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A Chip War Made in Germany? US Techno-Dependencies, China Chokepoints, and the German Semiconductor Industry

Julian Germann [1], Steve Rolf [2], Joseph Baines [3], and Sean Kenji Starrs [4]

[1] Department of International Relations, University of Sussex, UK
[2] Business School, University of Sussex, UK
[3] Department of European and International Studies, King's College London, UK
[4] Department of International Development, King's College London, UK

Correspondence: Julian Germann (j.germann@sussex.ac.uk)

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Abstract

As geo-economic and geopolitical rivalries intensify, the US is weaponizing its power in global semiconductor supply chains to restrict Chinese technological development. To win this chip war against China, the US must compel key foreign firms in Asia and Europe not to supply its adversary with the materials, tools, and know-how needed to make advanced semiconductors. But will these firms agree to follow the US chip embargo and avoid the lucrative Chinese market? This article examines Germany's "China chokepoint" firms, whose identity and behavior remain critically understudied. Drawing on novel data sets and annual company reports, we show that German firms across three case studies are highly "techno-dependent" on the US. Despite this techno-dependence, German firms have so far sought to circumnavigate US export controls. This constitutes a puzzle because Germany's semiconductor firms are no more involved in the Chinese market than are firms in Japan and South Korea—which have frequently signaled voluntary compliance or even withdrawn from China in anticipation of harsher US sanctions. To resolve this puzzle, we map out Germany's semiconductor network and demonstrate that it is tightly articulated with Germany's auto industry—which is in turn heavily exposed to Chinese markets. We propose that this secondary exposure, through firms' embeddedness in Germany's "national production regime," encourages them to resist the US chip embargo. In this way, we contribute empirical and conceptual insights to international political economy scholarship on firms as geo-economic actors, actively engaged in a protracted and contentious policy process with US authorities.

Keywords
China; geopolitics; Germany; international political economy; sanctions; semiconductors; supply-chain analysis; techno-dependency; weaponized interdependence; United States

1. Introduction

Our contribution to this thematic issue starts with the proposition that the decisive "geo-economic turn" away from the neoliberal project of free trade and free markets—though not from globalization as such—has come from the US. This turn is epitomized by the unprecedented measures the Trump and Biden administrations have taken to sabotage China's development of advanced semiconductors. Waging this "chip war" involves incising deep cuts into an interconnected web of highly specialized suppliers in a globe-spanning industry estimated to grow to US$1 trillion in revenue by 2030 (KPMG & GSA, 2024). Winning this chip war depends in large part on whether the US can compel not only its own but also foreign firms to stop selling chipmaking tools and related materials, components, and services to China—the world's largest consumer of semiconductors (Araya, 2024).

Most important to these efforts are so-called "China chokepoint" firms based in a handful of US-allied countries, which occupy critical nodes in advanced semiconductor production networks where China has little to no domestic capacities (Khan et al., 2021). To curb Chinese access to these technologies, the US has pressured allies to impose export controls on chokepoint firms under their national jurisdiction. In parallel, the US has also given its own restrictions extraterritorial force, which legally oblige compliance from users of US technology and thus weaponize these non-US firms directly. This mix of bilateral talks and unilateral sanctions worked in the case of the Netherlands and Japan, with both states and national semiconductor giants ASML and Tokyo Electron agreeing to follow US sanctions in law and in spirit (Starrs et al., 2024; Haeck & Moens, 2023). Talks with other US allies—such as South Korea, Taiwan, and Germany (Baazil et al., 2024; "Germany plays down report," 2023; Nienaber et al., 2023)—have not yet yielded formal deals, and one recent study finds that there are still "gaps in compliance between U.S. companies and those of allies" (Shivakumar et al., 2024, p. 1). Nevertheless, firms from countries without such agreements yet in place (such as South Korea and Taiwan) appear to be practicing strategies of "anticipatory compliance" by drawing down China investments and partnerships in favor of alternate locations (Lim, 2024; Nussey et al., 2024). This raises vexing questions about the nature, extent, and limits of US power, particularly in relation to the capacity of foreign transnational corporations (TNCs) to resist or evade US weaponization against China (e.g., Malkin & He, 2024; Moraes & Wigell, 2022; Shukla, 2022).

This article examines Germany as a counter-intuitive but high-stakes case study for addressing this research problem. That the US should seek to engage Germany in export control negotiations is understandable, given that Germany holds considerable influence within the EU and China is its most significant trading partner. Getting German firms to follow US export sanctions would therefore be a big win for US attempts to multilateralize its chip war. But the German case is also puzzling. To start, Germany is not generally known to have a world-leading semiconductor industry and it has very few well-known companies in the sector. It is also not well understood how exposed its chip firms are to Chinese markets. This has meant that Germany's involvement in the chip war has remained critically underexplored, and the identities of Germany's potential "China chokepoint" firms remain unclear. To our knowledge, there has been no attempt

to systematically identify these firms, nor to determine whether they are already adhering to existing US export controls, waiting to see whether the German government will yield to US pressure, or actively avoiding US sanctions.

Our article seeks to contribute to ongoing attempts to more thoroughly explain and theorize firm behavior in the new geo-economic era. To do so, we identify who the key German firms are that the US needs to enlist in its chip embargo, and we assess the specific leverage the US has over them. We then ask our central research question: To what extent do these firms choose to follow or evade US export controls, and what explains these outcomes in firm decision-making? This article sets out and develops our answer to this question in four steps.

The next section locates our work within the recent international political economy literature on TNCs as geo-economic actors. We argue that firm behavior needs to be examined in relation to "techno-dependency" on the US, weighed against their embeddedness in "national production regimes" (Koddenbrock & Mertens, 2022). Section 3 analyzes the German firms that matter to the US chip war on China. Building on industry and media reports, we show that there are just shy of a dozen German semiconductor firms that, alongside a handful of foreign firms, occupy different chokepoints across the length of the semiconductor supply chain—from design and materials to equipment and testing.

The remainder of Section 3 zooms in on an illustrative subset of these "China chokepoint" firms from across the chain—Siemens, Merck, and SÜSS MicroTec—on the basis not only of their strategic importance but also their specific attributes and varied visibility to US regulators. Drawing on Bloomberg Professional and S&P Capital IQ Pro datasets, we demonstrate that all three firms are techno-dependent on the US in terms of the facilities, subsidiaries, and affiliates they have located in the US, supply chains with suppliers or customers in the US, and the technologies that they use which are derived from US sources. We show that the three firms have nevertheless delayed compliance by either dragging their feet until directly ordered by US officials or by shifting their operations to minimize their potential legal liabilities. This is not, at least in two of our three cases, due to direct exposure to the Chinese sales market, which represents a modest proportion of overall revenues.

Instead, Section 4 maps the supply-chain linkages within and between Germany's semiconductor industry and other sectors of the German economy. We reveal how Germany's chipmakers are embedded in a "national production regime" (Koddenbrock & Mertens, 2022) which deeply integrates them with the German automotive industry. This integration is pivotal because the automotive sector maintains substantial investments in and commitments to the Chinese market, rendering it particularly susceptible to potential retaliatory actions. Consequently, firms will likely demur from any measures which might imperil Germany's auto sector. German chipmakers' "secondary exposure" to the Chinese market therefore renders them hostile to US chip sanctions.

We conclude that attention to *both* the embeddedness of TNCs within national production regimes *and* their techno-dependencies on the US is needed to move towards a fuller understanding of how they navigate the geo-economic turn. This turn, we insist, is not simply dictated by states any more than it is shaped solely by the commercial decisions of firms. Rather, it involves a complex and contentious policy process in which the US can target foreign firms directly, while these firms have some leeway to resist US "weaponization" in favor

of pursuing their own commercial interests, shaped in part by the broader national production regime to which they belong.

2. US Power and Corporate Agency in the Geo-Economic Turn

As the networks of globalization become arenas of great power contestation, a new body of international political economy scholarship has emerged that recognizes TNCs as actors navigating the geo-economic turn (Abels & Bieling, 2023; Malkin & He, 2024, p. 694; Moraes & Wigell, 2022; Rolf & Schindler, 2023). This literature eschews a realist-inspired and security-establishment-adjacent worldview in which companies are mere instruments through which state power is projected or received (Babić et al., 2022a, pp. 4–6). But it also dispels the liberal myth that TNCs are globally footloose and can simply evade national policies that do not suit their interests. Instead, these scholars are interested in the structural constraints and strategic choices faced by TNCs as states seek to redraw global supply chains in the name of national security. The principal question that animates this scholarship is how far and under what conditions companies are bound to follow or able to resist such "supply-chain statecraft" (Babić et al., 2022b, p. 191; Baines et al., 2024). Scholars have developed typologies of firm behavior linked to the profiles and profitability of firms, the political systems to which they are tied, or varieties of state-firm relations (Calcara, 2022; Geertz & Evers, 2020, pp. 124–127; Moraes & Wigell, 2022, pp. 44–45; Rolf & Schindler, 2023).

Our article contributes to this budding research agenda in three ways. First, we propose that the US chip war against China, as the pivot of the geo-economic turn, holds unique insights into the changing dynamics between states and firms. Concretely, the US wishes to dictate with whom foreign TNCs can and cannot do business—which directly impinges on their established business models, investment, and locational strategies. Therefore, the US chip war on China offers, as Malkin and He (2024, p. 677) aptly put it, "something approaching a natural experiment that tests the extent to which the US as a state actor can exercise its preferences."

Second and related, to fully understand corporate responses, we need to situate them in the context of US power. The ability of the US to weaponize foreign firms in its chip war against China has been attributed to the prominence of US companies, capital, and technology in global semiconductor production (Beaumier & Cartwright, 2024, pp. 14, 16; "Chains of control," 2023, p. 36; Farrell & Newman, 2023, pp. 200–201; Malkin & He, 2024, p. 687). But the principal focus of this literature has, understandably, rested on the ultimate target of US weaponization, i.e., the Chinese state and its firms. The secondary power dynamic between the chip sanctions of the US and the commercial decisions of allied firms has yet to be extensively explored. This requires that we operationalize, and measure in concrete cases, the specific extraterritorial leverage that the US has over third-country firms. To do so, we introduce the concept of "techno-dependency," by which we mean the significance of the US as a base of operations, site of strategic investments, and source of know-how and products for individual companies. Techno-dependency is what enables the US to craft regulations, including with extraterritorial legal force, to ensure compliant behavior.

However, as our third contribution spells out and our empirical findings underline, it would be wrong to see firm compliance as a fait accompli, even where techno-dependencies on the US are very high. Corporate decisions, we contend, are complexly determined and shaped in important ways by a firm's place within a specific "national production regime" (Koddenbrock & Mertens, 2022)—that is, the network of connections

to domestic customers and suppliers within and beyond a given sector. Understanding the likely outcomes of particular geo-economic conflicts, then, requires undertaking detailed mappings of these supply chains in both their domestic and global configurations. By empirically mapping these networks in the case of Germany's semiconductor industry, we are better positioned to analyze the strategies of key firms and the limitations of "weaponization" in the context of growing Sino–American competition.

3. The German Semiconductor Network and Its China Chokepoints

This article zooms in on the relationship between the US and German firms whose cooperation is needed to close loopholes in the US chip embargo against China. The US has two avenues to pursue compliance. First, the US can ask German regulators to mirror US export controls so that they apply to German firms. And indeed, media reports confirm that talks between the US and Germany have been ongoing since at least 2023 (Baazil et al., 2024; "Germany plays down report," 2023; Nienaber et al., 2023). Second, in addition to inter-state bargaining, the US can also proceed unilaterally and mobilize its export control regime so that it prohibits German firms that use US products or know-how from selling specified items to China and/or doing business with blacklisted Chinese firms.

Since Trump came into office, the US has placed dozens of Chinese tech firms on the Entity List. Under Biden, the US also added advanced chips and numerous tools and technologies to manufacture semiconductors and supercomputers to the Commerce Control List. Both lists are maintained by the Bureau of Industry and Security (BIS) with the Department of Commerce. The latter catalogs dual-use items that cannot be exported without a license if they are destined for specific countries, specific end uses, or specific end users that are considered to be of concern. The former specifies the foreign entities, including now over 600 Chinese companies, that may not be supplied with these items.

Crucially, the Foreign Direct Product Rule (FDPR) applies these export controls to certain items made anywhere in the world if they meet a specified threshold of US-origin content or use US-origin technologies or equipment. Thus, the BIS has effectively banned all worldwide shipments of leading-edge graphics processing units to China because they cannot be made without US software or equipment. It has also banned sales of foreign-made items made with US inputs to China if they can be used to produce supercomputers or if they are destined for certain Entity List firms, i.e., those with a so-called "footnote 4" designation (Rasser & Wolf, 2022). The FDPR has been extended to other countries of concern outside China (Dohmen & Feldgoise, 2023; Reinsch et al., 2023), along with expanded export licensing requirements, to keep them from re-selling certain items to China (Dohmen & Feldgoise, 2023). And, in a spectacular expansion of extraterritoriality, the BIS in October 2023 specified a type of lithography equipment to which the FDPR rule applies even if it does not contain any US inputs (Goujon & Kleinhans, 2023).

How far these regulations already legally oblige German suppliers, let alone induce compliance, depends on the specific firms in question. Germany is not generally known as a home to key players in the global semiconductor industry. While Infineon is often cited as a leading manufacturer of automotive and power semiconductors, it does not belong to the same class of cutting-edge chip firms as TSMC or Samsung. Smaller German companies—like Zeiss or Trumpf—have made the news. But they are usually discussed as suppliers to ASML (ASML, n.d.; Hofer, 2023; Höltschi, 2023; Rudzio, 2023) whose coveted extreme ultraviolet and deep ultraviolet lithography machines have already been hit by US and Dutch export

controls (Starrs et al., 2024). The future role of these and other suppliers in the US-led chip war is therefore unclear.

To fill in this picture, we build on a landmark study by the Center for Security and Emerging Technology (Khan et al., 2021) that systematically surveys the global semiconductor supply chain to identify areas where Chinese firms currently have little to no capacities. These segments of advanced semiconductor manufacturing constitute potential "China chokepoints," insofar as the dominant firms, usually from a handful of countries, can be convinced not to sell to China.

Figure 1 shows the 11 German "China chokepoint" firms listed in the Center for Security and Emerging Technology report. As we can see, they primarily cluster around semiconductor manufacturing equipment but are also present at other steps in the supply chain. Siemens, for instance, is one of four firms globally that own over 95% of chip design software. Siltronic ranks fourth in the world in the production of silicon "wafers," including advanced 300 mm diameter wafers from which virtually any chip below 45 nm is made (Khan et al., 2021, pp. 55, 57, 92). Furthermore, Zeiss is not only ASML's largest known supplier, accounting for over 25% of the company's costs (Bloomberg, 2024); it is also among the few firms worldwide that make the tools China relies on to inspect these wafers and the transparent plates ("photomasks") used to transfer circuit patterns onto them (Khan et al., 2021, p. 44).

Figure 1 also shows a concentration of German chokepoint firms in chipmaking tools. All but one of these firms make alternative lithography equipment that does not use ultraviolet light but ion-beam,

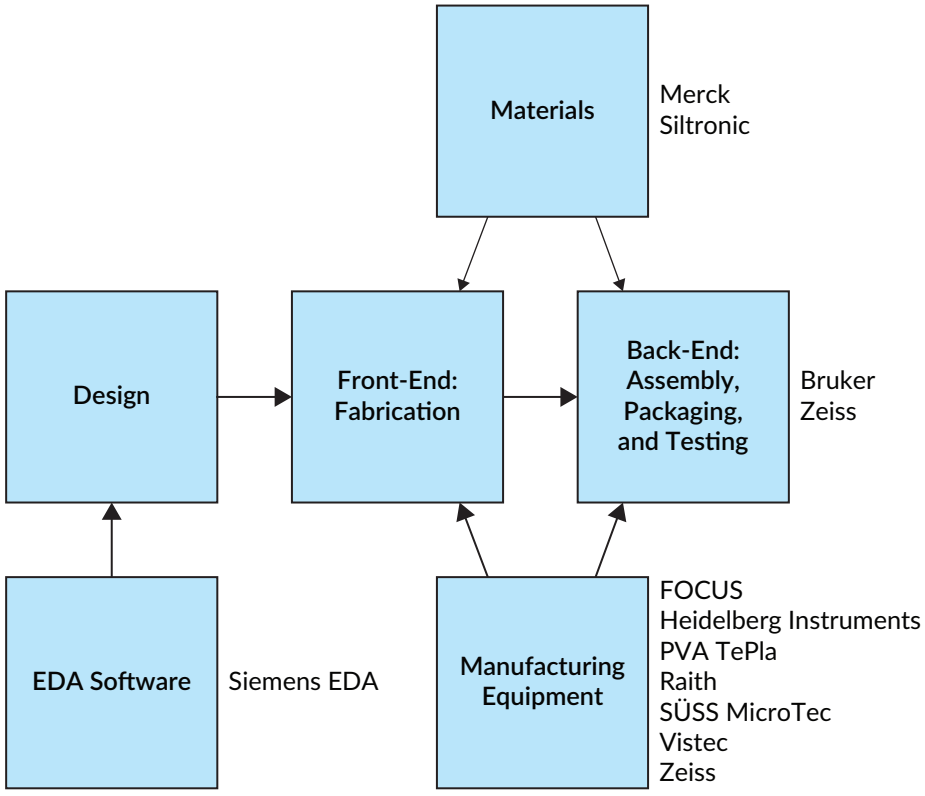

Figure 1. Germany's "China chokepoint" firms in the semiconductor supply chain. Source: Authors' work based on Khan et al. (2021) and Varas et al. (2021).

electron-beam, laser, or imprint technology to draw circuits onto chips (Khan et al., 2021, p. 34). This type of equipment presents a potential, though not yet fully developed, substitute for the sanctioned extreme ultraviolet and deep ultraviolet machines (e.g., Shivakumar, et al., 2024, p. 5). Vistec, for instance, has an over 90% global market share in electron-beam lithography for chipmaking (Khan et al., 2021, p. 30). Japan added this technology to its export control list in 2023, but at least one other German company (Raith) has so far continued to sell it to China (Wettach, 2024, p. 30). To sum up, though less critical than Dutch, Japanese, Taiwanese, and South Korean firms, German firms do matter for the US's ability to curtail China's access to critical supplies, hamper its production, and prevent technical workarounds and future innovations.

Unlike those in other US-aligned countries, Germany's chip firms have not been widely reported to be withdrawing from China. In fact, as we demonstrate below, they have pursued business strategies predicated on deepening their China dependencies and systematically worked to evade the spirit of US decoupling initiatives. As Table 1 indicates, this is not because German chip firms are more directly exposed to China than those in other countries. Germany and Japan each send about a quarter of their exports of semiconductor manufacturing equipment to China. That is more than the Netherlands, but significantly below the percentage of exports that Taiwan and South Korea send to China. Measured in US$ values, moreover, Germany ranks last. Japan exports nearly 10 times as much equipment to China as Germany, and even the Netherlands exports nearly three times as much.

To better understand the role and strategies of German firms in the US–China chip war, the remainder of this section examines three of these "China chokehold" firms—Merck, Siemens, and SÜSS MicroTec—selected for pragmatic and strategic reasons. First, all three companies are publicly listed and large enough for sufficient supply-chain and facilities data to be available on Bloomberg Professional and S&P Capital IQ Pro. Second, they occupy distinct yet critical roles across the semiconductor supply chain, which gives scope to our analysis. Merck is a world-leading producer of specialty gases and high-quality materials needed for semiconductor manufacturing. Siemens is an industrial conglomerate that has become one of four firms globally that own over 95% of chip design software. SÜSS MicroTec is a manufacturer of chipmaking tools developing the most promising alternative to US-sanctioned photolithography equipment. Third, the three firms offer helpful contrasts because they are of vastly different sizes. With a market capitalization of €142 billion, Siemens is an industrial giant more than twice as large as Merck (€65 billion), while SÜSS MicroTec, valued at €891 million, is a significantly smaller, self-styled "hidden champion" (SÜSS MicroTec, 2023a). Such variation allows us to explore whether size has an impact on firm responses. Lastly,

Table 1. Exports of semiconductor manufacturing equipment to China (2022).

	US$	China % of total exports
Germany	926,454,000	25.8
Netherlands	2,450,173,380	14.7
Japan	8,927,690,000	28.7
South Korea	1,601,329,000	51.3
Taiwan	2,192,458,200	34.4

Notes: Aggregated trade data for products classified under Harmonized System codes 381800, 848610, 848620, 848640, 903082, and 903141; we follow Beaumier and Cartwright's (2024, p. 6) aggregation for "semiconductor manufacturing equipment" but also add "machines and apparatus of a kind used solely or principally for the manufacture of semiconductor devices or of electronic integrated circuits." Source: Authors' calculations based on Observatory of Economic Complexity (2024).

the three companies have received different types of scrutiny by US authorities. Siemens has had numerous Chinese customers put on the US Entity List, and in one prominent case, was singled out and virtually directly ordered by US regulators to review its business ties (Heide & Murphy, 2023). Merck is rumored to be the subject of US–German trade talks (Nienaber et al., 2023). SÜSS MicroTec, finally, has seen export licenses delayed by German regulators, which suggests indirect pressure by the US (Finkenzeller, 2023). Thus, in so far as we find that all firms responded similarly in resisting US decoupling initiatives, the reasons for this common behavior need to be sought elsewhere.

3.1. Merck

The importance of Germany for the US tech embargo first became apparent in April 2023 when news broke that the German government was in talks to restrict the export of "chip chemicals" to China (Nienaber et al., 2023). The two companies potentially affected are BASF and Merck, the latter occupying a China chokepoint ("Germany plays down report," 2023; Nienaber et al., 2023). A science and technology company with a dedicated and newly expanded electronics division (Merck, 2021), Merck offers a range of materials and material solutions for the semiconductor industry. It is one of the world market leaders in the production of electronic gases (Khan et al., 2021, p. 56) and supplies chemicals for polishing wafers (Wettach, 2023). In addition, Merck builds supply systems for the chemicals and gases used in semiconductor manufacturing (Hofer, 2023). The company prides itself on the fact that "almost every chip in the world uses one of our products or services" (Merck, n.d.) and counts YMTC and SMIC among its customers, leading Chinese firms that are both on the US Entity List (Bloomberg, 2024). As a result, Merck has become engulfed in the tech war between China and the US, noting as early as 2020 that the conflict touches on every aspect of its business (Ziesemer & Steinmann, 2020).

When the possibility of Germany aligning its export controls with the US was first reported, one chemical industry expert objected that extending the German dual-use list to chip chemicals would make little sense because "the majority of the semiconductor chemical value chains of Merck and BASF did not involve Germany or Europe geographically" ("Germany plays down report," 2023). Contrary to this criticism, this is not because production has been fully localized in China. Rather, our analysis suggests that Merck's production network runs through the US. Some 29% of Merck's facilities are located there, compared to just 8% of its facilities in Germany (Bloomberg, 2024). Moreover, whereas just 12% of its long-term assets are based in Germany, 64% are based in the US (Bloomberg, 2024). The long-term assets Merck has in the US include two of its four facilities producing specialty gases (with the other two located in South Korea; Bloomberg, 2024) and several facilities of its high-tech materials business in North America. In 2019, Merck acquired two US-based firms: Versum Materials, which makes slurries used for flattening wafers (Wettach, 2023), and Intermolecular Inc., which provides technology platforms for high-tech materials research and development (Merck, 2019). Indeed, Merck has confirmed that its US subsidiaries and affiliates are already subject to US export controls (Wettach, 2023).

Given these significant techno-dependencies and the relatively modest contribution of the Chinese market to its total revenue (13% of its total revenue in 2023; Merck, 2024, p. 251), it is surprising that the company is going to great lengths to defend its China operations. To continue to sell to China, Merck has embraced "a strong local presence" and is investing in a new site for advanced semiconductor solutions in Zhangjiagang (Merck, 2024, pp. 60, 82). It also plans to reduce its reliance on raw materials from outside of China, especially

from the US (Yang & Nilsson, 2023). Increasing investment in and sourcing from China is the opposite of what the US wants. With Merck, then, we have our first case of a German "China chokepoint" firm that is circumventing rather than following the US chip embargo.

3.2. Siemens

The second and most prominent example is Siemens. It is the world's fifth-largest industrial conglomerate by market value and a leading supplier of manufacturing software including semiconductor production (Statista, 2024). With its acquisition of Mentor Graphics in 2017, it became one of only four companies worldwide that possess the software to design next-generation semiconductors (Hägler, 2023). This oligopoly position in EDA puts Siemens at the center of the US chip embargo, and its diversified product portfolio extends to other advanced technologies and military applications where the US seeks to curtail China's access, including aerospace, battery manufacturing, and biotechnology ("Chains of control," 2023, p. 36; Hayashi & McKinnon, 2023).

While Siemens has no less than 43% of its long-term assets in the US, it has been present in China since the late 19th century, where it generates 12% of its total revenue (Siemens, 2024, p. 14) and where 17% of its known customers are domiciled (Baines et al., 2024). What, if any, resources does the US possess to compel this industrial behemoth to follow its sanctions? And what, if any, evidence is there to suggest that Siemens has complied?

The most compelling source of US legal authority over Siemens is that Mentor Graphics, which the firm acquired as "Siemens EDA" in 2021, is domiciled in the US. This establishes a direct obligation for its US subsidiary to abide by US export controls, which the Commerce Department extended to EDA software in August 2022. Moreover, under the revised FDPR in October 2022, any foreign item made using EDA software or any foreign item made by a facility (or major component of a facility) linked to EDA software is subject to the same restrictions. Any company that uses, let alone owns and develops, Siemens' EDA software must comply with US export restrictions—no matter where in the world it is located.

It is therefore noteworthy that Siemens became engulfed in a scandal following media reports in 2022 that some of its non-EDA engineering software had been resold by Chinese distributors—Transemic and Zhongke Beijing Hope—to two universities with ties to the Chinese military (Cadell & Nakashima, 2022; Heide & Murphy, 2023). At least some of the software in question came from a subsidiary registered under a business address previously shared with Siemens EDA (Cadell & Nakashima, 2022; Standard & Poors, 2024). Siemens had also moved to acquire Arizona-based Zona Technology, which was reported to have sold its aerodynamics simulation software to a research institute involved in China's hypersonic missile program (Cadell & Nakashima, 2022).

Despite the revelations, Siemens took the position that the specific software had not been sanctioned either by the US or EU and that it had no knowledge of the military ties of its distributors (Heide & Murphy, 2023). However, a BIS official clarified that under its missile "catch-all" provisions, no US-made item whatsoever—not even a pencil—may be shipped to a missile end user and that companies cannot plead ignorance (Cadell & Nakashima, 2022). This turned the attempted Zona acquisition toxic. To date, the deal has not been completed.

Nevertheless, Siemens held on to its Chinese distributors until the US finally put them on the Entity List in June 2023 and made it clear that Transemic's ties to the military "included the development of hypersonic weapons" (Heide & Murphy, 2023; "Siemens kappt Verbindung," 2023). This episode demonstrates that the US has the power to compel even a non-US TNC with over a century of business links with China to abide by its sanctions. But it also shows that the company dragged its feet and had to be publicly called out and legally compelled to cease commercial dealings even when they aided China's military development—ostensibly the target of the US chip embargo. This, then, constitutes the second case of a German "China chokepoint" firm that has sought to resist the US chip war.

3.3. SÜSS MicroTec

Our last case is SÜSS MicroTec, which presents itself as the only provider of photomask cleaners "so far qualified for the 3nm technology node" (SÜSS MicroTec, 2024, p. 29) and thus, an indispensable supplier for ASML and its customers (Finkenzeller, 2023). SÜSS MicroTec also holds an 85% market share in mask aligners (Khan et al., 2021, p. 30), which Chinese companies do not make. Mask aligners are said to "lack strategic importance" (Khan et al., 2021, p. 34) because they are less precise than scanners and steppers as they physically attach the photomask to the wafer. And yet, in 2024, the *Asia Times* reported that SÜSS MicroTec's mask aligners had been used to make a new Chinese quantum chip (Pao, 2024). This may not technically violate the restrictions the US has taken so far to prevent Chinese advances in quantum computing (Klyman, 2023; Pao, 2024), but it certainly puts SÜSS MicroTec in the limelight.

SÜSS MicroTec also matters because it is one of five companies worldwide—alongside EV Group (Austria), Canon (Japan), Obducat (Sweden), and Nanonex (US)—that is developing nanoimprint lithography. Nanoimprint lithography uses a similar template to photomasks to print patterns onto wafers at the nanoscale frontier and with throughput comparable to photolithography (Foster, 2023; Khan et al., 2021, p. 34; Yamamoto et al., 2022). It is, therefore, the most commercially viable rival to extreme ultraviolet machines and constitutes a workaround for China which cannot purchase EUV equipment from ASML due to US restrictions. EV Group currently dominates the nanoimprint lithography market, and Canon plans to sell equipment from 2025 capable of stamping circuit patterns of 2 nm (Mochizuki & Furukawa, 2023). SÜSS MicroTec's nanimprint machines can also be used to produce advanced semiconductors (SÜSS MicroTec, n.d.-a, p. 9). And while Canon's CEO already concedes that "I don't think we'll be able to sell" (Mochizuki & Furukawa, 2023) the technology to China (even though it is not on Japan's export control list), SÜSS MicroTec, by contrast, has made no such statement.

SÜSS MicroTec currently has manufacturing facilities in Garching and Sternenfels in Germany, in Eindhoven in the Netherlands, and in Hsinchu in Taiwan (SÜSS MicroTec, 2020, p. 80). In 2020, the company shut down its production site in Corona, California (SÜSS MicroTec, 2021, pp. 29). Its remaining US locations are sales centers (Standard & Poors, 2024). Overall, SÜSS MicroTec is the most embedded in Germany: 73% of its invested capital is in Germany, compared to just 15% in the US (SÜSS MicroTec, 2024, p. 151). Whereas 73% of its purchasing volume originates from suppliers in Europe, only 6% of its purchasing volume comes from suppliers in North America (SÜSS MicroTec, 2024, p. 73).

But even though it no longer has a manufacturing footprint in the US, SÜSS MicroTec continues to rely on US technology. In 2001, SÜSS MicroTec first established itself as a supplier of precision photomasks when

it acquired Image Technology Inc., based in Palo Alto (Pao, 2024). In 2010, it consolidated this position with the purchase of HamaTech APE, which specializes in photomask cleaning equipment (SÜSS MicroTec, n.d.-b). In 2012, SÜSS MicroTec added projection lithography to its portfolio by buying up Tamarack Scientific Co. (based in Corona, California; Holton, 2012). In 2019, it signed a five-year cooperation agreement with a US customer, allowing its lithography and bonder divisions (the latter used to join wafers) to use its partner's facilities and machines for research and development (SÜSS MicroTec, 2024, p. 164). This right-of-use, and reliance on US technology more broadly, expose SÜSS MicroTec to FDPR provisions that the US could use to strong-arm the firm.

German authorities, for one, started to more strictly screen the export of equipment including mask aligners to China. This led to significant delays in deliveries in 2023 even though, as SÜSS MicroTec complained, "the legal basis for shipments of SÜSS MicroTec equipment to China has not fundamentally changed in recent months" (SÜSS MicroTec, 2023b).

How, then, has SÜSS MicroTec responded? In 2020, it already moved the production of ultra-violet projection scanners from California to Taiwan, citing "the current market situation and low investment demand from potential customers" (SÜSS MicroTec, 2020, p. 4). More recently, SÜSS MicroTec decided to expand its facility in Taiwan to supply the Asia–Pacific region, which accounts for 66% of its total sales (SÜSS MicroTec, 2024, p. 44). According to the company, this investment is to respond to record demand for its products driven by the boom in artificial intelligence (SÜSS MicroTec, 2023c). But this move also has the added advantage of solving the German export licensing issue. Beyond these investment decisions, SÜSS MicroTec is also reconfiguring its supplier base. In its latest annual report, the company acknowledged that using US-based components puts it at risk of being cut off from its Chinese customers by US restrictions and states that it "tries to avoid this risk by qualifying alternative suppliers for the previous US suppliers" (SÜSS MicroTec, 2024, p. 106). The decision to expand operations in China's near abroad and substitute non-US suppliers for US suppliers points to SÜSS MicroTec's intent to respond to US pressures in ways that mitigate any potential loss of access to the lucrative Chinese market, which is said to account for a third of SÜSS MicroTec's sales (Finkenzeller, 2023). SÜSS MicroTec—like Merck and Siemens—is following the letter of US exterritorial law while, in some crucial respects, actively circumventing its spirit. How to explain this behavior in the face of US power is the subject of Section 4.

4. Secondary Exposure and National Production Regimes

The previous section has identified how three German companies relevant to the US chip embargo are equally techno-dependent on the US and yet trying to circumnavigate US efforts to restrict flows of technology to China. Merck (2024, p. 106) plans to localize production and source raw materials from *within* China, noting that "many relevant components of US origin were replaced by alternative suppliers." Despite media revelations that two of its Chinese distributors had supplied software to blacklisted Chinese firms, Siemens cut ties only after these distributors were themselves added to the Entity List, notwithstanding negative publicity and clear signaling from US regulators. For its part, SÜSS MicroTec is expanding production in Taiwan and switching to non-US suppliers to remain in the Chinese market after German authorities (possibly at the behest of the US) stalled the issuing of export licenses.

It is clear from these cases that corporate compliance cannot be extrapolated from techno-dependency. To be sure, our analysis of the three companies does indicate that the US can force their hands if regulators decide to expand the scope of the FDPR rule and prosecute violations or strike a multilateral agreement with the German government. In a clear indication of its willingness to do the former, the BIS in October 2023 reduced the percentage of US content required to trigger the FDPR to zero for some advanced lithography equipment. This unprecedented expansion of the extraterritoriality of US tech sanctions is so far confined to a small range of goods, targeting one of ASML's machines that is not (yet) on the Dutch export list (Goujon & Kleinhans, 2023). Still, one could easily foresee this rule being extended to nanoimprint lithography if it were to rival photolithography in precision and output. If SÜSS MicroTec or any other company were to really advance in these or other areas, the US seems prepared to intervene—multilaterally if possible, but unilaterally if need be.

Our point then is not to deny that the US possesses this go-it-alone power, but to insist that we cannot treat firms' anticipatory compliance as a prefigured outcome. To do so is to miss out on what our case study suggests is better understood as a politicized, negotiated, and protracted policy process. To understand the reservations and resistance of the three German firms, we need to take a closer look at how Germany's semiconductor industry ties into other sectors of the German economy—its "national production regime" (Koddenbrock & Mertens, 2022).

Figure 2 presents the position of the three companies within Germany's broader semiconductor production network. This network diagram shows both their first-tier customers and suppliers headquartered in Germany and those German-headquartered second-tier customers and suppliers that are connected to the three focal firms via other semiconductor and semiconductor equipment companies. This mapping of supply chain connections reveals that all three focal firms have Infineon as their customer, which is the hub of Germany's semiconductor production network. As the world's leading automotive chip company, Infineon is geared towards the Chinese car market, which is the largest in the world by output and sales, and, in 2024, became the largest by export (Kawakami et al., 2024). As of 2023, 32% of Infineon's revenue came from China, whereas the US and Germany each account for 12% of its revenue (Bloomberg, 2024).

The company is tightly articulated with the German automotive industry. Three of Infineon's top five highest spending customers for which we have data are major auto-suppliers (ZF Friedrichshafen, Robert Bosch, and Denso Corp; Bloomberg, 2024), and Infineon's automotive segment itself accounts for 51% of the company's overall revenue (Infineon, 2024, p. 2).

The fact that automotive companies—both lead firms such as Volkswagen and major auto suppliers such as Continental—feature so prominently in Germany's semiconductor network offers strong suggestions as to why Germany's chip firms have so far hesitated to align themselves with the US chip war. Germany's auto industry is deeply embedded in China and highly vulnerable to potential Chinese countermeasures (Baines et al., 2024). Most important here are China's recent anti-foreign sanction regulations that threaten to curtail the operations or even seize the assets of companies that support discriminating restrictions against China (Reich, 2021, pp. 32–33). To prevent this worst-case scenario, German companies are advised to show that their hand is being forced by US regulators (Industrie- und Handelskammer Region Stuttgart, n.d.). Given their close integration with the German automotive sector, German chip firms must take their secondary exposure to the Chinese market into account and are therefore unlikely to take actions that could trigger Chinese retaliation, despite techno-dependencies on the US.

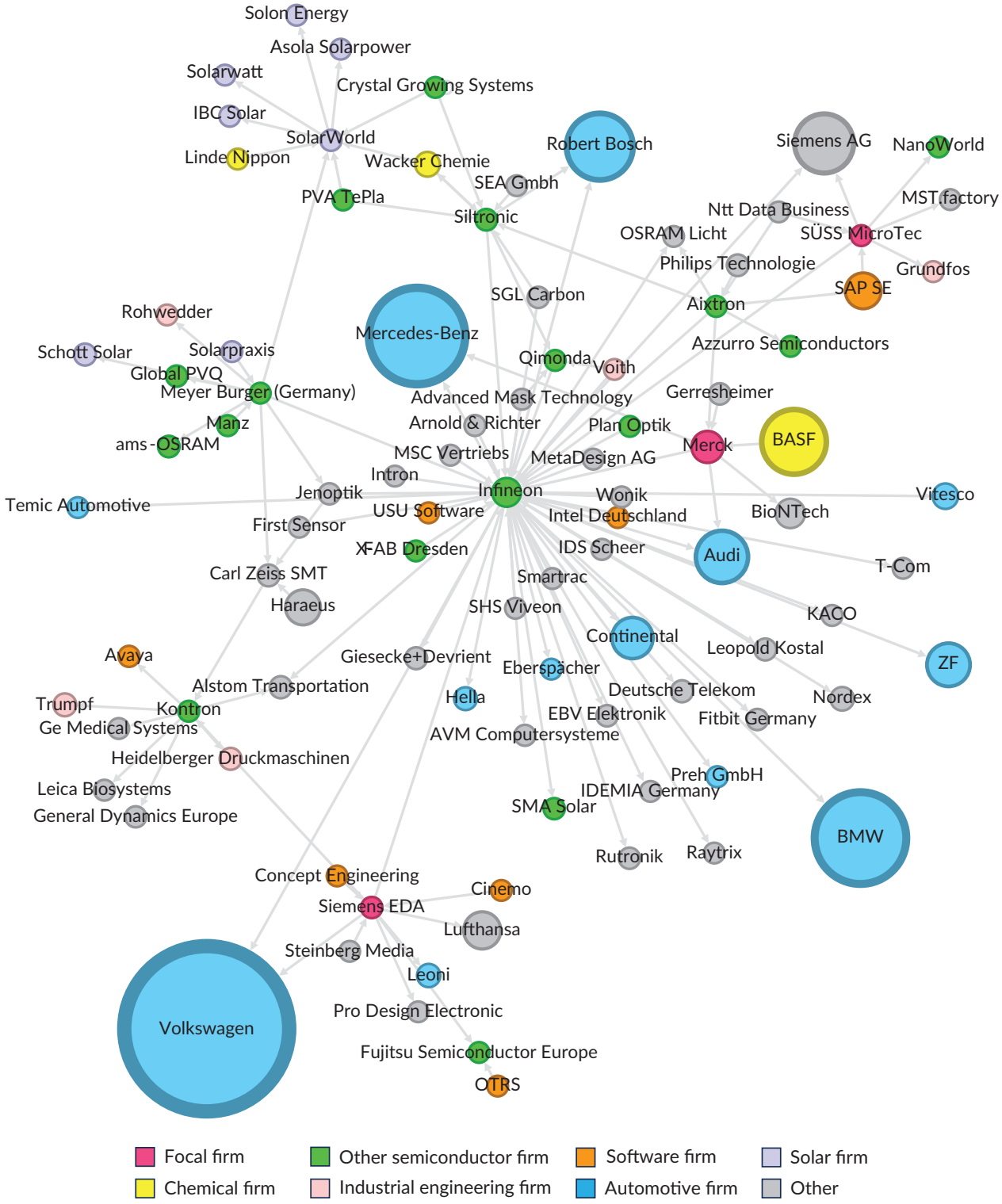

Figure 2. The German semiconductor network. Note: Node size is proportional to annual revenues for the latest available year. Source: Authors' work based on Bloomberg (2024), Standard & Poors (2024), and SÜSS MicroTec (2019).

5. Conclusion

As growing US–China tensions drive deeper fissures through the global economy, attention has shifted to how the US has increasingly sought to "weaponize interdependence" (Farrell & Newman, 2023). Our research into Germany's semiconductor industry has empirically demonstrated the centrality of the US as a base of operations, target of strategic investments, and source of know-how and products for foreign semiconductor firms. This gives US regulators significant extraterritorial reach and the ability to set the parameters within which these firms ultimately operate. But our case has also highlighted the complexities involved with US efforts to mobilize allied firms as weapons in a battle over future technologies. This adds new insights to an emerging research agenda on TNCs as geo-economic actors whose interests and behavior can converge or collide with governments' supply-chain statecraft (Babić et al., 2022b; Geertz & Evers, 2020; Moraes & Wigell, 2022; Rolf & Schindler, 2023).

This article has offered a deep dive into three "China chokepoint" firms that—though similarly techno-dependent on the US—have sought to circumvent the US chip embargo to continue to sell to China. That German chip firms would take extraordinary measures to try to evade the long arm of the US—even in cases when China is not a vital sales market—poses a puzzle. A potential solution, we argue, is provided by their extensive links (largely via Infineon) to the German automotive industry, which is in turn deeply embedded in China and most vulnerable to Chinese countermeasures. Given the significance of the auto sector to the broader German economy, its chipmakers are likely to be highly conscious of the potential implications and risks of any decoupling from sales in China. Our data highlights the stark limitations of both bilateral trade statistics and firm-level geographical revenue data for adjudicating dependency on particular country exports.

The US–China chip war is of course not *only* made in Germany, but non-compliance of certain nodal German firms could significantly complicate and delay US efforts to constrain China's technological ambitions. If the US were to extend its China sanctions to other sectors such as advanced battery manufacturing or biotechnology, more German companies would move into its crosshairs. Furthermore, if German firms were to shift the battlefield of production from Germany to Taiwan or other countries to keep trading with China, the US would be forced to act more aggressively towards them to enforce its export controls. The outcome of the geo-economic turn remains inconclusive, then. Empirically mapping out these dynamic production networks, state-firm relations, and firm strategies will be of ongoing importance in adjudicating the efficacy of US supply-chain statecraft in the coming years.

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Conflict of Interests

The authors declare no conflict of interests.

Data Availability

The data that support these findings are derived from sources in the public domain (The Observatory of Economic Complexity, http://oec.world/en) or available from Bloomberg Professional and S&P Capital Pro IQ, subject to commercial restrictions. The authors' calculations are available within the article and/or upon request for non-commercial academic purposes.

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About the Authors

Julian Germann is a senior lecturer in international relations at the University of Sussex. He researches European and German policy responses to Sino–American competition. He is the author of *Unwitting Architect: German Primacy and the Origins of Neoliberalism* (Stanford University Press) and has published in *Review of International Political Economy*, *International Studies Quarterly*, and *European Journal of International Relations*, among others.

Steve Rolf is an ESRC research fellow at the University of Sussex Business School. He is a political economist researching the emergence, dynamics, and implications of Sino–American competition in the field of digital technologies. His current research focuses on the economic and power dynamics of digitalization, including the intersection of state capitalism and digital platforms.

Joseph Baines is a senior lecturer of international political economy at King's College London. His research interests include global value chains, corporate power, and the Sino–American trade conflict. He has published in *Review of International Political Economy*, *New Political Economy*, and *Competition & Change*, among others.

Sean Kenji Starrs is a lecturer of international development at King's College London. He researches the nature of American power globalized, the capitalist rise of China, and world order. He has published in *Development & Change* (with Julian Germann), *International Studies Quarterly*, *New Left Review*, and *Journal of Contemporary Asia*, among others. His book manuscript is currently under review with Oxford University Press (New York).