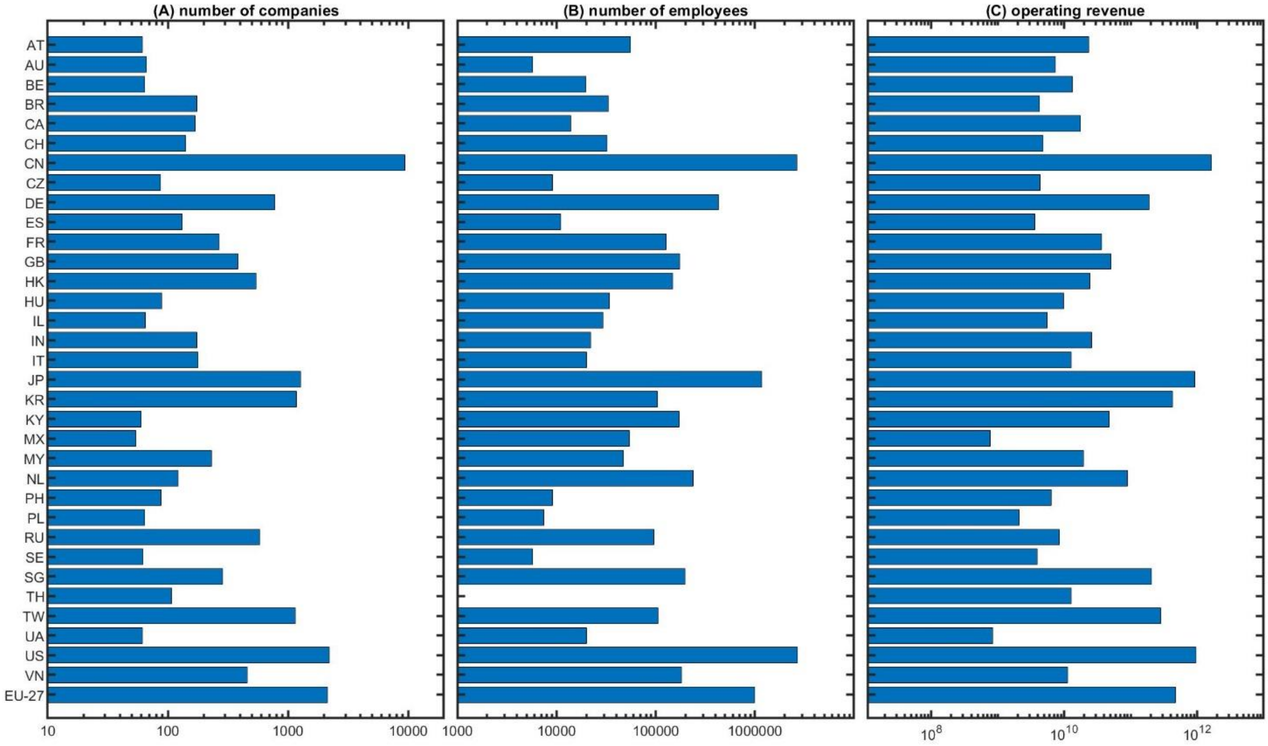

Figure 11: Descriptive overview of semiconductor companies. The number of companies in each country with more than fifty companies is shown (A) along with their combined number of employees (B) and operating revenue (C).

Compared to the clearly defined semiconductor manufacturing process, their application areas are much more diverse and not easily amenable to a systematic classification. We use topic modeling as a method to logically extend the semiconductor value chain to include both application areas – as inferred from data – and semiconductor-related products of individual companies. The LDA model identified an optimal set of eighty 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 thirteen such topics, see Figure 12. 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. Advanced product design (encompasses various advanced technical products in connection to semiconductors and microelectronics) ranks third, followed by power electronics, design automation, mixed-signal circuits, network and communication devices, LCD panels, imaging, and other sensors (including RFID and security applications), wafer-based solar cells, memory cards, processors and controllers, and various accessories. The three least common topics include the automotive industry with respect to electric vehicles, memory cards, and processors and controllers. 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 13 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 top to bottom according to their overall frequency.

Figure 13 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, advanced product design, 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.

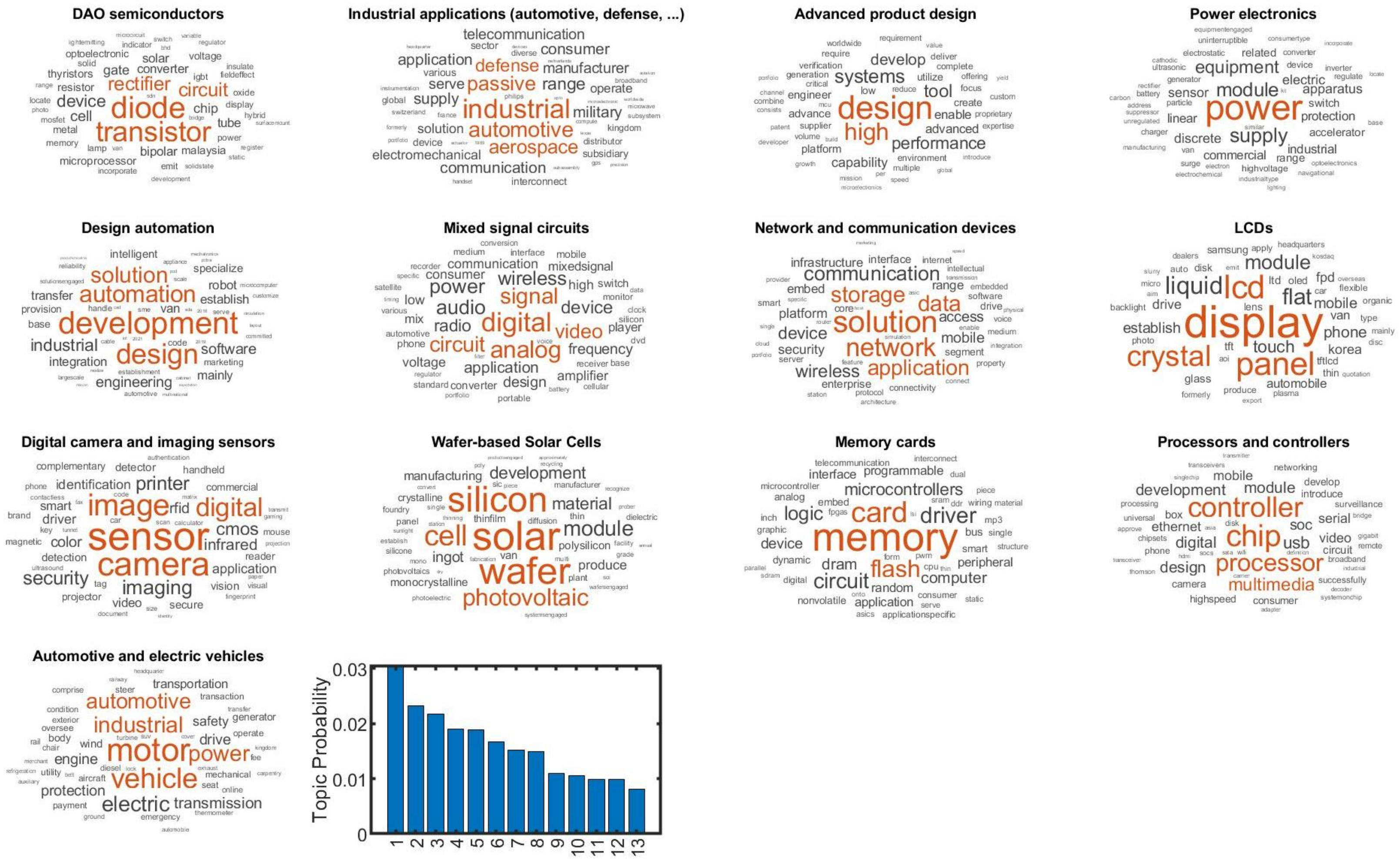

Figure 12: Word clouds for application-relevant topics identified by the LDA model. Each word cloud corresponds to a topic, where the word size is proportional to the relevance of the term to the corresponding topic. The distribution of topic probabilities gives the probability for each company to be related to one of these topics.

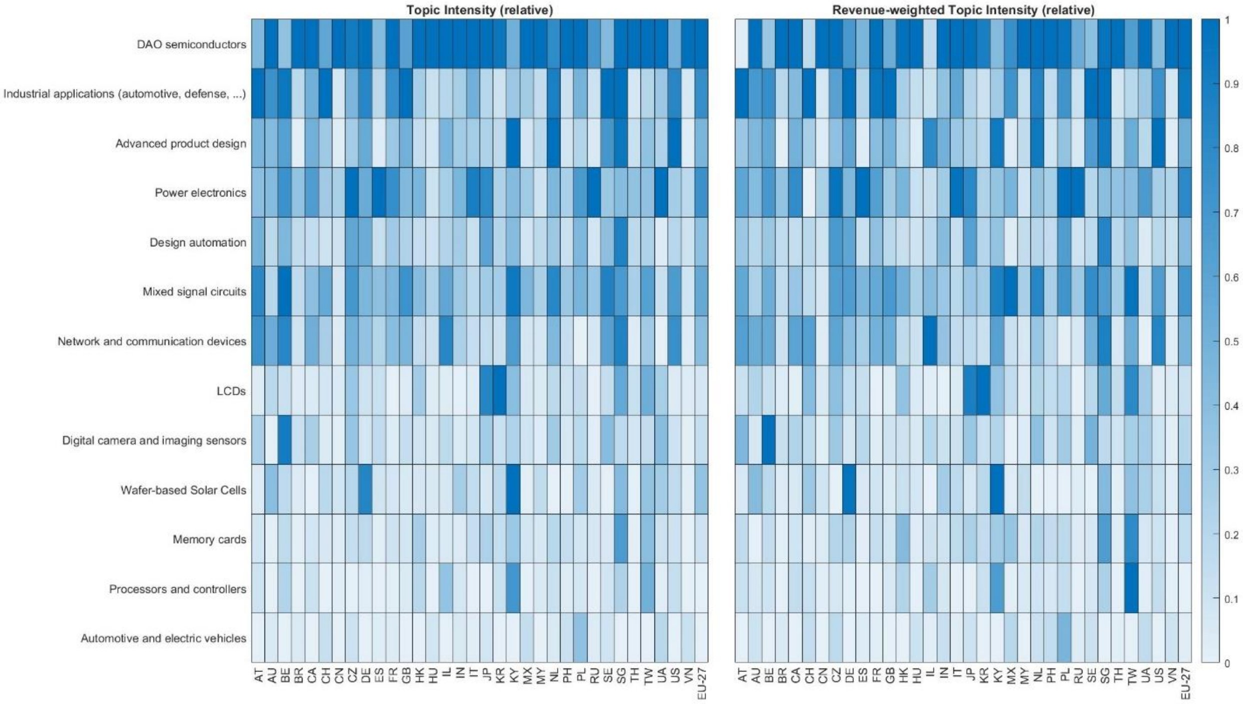

Figure 13: Intensity of LDA topics across companies in different countries. Topics are ranked from top to bottom according to their overall frequency. To obtain the topic intensity, the relative frequency of each topic across all companies in each country is calculated. For revenue-weighted intensity, companies are additionally weighted by their log operating revenue.

3.3. Embedding semiconductor companies in their interfirm network

We study the network embeddedness of these firms by extracting their inter-firm hyperlink network, see Figure 14 for the network extracted for 2023. In this network, firms are shown as nodes in a network with a color 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 14 reveals several interesting properties upon inspection. First, although most of the lead firms (black nodes) have a 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 15 shows the sum over the closeness values of all companies in each country (column) to the lead companies in a value chain segment (row), 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 surprising that US companies dominate most value chain segments, along with Japan and Korea, as opposed to China, despite the substantial number of Chinese companies. Overall, there are few major changes in value chain intensities between 2013 and 2023.

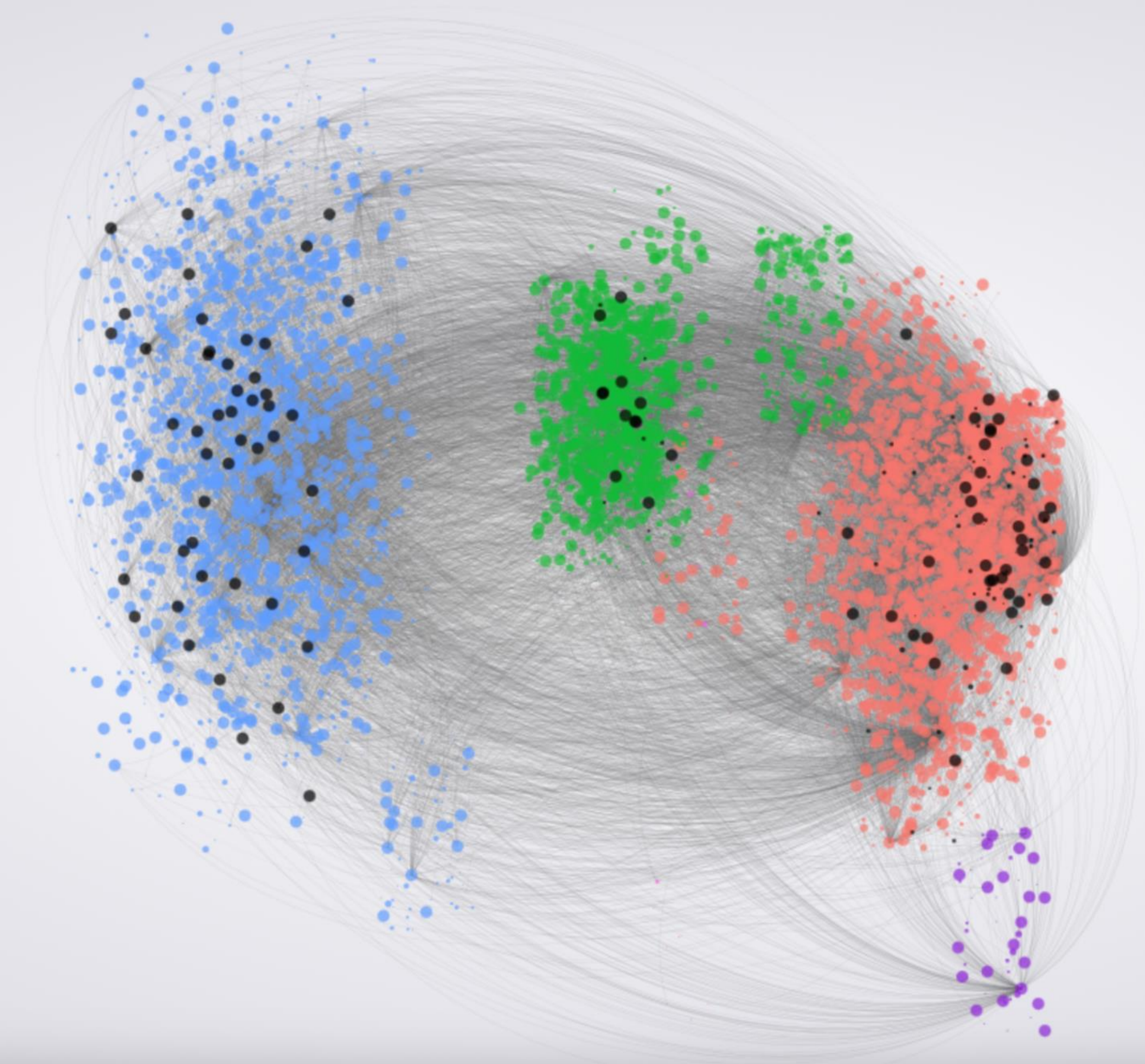

Figure 14: Inter-firm network for 2023. Nodes correspond to semiconductor-related companies with colors indicating their world region (blue for the Americas, green for Europe, red for Asia, pink for Africa and purple for Australia) except for lead companies, which are highlighted as black nodes. Node 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.

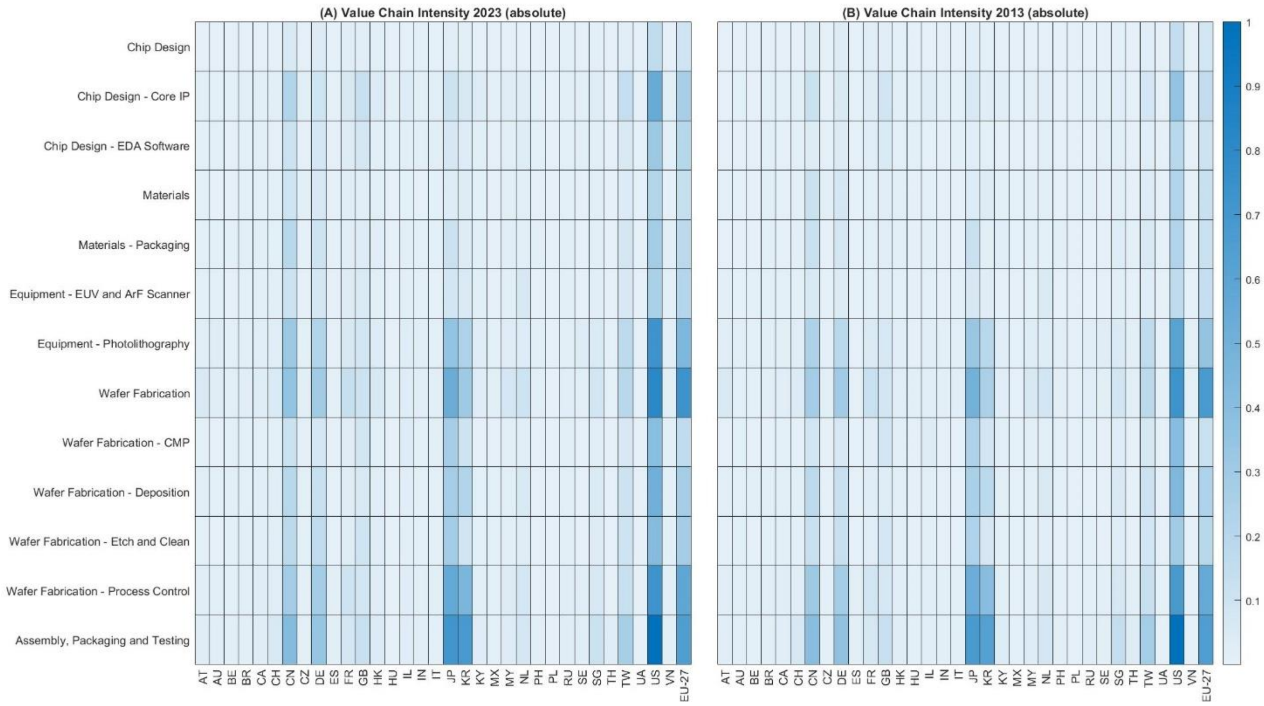

Figure 15: Results for absolute value chain intensity in (A) 2023 and (B) 2013. For each value chain segment (row), we evaluate how many companies in each country are in close network proximity to the leading companies in the segment.

Figure 16 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 segment (i.e., results are row-normalized). This analysis places more weight on the closeness of high-revenue companies (weights are given by 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.

One important distinction between the revenue-weighted and unweighted findings lies in Taiwan's role. In the revenue-weighted analysis, Taiwan stands out prominently across wafer fabrication, assembly, packaging, and testing, even in absolute terms. TSMC's internal production of photomasks gives it an estimated 7% market share in advanced photomasks as of 2019, making Taiwan a significant player in the broader photolithography segment. However, in the unweighted analysis, its prominence seems diminished. This nuance highlights differences between the two methods, likely influenced by TSMC's strong position in these areas. Our findings suggest that despite TSMC's dominance, it is deeply integrated into multinational networks across other countries. This integration leads to significantly lower values for TSMC in the unweighted analysis, which offers insights into the entire semiconductor ecosystem, compared to the revenue-weighted analysis, which may be skewed by individual large companies. This episode also highlights one of the limitations of this approach. Companies may occupy different segments of the value chain, but for most of these companies there is no reliable information on revenue shares by segment, which could distort this analysis if companies with large revenues from one segment also play a perhaps less pronounced role in other, smaller segments.

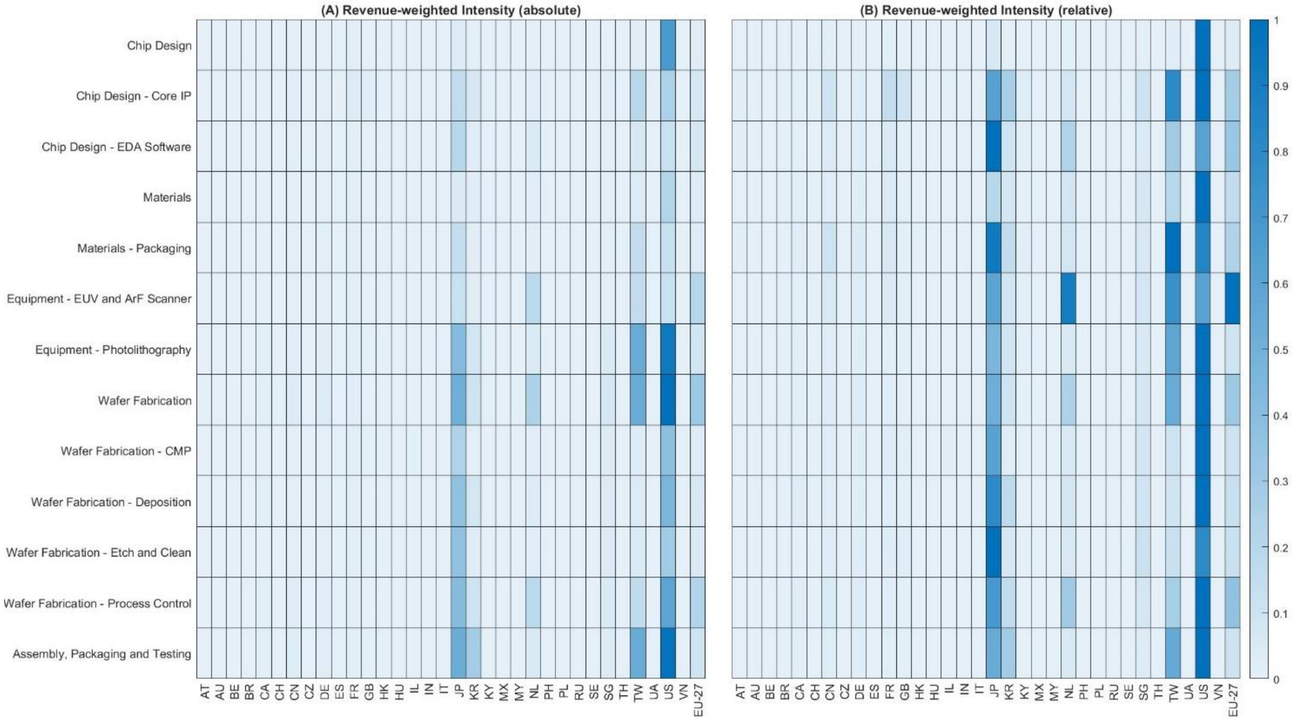

Figure 16: Revenue-weighted intensity scales the proximity of a given company to a leader by its revenue. Results are shown (A) in absolute terms, where they are driven by the number of high revenue companies in a region, and (B) relative to the total revenue of all companies in the segment (row-normalized).

To take a closer look at changes over time, Figure 17 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 intricately 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 smaller increase in the EU compared to the US and China. The US shows little movement in chemical mechanical planarization (CMP), while the EU and China show an increase. The segment of assembly, packaging and testing decreases in the EU while it increases in the US and China.

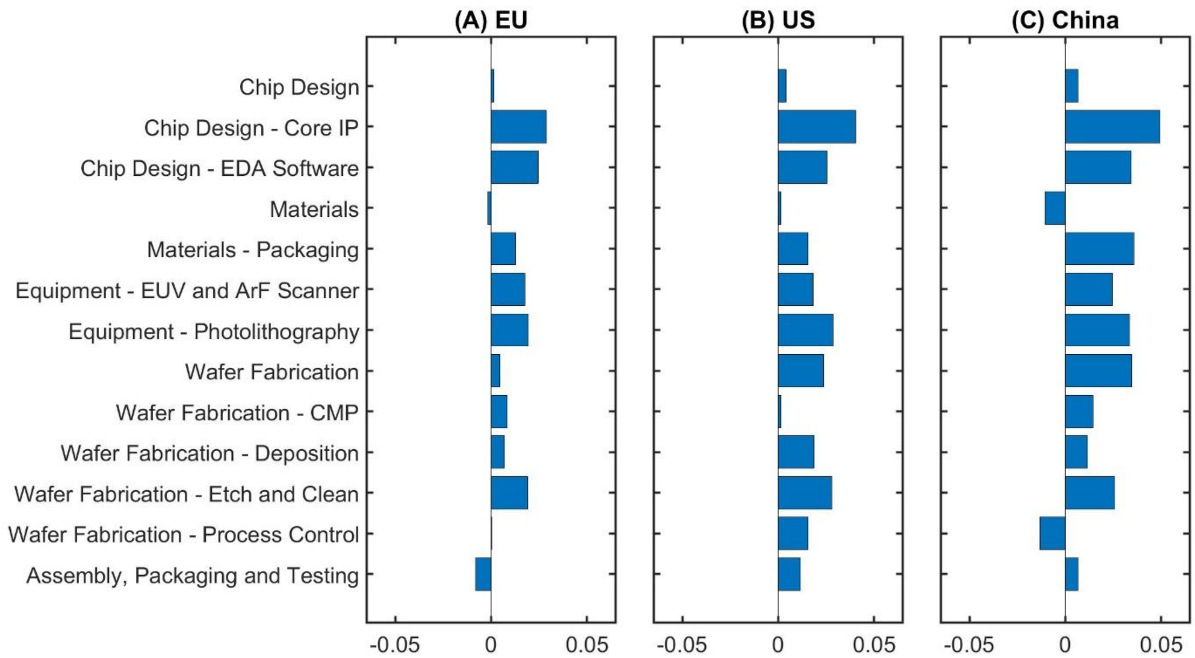

Figure 17: Percentage change in value chain intensity between 2013 and 2023 in (A) the EU, (B) the US, and (C) China.

3.4. To whom are companies from specific countries connected?

We now profile the type of firms to which firms from a given country are linked. Specifically, we consider all firms from a region, identify their neighbors from other regions in the interfirm network, and characterize these neighbors by country and topic as derived from the topic modeling approach.

The results for EU firms are shown in Figure 18. EU firms show a clear tendency to link with the US, Singapore, Korea, or the UK rather than with firms from China or Russia. They also show a strong tendency to link to India and Switzerland, but these links are overall much less frequent.

The most over-represented topics among EU neighbors are DAO semiconductors (appearing 2.5 times as often as would be expected by chance) and a more general topic related to networking, storage, communications, and data applications (score 2.54). We also see frequent links to various industrial applications, design (advanced product), accessories, test equipment, memory cards and wafer substrates.

It is instructive to compare this finding with the results of the trade data analysis. We found that many product categories related to these themes (memory, semiconductor production equipment, consumer applications, etc.) represent large segments in terms of export volume combined with low comparative strength of EU countries. There is therefore a tendency for EU enterprises to link up with - in this sense - non-EU enterprises that have complementary strengths to their own.

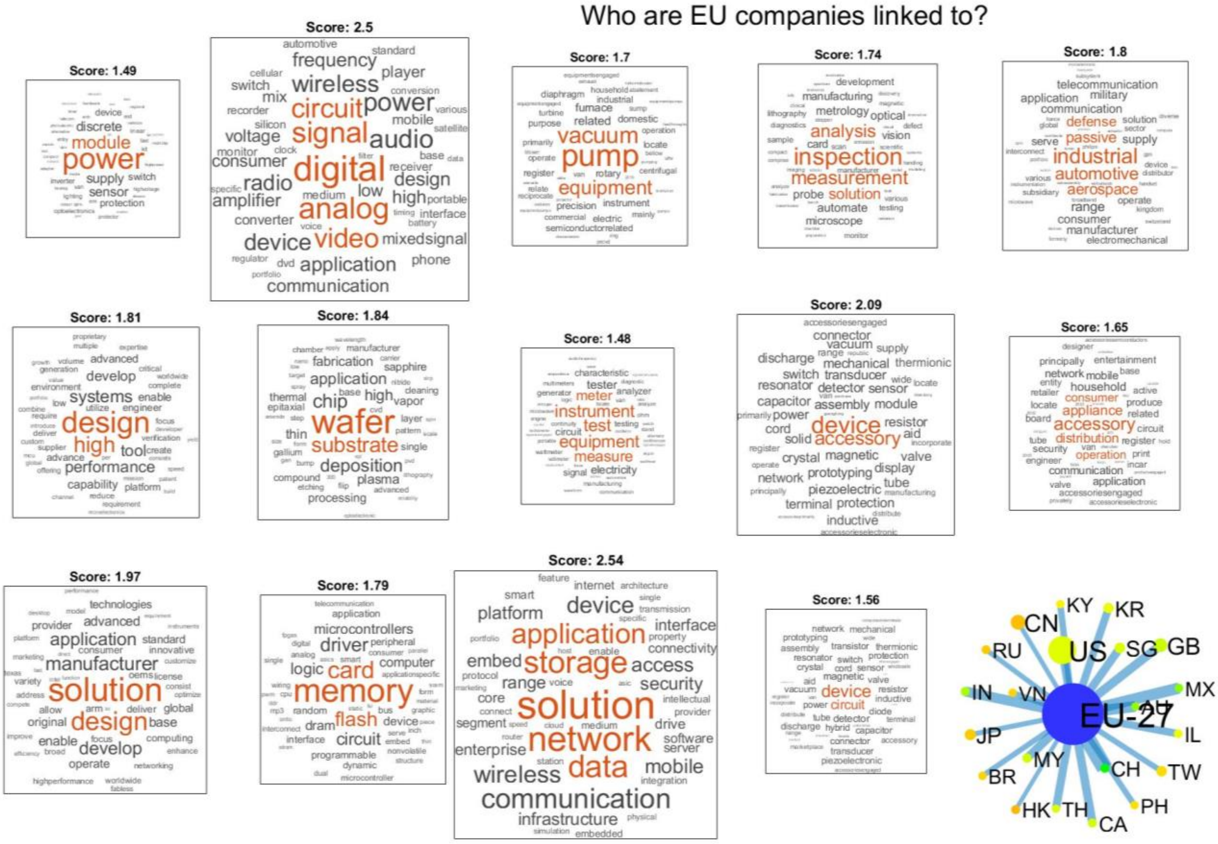

Figure 18. Profiles of semiconductor companies with which EU companies are linked in the interfirm network. The panels show individual topics that are more common in neighboring companies (a score of 2 means that this topic is twice as common in neighboring countries as would be expected by chance). The network shows most locations of these companies. The size of the nodes is scaled with the number of firms, and the color indicates whether links to such firms from such regions are less (red), equal (yellow), or more (green) common than would be expected by chance.

Figure 19 shows results for US companies. They prefer links with the UK, Korea, Singapore, and some European countries such as Ireland, Belgium, or Sweden over links with China, Russia, or Japan. Like the EU, the topic of DAO semiconductors is strongly overrepresented among US neighbors (score 2.59). Compared to the EU, there is a stronger tendency to link to companies related to memory cards than to industrial applications or clean room equipment.

The results for the Chinese firms are shown in Figure 20. They have frequent and stronger links with companies from Hong Kong, Vietnam, the Cayman Islands, Thailand, and Taiwan, but tend to have less frequent links with most European countries and the USA. The topics DAO Semiconductors (score 2.89) and diverse types of devices and circuits (score 2.68) are strongly overrepresented. The most overrepresented topics also include assembly, packaging and testing and diodes, transistors, and rectifiers, which were not among the top-ranked topics for the US and EU.

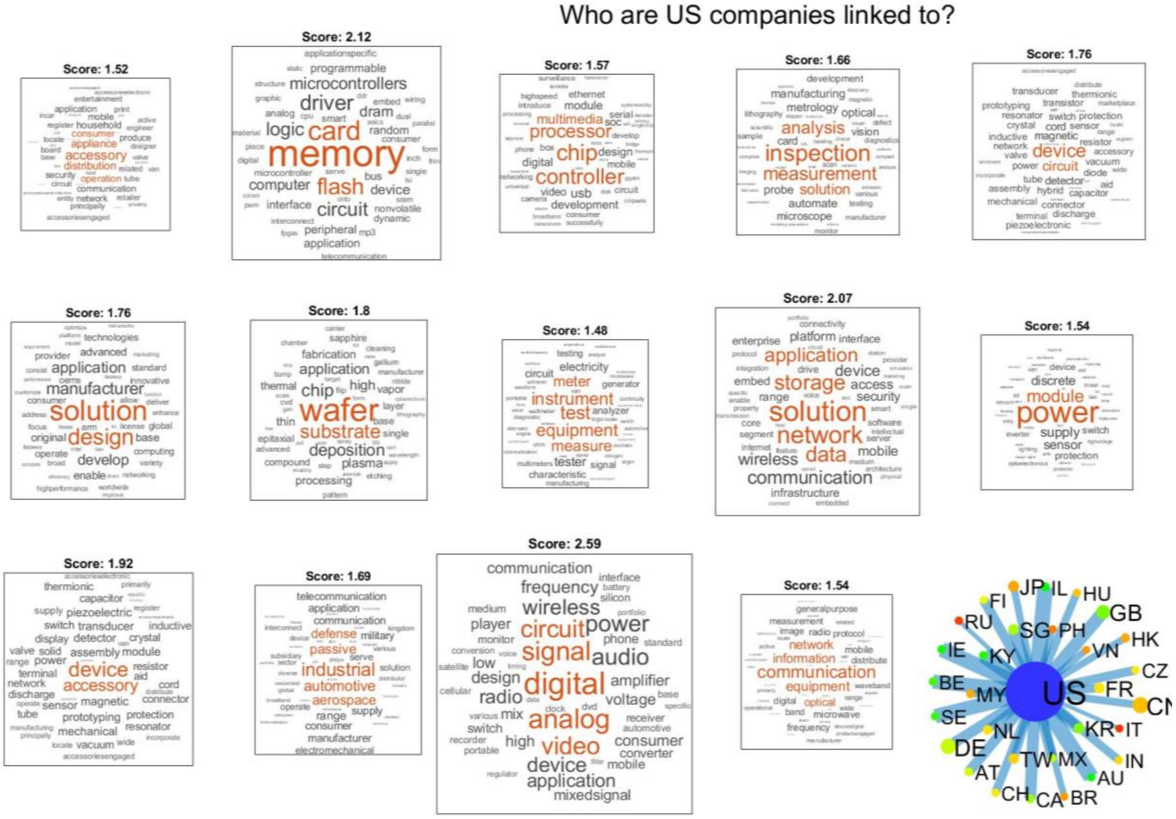

Figure 19: Profiles of semiconductor companies with which US companies are linked in the interfirm network.

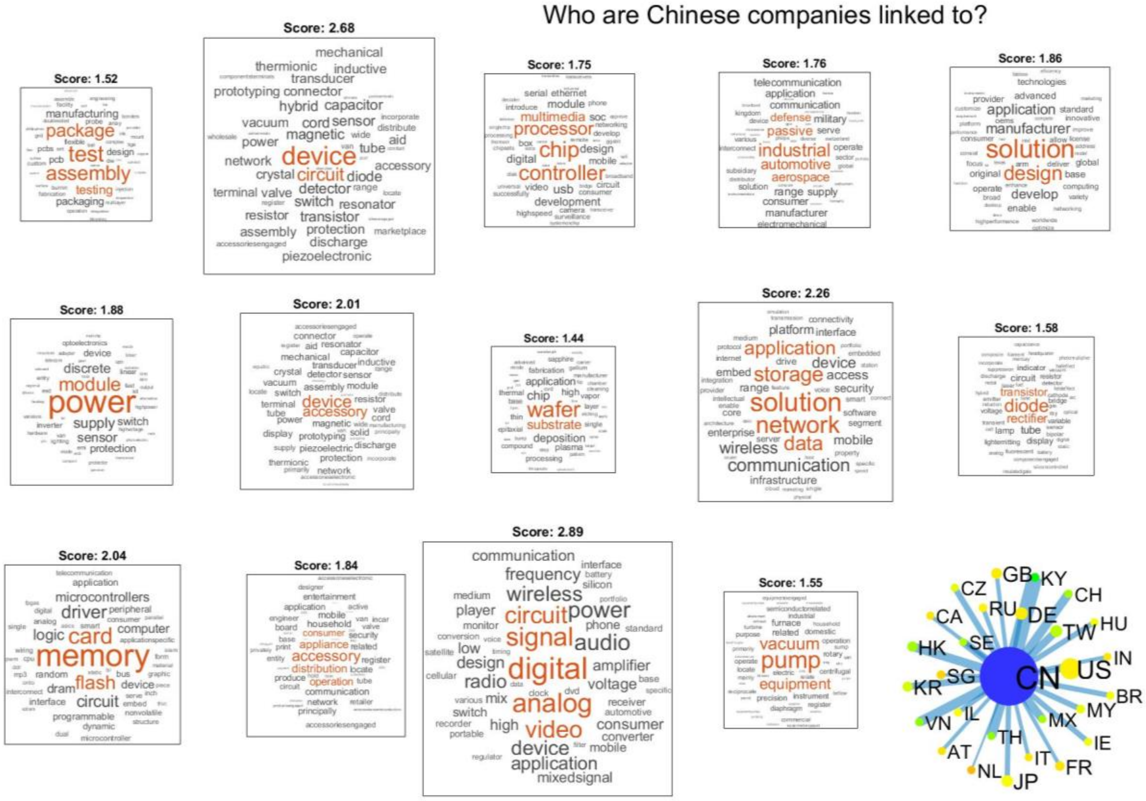

Figure 20: Profiles of semiconductor companies with which Chinese companies are linked in the interfirm network.

Our approach also allows us to map the restructuring of the inter-firm network from 2013 to 2023 from a regional perspective, see Figure 21. There is a modest tendency in the EU to reorient its links, away from Japan, Taiwan, and Brazil and towards Singapore, China, India, UK amidst other countries. 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.

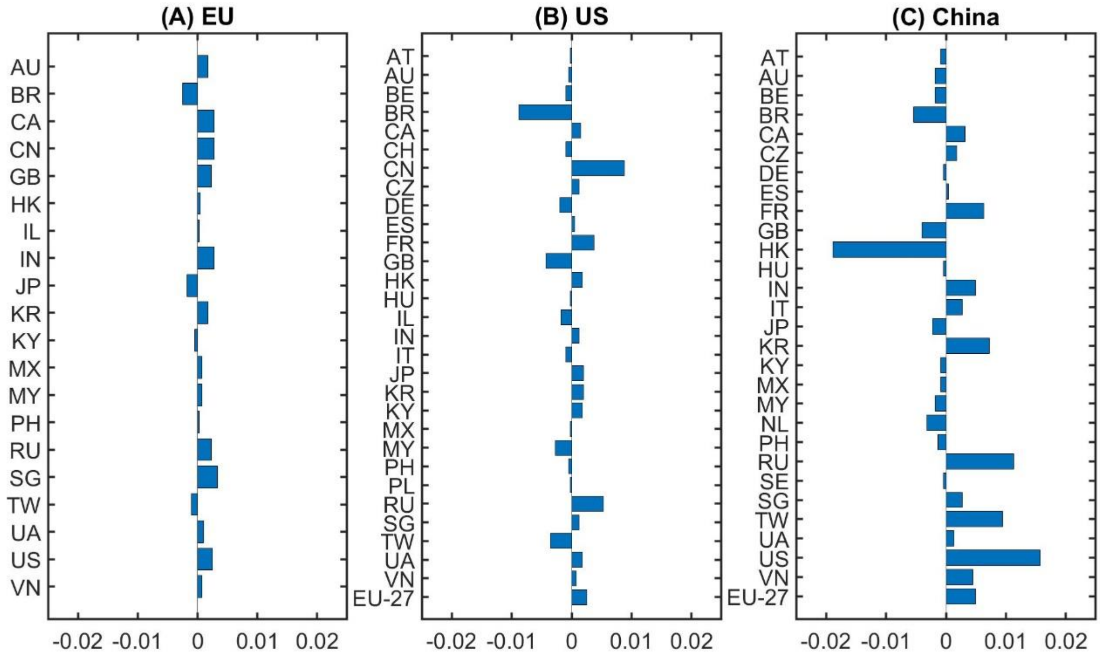

Figure 21: Rewiring of the inter-firm network from 2013 to 2023 for (A) the EU, (B) the US, and (C) China. The percentage change in the probability of links from a firm in these regions to another country (column) is shown. Positive (negative) values indicate a higher (lower) proportion of such links in 2023 compared to 2013.

4. Austria’s role in the semiconductor value chain

According to trade statistics, Austria has comparative strengths in several product categories related to equipment for semiconductor production, inputs for intermediate electronics, as well as intermediate outputs for industrial use, see Figure 22. For a more detailed view, we consider a version of the Austrian Product Space over time and the Austrian RCA dynamics, see Figure 23 and Figure 24, respectively. In the Product Space, the node size is now proportional to the Austrian export volume in each category, and the evolution of Austria's comparative strengths is shown in 2014, 2018 and 2022.

Austria consistently shows comparative strengths in filtering equipment for semiconductor production, smart cards, resistors, diodes, transistors with a dissipation rate higher than 1W, hardness testing machines, control and regulating instruments and arcade machines. These categories also make up the largest shares of Austrian semiconductor-related exports.

Our analysis reveals dynamics in several segments, most of which are smaller in terms of export volume. Austria has acquired comparative strength in the product category with the code 902190, which refers to parts and accessories for microscopes, which occur at several stages of the value chain. These parts are, on the one hand, required as inputs to produce semiconductors, but are also outputs of the value chain at intermediate and final stages for industrial use. Austria has also gained comparative strength in optical mirrors (input for semiconductor production). On the other hand, Austria's comparative strength decreased in a few categories, including telephone sets, filtering and purification equipment, and radar and radio navigation equipment.

Taken together, these changes in comparative strength result in a movement in the product space. Austria's strengths in this area are concentrated in two different regions. One of these regions contains semiconductor manufacturing inputs and equipment categories and electronic intermediate inputs. The second region includes industrial intermediate and final electronics. While the first region shows an increasing trend, the second region shows a lateral movement with changing industrial applications.

Our research shows that Austria follows the same specialization pattern as the EU, focusing primarily on specific application areas and being rather specialized in terms of its product space. 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. Some analysts even speak of "silent" monopolies in certain segments.[10] IMS Nanofabrication was recently estimated to have over 95% market share in the production of multi-beam mask writers in the sub-seven nanometer range, a critical input for the manufacture of advanced logic gates, DRAM, and image sensor applications.

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

We performed a more detailed mapping of the 50 Austrian companies by desk research. Sixteen of these identified Austrian companies active in the semiconductor industry were indeed classified as equipment manufacturers. For example, important Austrian companies offer wet etching and cleaning and wafer bonding tools. Seven companies occupied the chip design segment, three of which can be assigned to core IP and electronic design automation software, respectively. Furthermore, five companies could be classified as relevant raw materials suppliers (gases, chemicals, silicon). Other relevant Austrian companies are positioned as integrated device manufacturers, in the wafer fabrication segment, assembly packaging & testing, materials (e.g., crystals) and clean room facility services. Furthermore, four companies were identified as significant manufacturers of printed circuit boards and five companies as manufacturers of equipment for printed circuit boards. The Austrian comparative strength according to trade data in semiconductor production equipment, intermediate electronics inputs (diodes, transistors with a dissipation rate of more than 1W) therefore align with this profile of Austrian companies.

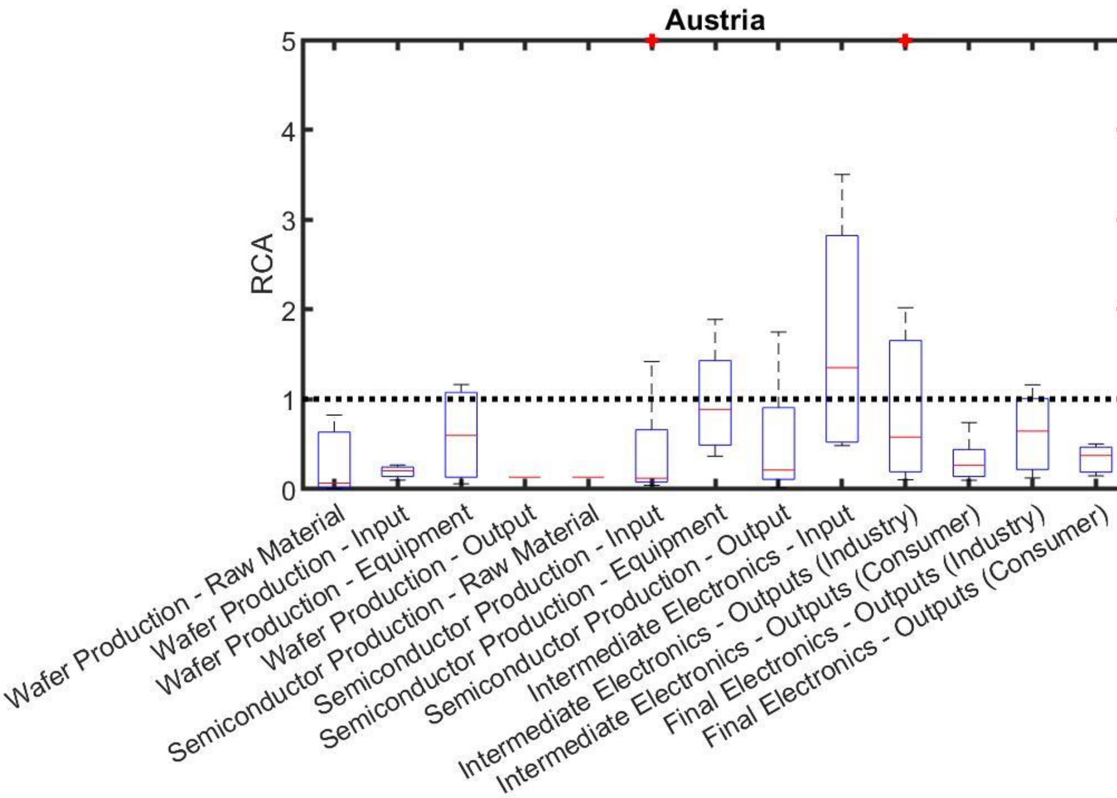

Figure 22: Distribution of RCA values over value chain segments. Austria shows comparative strengths in inputs for intermediate electronics and intermediate industrial outputs.

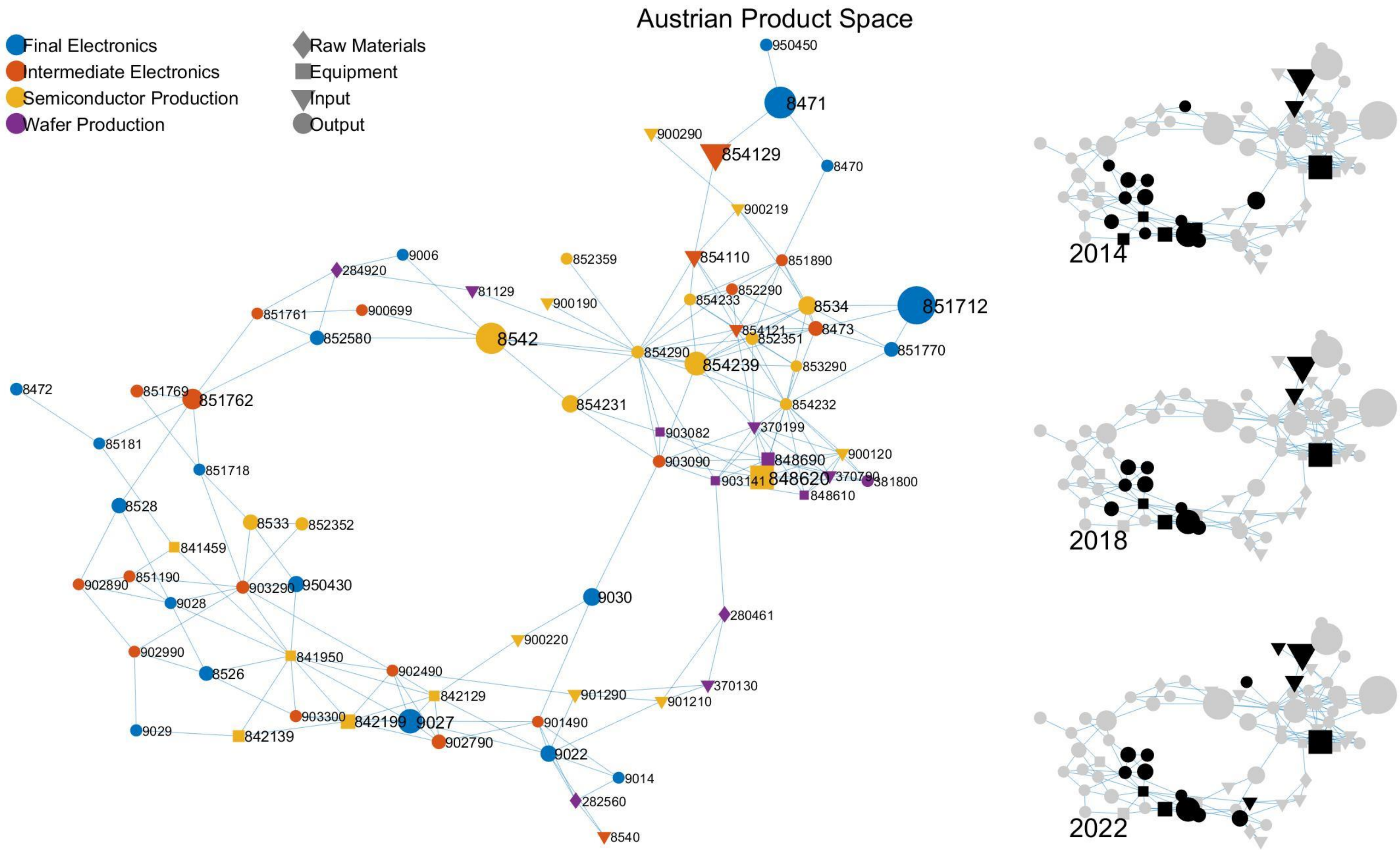

Figure 23: Austrian Product Space. Node sizes are now proportional to Austrian exports. The panels for 2014, 2018 and 2022, respectively, show categories in black in which Austria had comparative strength.

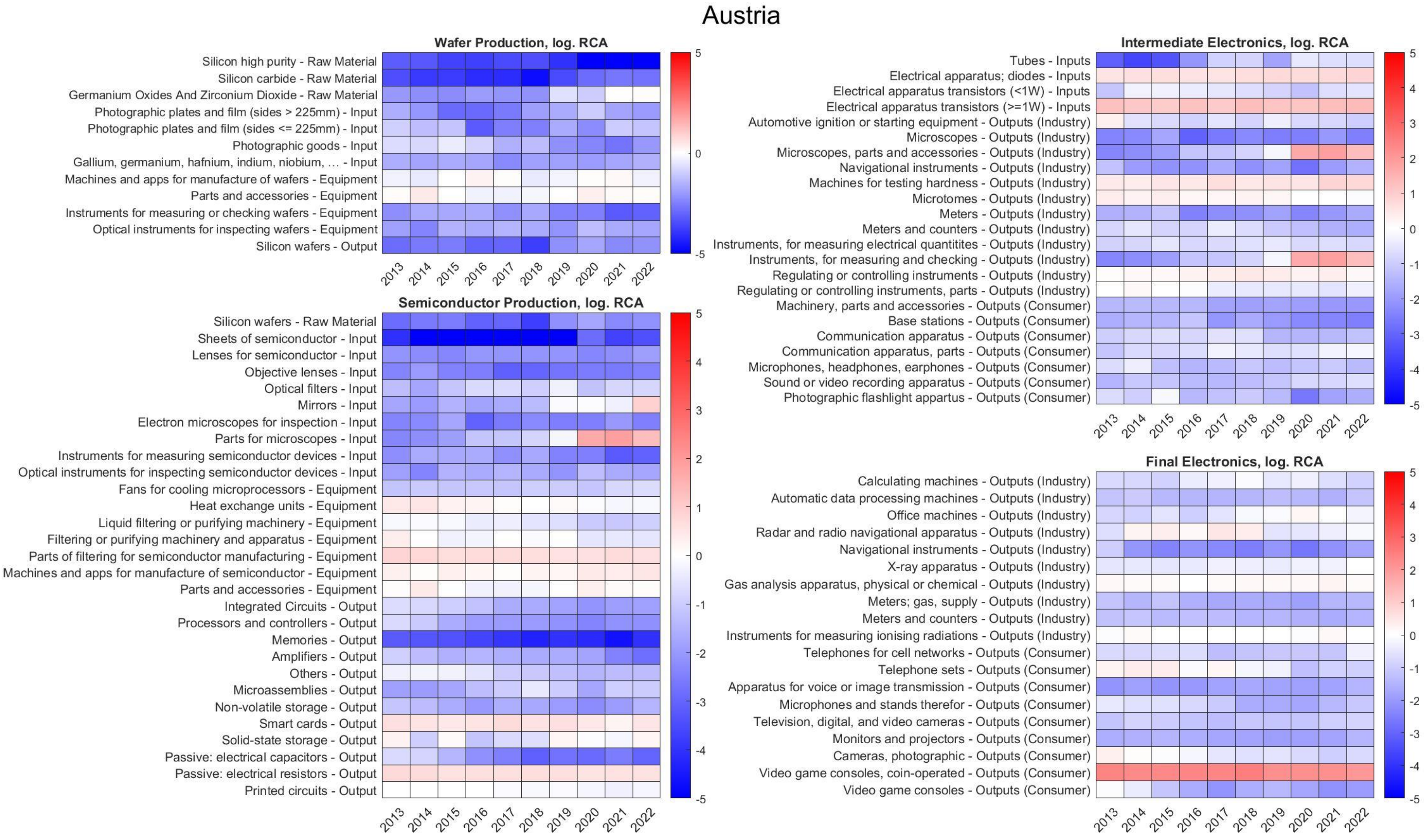

Figure 24: RCA dynamics in Austria from 2013 to 2022.

A category worth mentioning in an Austrian context is Assembly, Packaging & Testing, where we can see a positive development between 2013 and 2023 in Austria in contrast to the EU trend. 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.[11]

Austrian companies positioned in the chip design segment offer design services for a wide range of chips, covering a multitude of industrial applications such as Power-management, RFID, Automotive Electronics and NFC. Additionally, most relevant companies describe themselves via applications in automotive, consumer electronics, industrial applications, as well as communications and medical technology.

The importance of semiconductors in the automotive industry becomes apparent when considering the shift from traditional combustion engines to electric vehicles. While the average diesel-powered car requires about 1500 semiconductors, electric vehicles require twice as much, and they are not interchangeable.[12] According to a McKinsey Report topics like autonomous driving, connectivity, and electrification will drive most of the automotive semiconductor demand.[13] Applications of semiconductors in electric vehicles range from advanced driver assistance systems (ADAS) and infotainment systems to battery management systems and power distribution.[14] 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.[15] 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.

The profile of companies with which Austria is linked via the interfirm network is shown in Figure 25. Austrian enterprises prefer links with Germany and Singapore over links with enterprises from China. In terms of the topics that describe these neighboring firms, we observe pronounced differences compared to the EU results shown in Figure 18. Topics with the highest overrepresentation (almost four times) include power electronics - in line

[11] https://www.mckinsey.com/industries/semiconductors/our-insights/advanced-chip-packaging-how-manufacturers-can-play-to-win, accessed 03/21/2024.
[12] 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.
[13] https://www.mckinsey.com/industries/industrials-and-electronics/our-insights/will-the-supply-demand-mismatch-persist-for-automotive-semiconductors#/, accessed 03/21/2024.
[14] 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.
[15] 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

with Austrian strengths - and several types of circuits and devices (including thermionic, transducer, piezoelectric, magnetic, etc.), suggesting that Austrian companies play a role in the value chain of several of these devices. Industrial applications (score 3.44) and communications technology (score 2.92) are also among the top-ranked topics for Austria's neighbors, in line with Austrian companies playing relevant roles in these application fields.

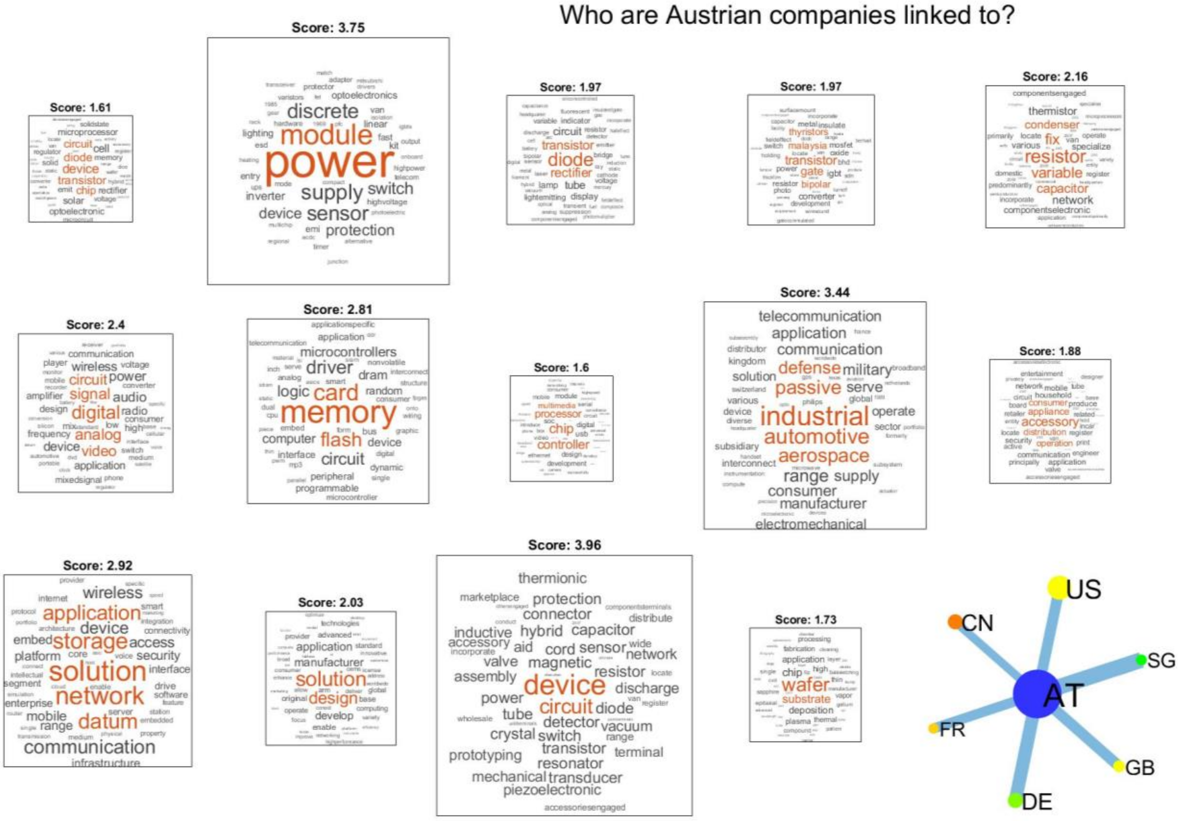

Figure 25: Profiles of semiconductor companies with which Austrian companies are linked in the interfirm network.

5. Limitations

There are several limitations to our work. First, Figure 13 illustrates significant developments and changes of priorities from 2013 to 2023, highlighting a major shortcoming of the current study design. All findings are derived from historical data obtained from publicly available sources. As a result, the conclusions drawn are limited by the retrospective nature of the data, making it impossible to estimate future trends and shifts in importance. Moving forward, the preliminary findings of this study need to be discussed with industry experts and the developed strategies need to incorporate current and potential future developments into the analysis.

Second, the analysis of trade data does not include semiconductor-related business activities that are not captured by trade in goods. These include important activities such as knowledge sharing or services. In addition, the classification underlying the trade data does not always uniquely identify semiconductor-related products, meaning that some categories may include trade in other business activities. For example, there is no six-digit trade category for germanium alone as a raw material, but only a combined category for zirconium and germanium. Therefore, in this study we have tried to analyze the industry from different perspectives, including topic modelling and inter-firm network analysis to capture additional activities.

Third, while it is the case that some lead companies can be clearly assigned to a value chain segment at a finer resolution level (e.g., "Wafer Fabrication - Chemical Mechanical Planarization"), in other cases such an assignment is more meaningful at the higher resolution level ("Wafer Fabrication"). This is particularly the case for larger companies that cover multiple segments or manufacturing steps. Therefore, in our analysis we treat both hierarchical levels in parallel and only assign companies to finer levels if these companies are not active in other segments within the same higher-level class (e.g., other segments of the "Wafer Fabrication" segment, such as “Deposition”). Consequently, the results of all subsegments at a finer hierarchy level do not necessarily add up to the results at the coarser level.

Fourth, there are limitations with respect to the depth and breadth of the companies analyzed. The dataset of 21,245 companies was structured around semiconductor-related keywords and therefore does not include a broader view of "microelectronics" as a holistic industrial sector. As a result, the system boundary does not include companies related to the many more microelectronics-related products, semi-finished goods, equipment, or services. However, the structure of the dataset used includes many of the smaller companies in addition to the leading companies and well-known players in the semiconductor industry.

Fifth, we have not fully resolved the internal structure of these companies, which has resulted in several shortcomings. Revenues were analyzed only at the legal entity level. If the same legal entity is active in more than one application area or value chain segment, the company's sales are allocated to all these areas or segments in this analysis. However, if a company has only limited activity in a particular segment or area, it is unlikely to be identified as a leading company in that area, suggesting that this issue should have a cushioned impact on our results in most cases. An exception is here maybe TSMC, which, according to previous studies, is also an important company in photomasks, with a market share of 7% in this segment due to in-house photomask manufacturing. Of course, most of TSMC's revenue comes from other segments. Companies may also conduct different activities in different regions (e.g., research and development in Europe, manufacturing in Asia), which may not always be accurately reflected in the data, even in terms of revenue.

Sixth, for topic modeling, we relied on natural language processing to automatically identify common topics across companies. While in some cases these themes may be related to unique value chain segments or application areas, this is not always the case.

Seventh, further research is needed to better delineate distinct roles and meanings behind the structure of the interfirm network. We confirmed by means of a regression analysis that trade flows and interfirm links are strongly correlated. More concrete, the logarithms of the trade flows between two countries and the number of interfirm links between firms of the corresponding countries show a bivariate Pearson correlation of 70%, meaning that the global structure of the trade network can largely be explained by the interfirm links. We further confirmed that this strong correlation is not a trivial size effect by considering a multivariate regression model in which we adjusted for the number of companies in each country, the null hypothesis being that countries with a lot of exports have many semiconductor-related companies and hence links are more often randomly observed between such countries. However, we confirmed that this potential bias played a negligible role with an effect size that is one order of magnitude smaller than the interfirm network effect.

Eighth and finally, we reiterate that the analysis presented in this report is a historical representation/analysis of the semiconductor landscape and a snapshot of the status quo. Estimates of future trends or market sizes are not within the scope of this report.

6. Discussion and conclusions

Here, we have analyzed the semiconductor industry from different methodological angles. We performed a trade analysis to map comparative strengths in traded goods across different regions and time. We 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 companies over the last decade. This analysis was 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 multiple perspectives, one focusing on various aspects of the semiconductor manufacturing process as well as industrial and consumer applications of semiconductor-related products.

We find that these perspectives lead to quite different results. Many manufacturing steps, such as wafer fabrication, are concentrated in Asian countries such as Japan, Taiwan and South Korea. However, these countries are typically not as strong in industrial applications where many European countries and the US play a role. The United States plays a special role from a global perspective, occupying both multiple applications and manufacturing steps. In fact, the US and China occupy almost complementary regions in the semiconductor product space in terms of their comparative strengths, revealing clear patterns of distinct regional specialization.

The EU's comparative strengths largely overlap with those of the US. They are concentrated in several types of equipment for semiconductor production and in several intermediate and final industrial applications. The product space analysis also shows that most of the EU's comparative strengths are in segments with relatively low overall export volumes. By this measure, the largest segments in intermediate and final electronics are dominated exclusively by China; the largest segments in manufacturing steps are dominated by Taiwan or the United States. In contrast, EU strengths are currently concentrated in highly specialized and smaller application segments and equipment types.

An analysis of comparative strengths over the last ten years shows that there has been minor change in EU strengths over time. China has gained comparative strengths in several segments of the value chain, while the US has lost strength in several categories.

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. This may seem surprising given the current US-China chip rivalry. However, U.S. semiconductor exports to China have quadrupled from 2013 to 2021[16]. Starting in late 2022, the US revised and dramatically tightened its export controls to curb

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

China's push toward autonomous production of high-end chips[17]. 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 highly complex and 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. Applications 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, have typically been outside the specialization of most EU companies. In the past, the EU's strategic interests have therefore been more focused on industrial and other types of applications that do not necessarily require cutting-edge production processes. However, against the background of the current transition in some of the EU's key industrial application sectors, most notably the electrification of vehicles, these strategic interests may change in the future.

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

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

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 seventy-nine different supply chain segments.

Each of these segments is provided along with a text description in the ETO Advanced Semiconductor Supply Chain Dataset. [18] Furthermore, segments are linked by several 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 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 ninety-four such relations of either type, see Figure 26.

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. [19] 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.

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

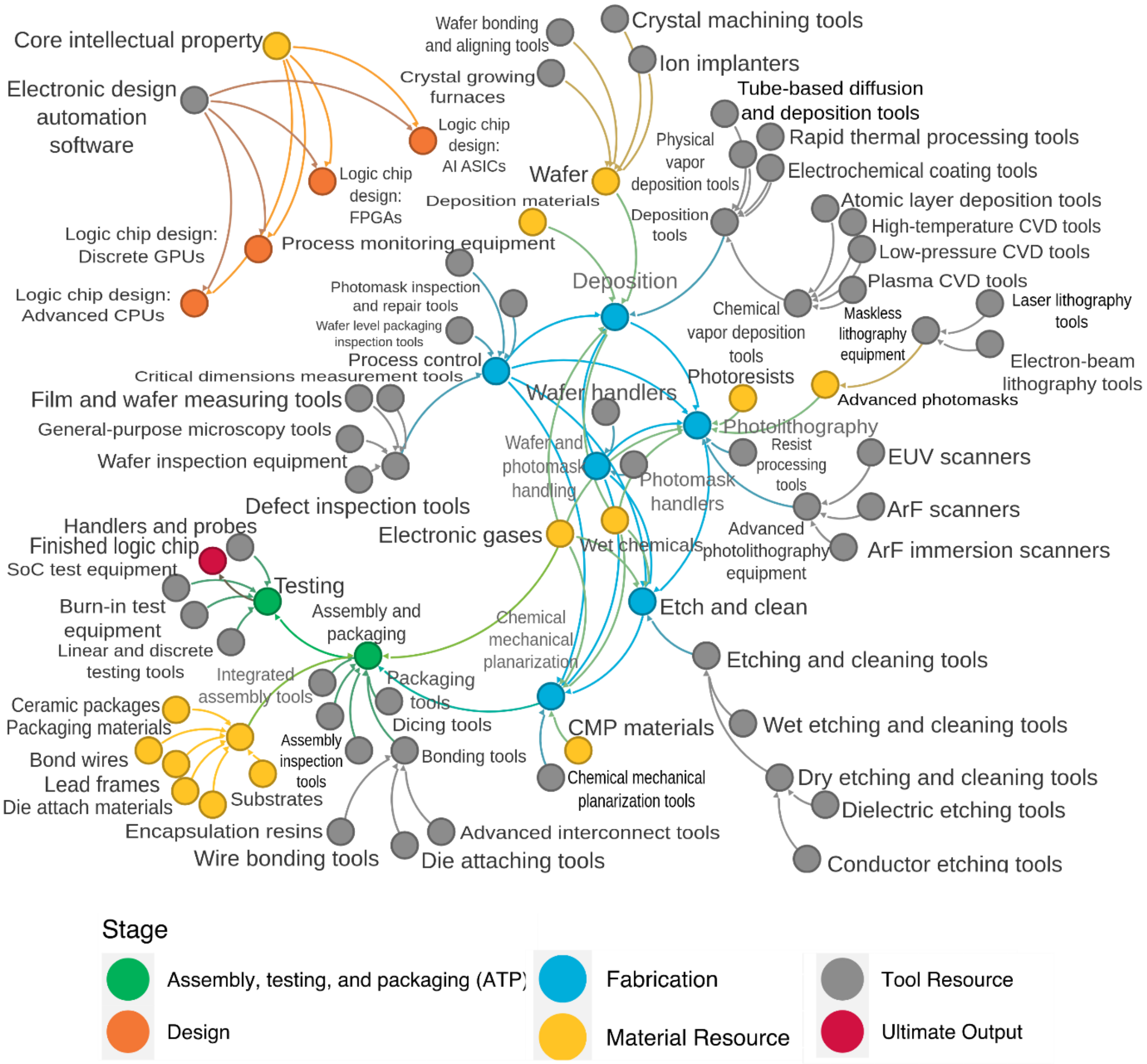

Figure 26: Network visualization of the stylized semiconductor value chain as constructed from the ETO Advanced Semiconductor Supply Chain Dataset. Each node corresponds to a segment of the supply chain with links indicating “goes into” (green) or “is type of” (grays) relations.

Extracting Private Semiconductor Company Data

A dataset on 462 million companies worldwide is used, forty-five million of which have financial information, the Orbis dataset. [20] Companies listed in the two industry-specific datasets (ETO and Abachy) were identified in Orbis, yielding a linkage of approximately seven hundred 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

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

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 five hundred characters. Note that for most of the larger companies such 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 for companies that lack text descriptions.

Appendix 2 – Harmonized System Codes

Table 2: Aligning the semiconductor value chain with product categories.

Code	Name	Type	Value Chain Step
280461	Silicon high purity	Raw Material	Wafer Production
284920	Silicon carbide	Raw Material	Wafer Production
282560	Germanium Oxides and Zirconium Dioxide	Raw Material	Wafer Production
370130	Photographic plates and film (sides > 225mm)	Input	Wafer Production
370199	Photographic plates and film (sides <= 225mm)	Input	Wafer Production
370790	Photographic goods	Input	Wafer Production
81129	Gallium, germanium, hafnium, indium, niobium, ...	Input	Wafer Production
848610	Machines and apps for manufacture of wafers	Equipment	Wafer Production
848690	Parts and accessories	Equipment	Wafer Production
903082	Instruments for measuring or checking wafers	Equipment	Wafer Production
903141	Optical instruments for inspecting wafers	Equipment	Wafer Production
381800	Silicon wafers	Output	Wafer Production
381800	Silicon wafers	Raw Material	Semiconductor Production
900120	Sheets of semiconductor	Input	Semiconductor Production
900190	Lenses for semiconductor	Input	Semiconductor Production
900219	Objective lenses	Input	Semiconductor Production
900220	Optical filters	Input	Semiconductor Production
Das	Mirrors	Input	Semiconductor Production
901210	Electron microscopes for inspection	Input	Semiconductor Production
901290	Parts for microscopes	Input	Semiconductor Production
903082	Instruments for measuring semiconductor devices	Input	Semiconductor Production
903141	Optical instruments for inspecting semiconductor devices	Input	Semiconductor Production
841459	Fans for cooling microprocessors	Equipment	Semiconductor Production
841950	Heat exchange units	Equipment	Semiconductor Production
842129	Liquid filtering or purifying machinery	Equipment	Semiconductor Production
842139	Filtering or purifying machinery and apparatus	Equipment	Semiconductor Production
842199	Parts of filtering for semiconductor manufacturing	Equipment	Semiconductor Production
848620	Machines and apps for manufacture of semiconductor	Equipment	Semiconductor Production

848690	Parts and accessories	Equipment	Semiconductor Production
8542	Integrated Circuits	Output	Semiconductor Production
854231	Processors and controllers	Output	Semiconductor Production
854232	Memories	Output	Semiconductor Production
854233	Amplifiers	Output	Semiconductor Production
854239	Others	Output	Semiconductor Production
854290	Microassemblies	Output	Semiconductor Production
852351	Non-volatile storage	Output	Semiconductor Production
852352	Smart cards	Output	Semiconductor Production
852359	Solid-state storage	Output	Semiconductor Production
853290	Passive: electrical capacitors	Output	Semiconductor Production
8533	Passive: electrical resistors	Output	Semiconductor Production
8534	Printed circuits	Output	Semiconductor Production
8540	Tubes	Input	Intermediate Electronics
854110	Electrical apparatus; diodes	Input	Intermediate Electronics
854121	Electrical apparatus transistors (<1W)	Input	Intermediate Electronics
854129	Electrical apparatus transistors (>=1W)	Input	Intermediate Electronics
851190	Automotive ignition or starting equipment	Outputs (Industry)	Intermediate Electronics
901210	Microscopes	Outputs (Industry)	Intermediate Electronics
901290	Microscopes, parts, and accessories	Outputs (Industry)	Intermediate Electronics
901490	Navigational instruments	Outputs (Industry)	Intermediate Electronics
902490	Machines for testing hardness	Outputs (Industry)	Intermediate Electronics
902790	Microtomes	Outputs (Industry)	Intermediate Electronics
902890	Meters	Outputs (Industry)	Intermediate Electronics
902990	Meters and counters	Outputs (Industry)	Intermediate Electronics

903090	Instruments, for measuring electrical quantities	Outputs (Industry)	Intermediate Electronics
901290	Instruments, for measuring and checking	Outputs (Industry)	Intermediate Electronics
903290	Regulating or controlling instruments	Outputs (Industry)	Intermediate Electronics
903300	Regulating or controlling instruments, parts	Outputs (Industry)	Intermediate Electronics
8473	Machinery, parts, and accessories	Outputs (Consumer)	Intermediate Electronics
851761	Base stations	Outputs (Consumer)	Intermediate Electronics
851762	Communication apparatus	Outputs (Consumer)	Intermediate Electronics
851769	Communication apparatus, parts	Outputs (Consumer)	Intermediate Electronics
851890	Microphones, headphones, earphones	Outputs (Consumer)	Intermediate Electronics
852290	Sound or video recording apparatus	Outputs (Consumer)	Intermediate Electronics
900699	Photographic flashlight apparatus	Outputs (Consumer)	Intermediate Electronics
8470	Calculating machines	Outputs (Industry)	Final Electronics
8471	Automatic data processing machines	Outputs (Industry)	Final Electronics
8472	Office machines	Outputs (Industry)	Final Electronics
8526	Radar and radio navigational apparatus	Outputs (Industry)	Final Electronics
9014	Navigational instruments	Outputs (Industry)	Final Electronics
9022	X-ray apparatus	Outputs (Industry)	Final Electronics
9027	Gas analysis apparatus, physical or chemical	Outputs (Industry)	Final Electronics
9028	Meters; gas, supply	Outputs (Industry)	Final Electronics
9029	Meters and counters	Outputs (Industry)	Final Electronics
9030	Instruments for measuring ionizing radiations	Outputs (Industry)	Final Electronics
851712	Telephones for cell networks	Outputs (Consumer)	Final Electronics
851718	Telephone sets	Outputs (Consumer)	Final Electronics
851770	Apparatus for voice or image transmission	Outputs (Consumer)	Final Electronics
85181	Microphones and stands therefor	Outputs (Consumer)	Final Electronics

852580	Television, digital, and video cameras	Outputs (Consumer)	Final Electronics
8528	Monitors and projectors	Outputs (Consumer)	Final Electronics
9006	Cameras, photographic	Outputs (Consumer)	Final Electronics
950430	Video game consoles, coin-operated	Outputs (Consumer)	Final Electronics
950450	Video game consoles	Outputs (Consumer)	Final Electronics

Appendix 3 – RCA by country

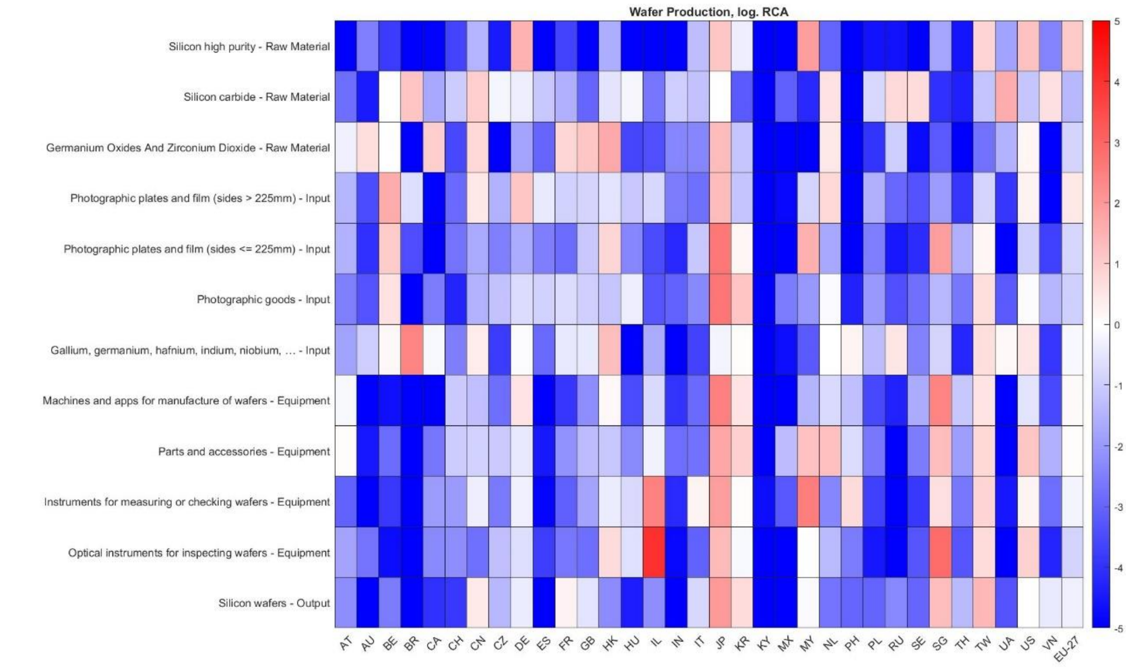

Figure 27: Logarithmic RCA values by country and value chain segment for wafer production as derived from trade data spanning 2020 to 2022. Red (blue) indicates the presence (absence) or comparative strength.

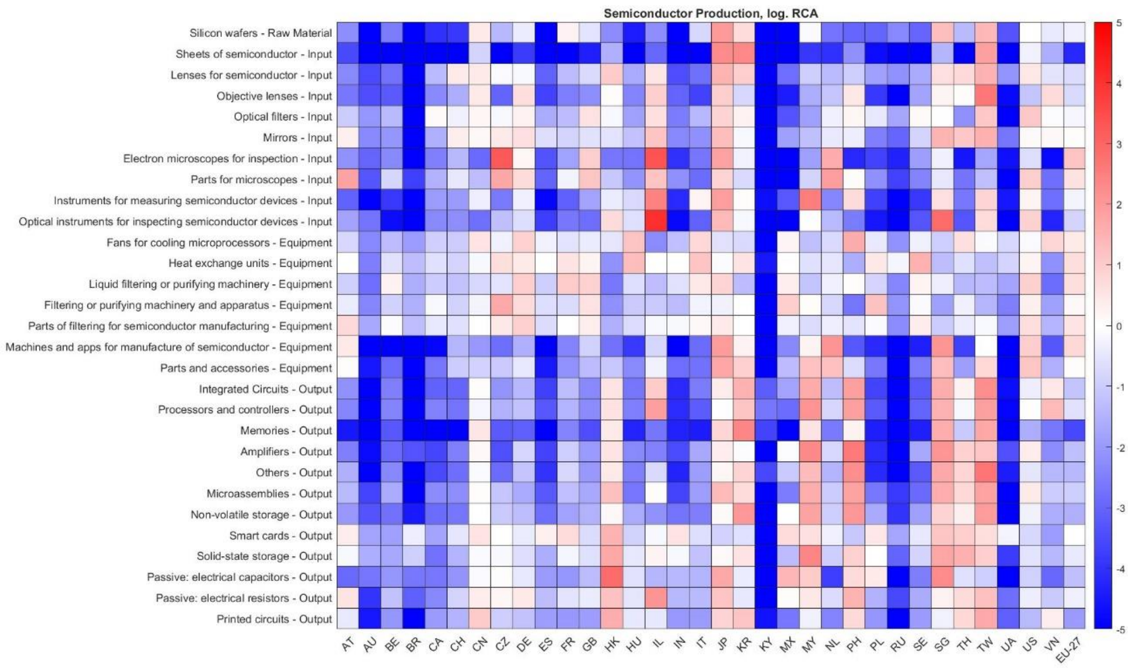

Figure 28: Logarithmic RCA values by country and value chain segment for semiconductor production as derived from trade data spanning 2020 to 2022. Red (blue) indicates the presence (absence) or comparative strength.

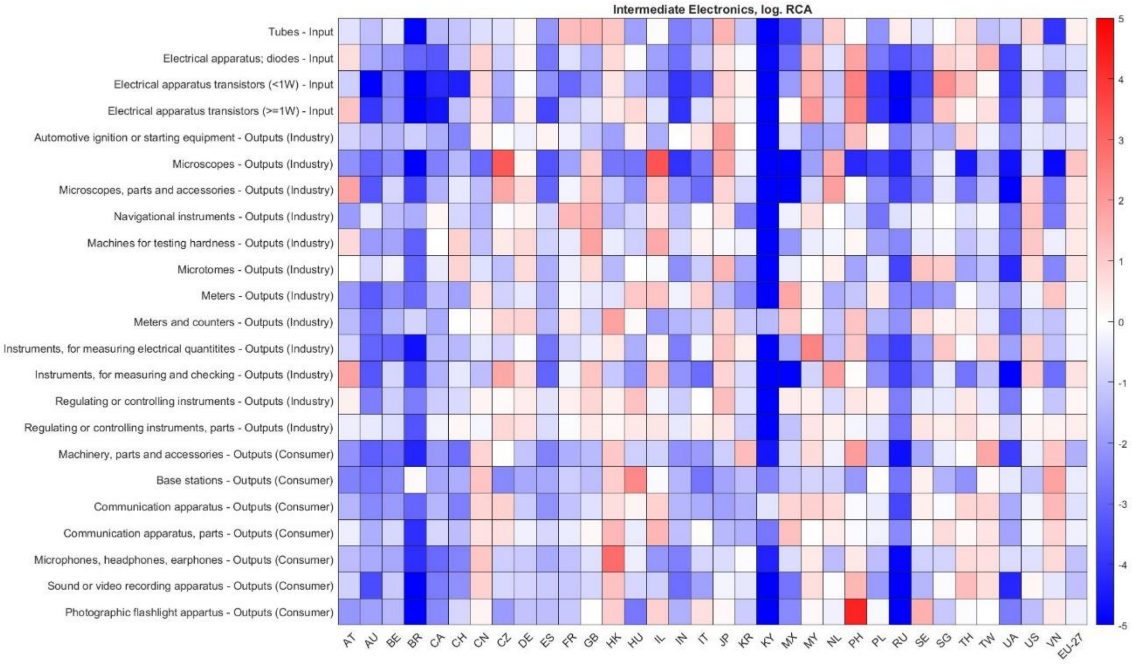

Figure 29: Logarithmic RCA values by country and value chain segment for intermediate electronics as derived from trade data spanning 2020 to 2022. Red (blue) indicates the presence (absence) or comparative strength.

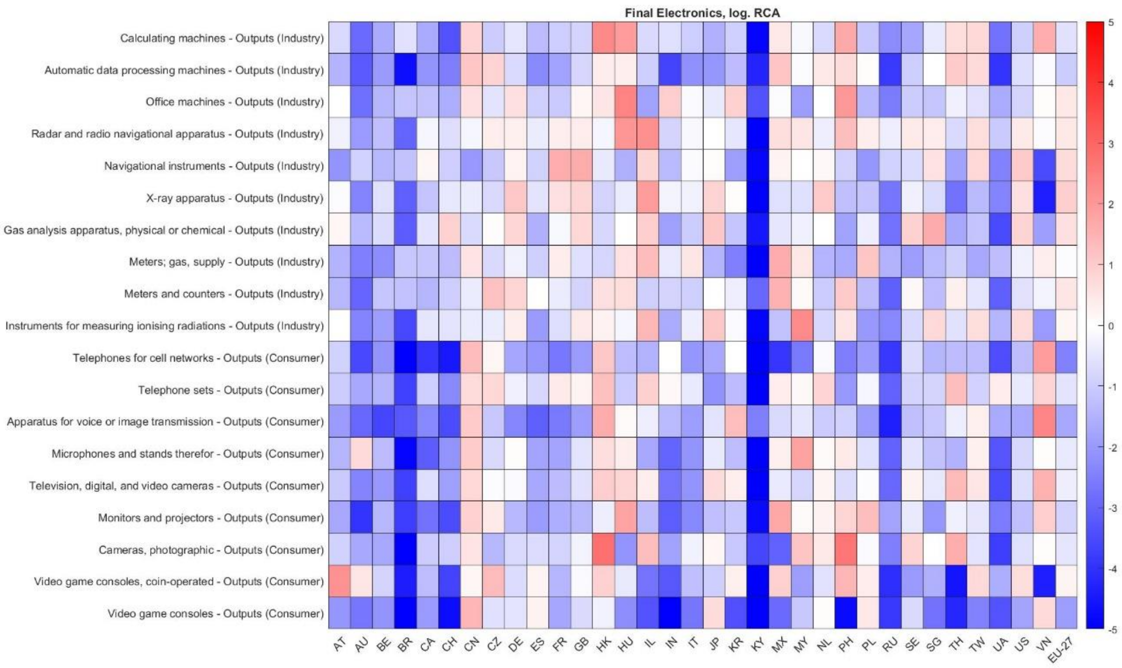

Figure 30: Logarithmic RCA values by country and value chain segment for wafer production as derived from trade data spanning 2020 to 2022. Red (blue) indicates the presence (absence) or comparative strength.