Weaponizing Interdependence & Global Value Chains: US Export Controls on Huawei

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Abstract

This paper contributes to the developing literature on weaponized interdependence by demonstrating through a case study of American export controls targeting Huawei that global value chain (GVC) analysis is a more appropriate tool to analyze the effects of weaponizing supply chains than the network topography approach proposed by Farrell and Newman (2019, 2020), which they used so effectively to analyze power dynamics in financial and informational networks. The case study examines two key chokepoints the US government has attempted to use in its campaign against Huawei: electronic design automation (EDA) software tools and chipmaking capital equipment.

The still developing weaponized of interdependence framework recognizes that some chokepoints may be more durable than others. However, with its network topography approach developed through exploration of cases involving intangible goods and service networks, such as SWIFT and the internet, the weaponization literature has not developed the appropriate approach to evaluate interdependence involving tangible goods. This paper argues that global value chain (GVC) analysis is a superior analytic approach because it can better evaluate the operations of interdependence involving tangible goods and offers more leverage to evaluate durability of chokepoints.

GVC analysis highlights the importance of GVC linkage characteristics, GVC polarity and GVC- and weaponization policy-shaped corporate interest as the important determinants of chokepoint durability. The paper demonstrates the importance of these GVC-related factors through case studies of the EDA tools and chipmaking equipment.

Introduction

States have traditionally used technology export controls to prevent others from developing their arsenals and economies. With the ballooning of economic interdependence over the last three decades of post-Cold War globalization, technology export controls have also become a means to weaponize interdependence i.e., states can exploit network structural asymmetries to gain strategic leverage in interdependent relationships. Similarly, states can maneuver to try to lessen their network structural dependence on others in these interdependent relationships. Previous works on weaponized interdependence (Farrell and Newman 2019, 2020; Drezner, Farrell and Newman 2021) employ a network topography approach to analyze the possibilities for weaponization in economic interdependence.

This paper argues that the real-world application of the network topography approach in the weaponization of interdependence (WI) literature is limited mostly to networks of intangible goods, such as information and finance. As much of economic interdependence resides in the world of physical goods, examination of WI involving such goods should more often employ a global value chains (GVC) framework in terms of the nature of information exchange and competitive dynamics to determine the existence and location of chokepoints in the complex international production chains. The paper will use the case of the Trump and Biden administration's attempts to weaponize technology export controls against China's Huawei to illustrate the application of GVC analysis to WI.

To illuminate these points, this paper first provides a literature review of WI. Then the paper explains how GVCs can provide greater purchase on remaining questions that the network topography-oriented approach to WI does not adequately address. The third section delineates America's weaponization of the global semiconductor chain targeting Huawei. The fourth section uses GVC analysis to evaluate the durability of the key chokepoints, electronic design automation and capital equipment. The concluding section argues that analysis using a GVC framework fills in many of the lacunae that the network topography-based weaponization framework leaves unanswered as well as bringing in new factors missed in the weaponization literature.

1. Literature Review: Economic Interdependence, Networks and Weaponization

The literature on economic interdependence in international relations has tended to approach this issue through the lens of dyadic trade relations (Gowa 1989; Pollins 1989; Copeland 2014) or the efficacy of trade sanctions (Pape 1997; Elliott 1998; Drezner 1999; Kirschner 2002). Here power was considered either as bilateral dependency of trade (Gowa 1989; Pollins 1989; Keohane and Nye 2012; Copeland 2014) or the market power of a given country over others by sheer economic weight (Shambaugh 1996; Simmons 2001).

When network structures of interdependence were considered in light of the obvious complex supply chains and other networks that connect economies, the dominant view was one from the liberal tradition emphasizing mutual gains under cooperation or enhanced power within cooperative networks for the US and its allies (Keohane and Nye 2009; Slaughter 2017). Network interdependencies created reciprocal vulnerabilities and force was not useful within these non-hierarchical systems (Keohane 2009). Some argue whatever power asymmetries exist will gradually disappear as structural holes are filled in (Keohane and Nye 2012) while others argue that decentralized networks create opportunities for mutual gains via diplomacy (Slaughter 2004 and 2017).

Farrell and Newman (2019, 2020) take issue with the liberal approach to networks of interdependence because they incorporate how networks constrain the behavior of actors and how networks have distributive effects in terms of power. They approach the study of interdependence through the power topography of economic networks of interdependence and its interaction with domestic institutions. Borrowing insights from network analysis as applied to international relations (Kahler and Montgomery 2009; Goddard 2018), Farrell and Newman posit that asymmetry in network structures shapes states' ability to weaponize interdependence to coerce other states. In terms of network structure, those states with network centrality (i.e., control/influence over the networks) have leverage over other states. Such states can pursue two leverage strategies: panopticon or chokepoint. In panopticon, the state uses its network leverage to gain informational advantages against its rivals. In chokepoint, the state uses its network leverage to cut off its rivals from the network. A state needs both physical and legal jurisdiction over the network hubs, and the appropriate legal and regulatory institutions to weaponize the hubs. Thus, even the United States has found itself somewhat hamstrung from using its network power over the internet infrastructure as a chokepoint (Farrell and Newman 2019).

Farrell and Newman (2021b) have been very careful to try to limit the stretching of the weaponization of interdependence concept. They set out several conditions. The basic structural requirement is that the existence of global networks that cause high amounts of interdependence between states. To weaponize these networks effectively, a state needs to have asymmetric power through control of hubs (network centrality as above) and the appropriate institutions to control and manipulate these hubs. Finally, the coercion via asymmetric power within these networks is applied by the weaponizer for geostrategic not economic ends. Thus, the target of weaponization is a state/non-state political adversary rather than purely economics actors. Thus, according to Farrell and Newman, the US weaponized interdependence global networks of supply against Huawei, which was as much a geostrategic actor as an economic one whereas China tried to leverage its asymmetric interdependence in rare earths within its bilateral relationship with Japan to punish Japan. The former is weaponization of interdependence and the latter is not because the former leverages the network structure and the latter is solely bilateral. However, the difference between networks and bilateral channels is not so clear cut in Farrell Newman (2021b). They view China's use of rare earths as asymmetric interdependence but reliance of global pharmaceutical industry on replacing but view India's leveraging its control of hydroxychloroquine production as a hub within the pharmaceutical industry.

Farrell and Newman (2021b) do however recognize that their initial exposition of weaponization of interdependence was too static and did not take into account the counter-strategies of other actors, including states and firms. They posit that weaponization can only sustainably work over the medium term when network structures are self-reinforcing and relatively impervious to the strategies used to undermine them. Here again they recognize that the complexity of networks and the interaction between different networks have not thus far been well addressed in this emerging literature. Happily, GVCs can address counter-strategies, network robustness and the complexity and inter-linkages of networks. To GVCs, we now turn.

2. Global Value Chains

While Farrell and Newman's WI advances our understanding of power asymmetries in certain networks, it is not fully applicable to many global supply chains where the control of the hub is much more diffuse. The network hub's structure as conceived by Farrell and Newman resembles early work from economic geography on Global Production Networks (GPNs) where global flagships dominated the GPNs (Ernst and Kim 2002). Our understanding of these supply chains has advanced whether within the GPN tradition (Coe and Yeung 2015) or, more usefully for our purposes here, the global value chain (GVC) approach

(Gereffi *et al*. 2005; Gereffi 2018) designed purposefully to analyze globe-spanning supply chains under globalization. Whereas GPNs and weaponized interdependence have featured relatively simplistic schema of power asymmetries, GVCs recognize different power relations at the interfaces along the supply chain.

For those readers unfamiliar with the GVC literature, we will now define the relevant terms. Linkages refer to the nature of the interactions between firms at specific nodes (e.g., interaction node between lead firm and first-tier supplier or the node where first-tier and second-tier suppliers interact). Following the seminal work of Gereffi, Humphrey and Sturgeon (2005), there are five modal types of value chains (market, modular, relational, captive and hierarchy) that exhibit increasingly high transaction costs due to complexity and intolerance of distance between the two actors at a specific node and decreasing codifiability of information and supplier capability (beyond the relational mode) as one moves from market transactions to hierarchical ones.

Value chain governance refers to the polarity and drivenness of value chains with unipolar chains being highly driven by one lead firm, bipolar chains heavily influenced by two lead firms/actors and multipolar value chains with relatively weaker drivenness (influence) by the multiple major actors involved (Ponte and Sturgeon 2014).

Both the linkage characteristics and the polarity/drivenness of GVCs have implications for weaponization, but the linkage characteristics are better developed and defined in the GVC literature with clear metrics by which to categorize particular linkages. For determining polarity and drivenness, the approach is more *ad hoc* and observational (Ponte and Sturgeon 2014).

GVC structures when combined with newer GVC theorizing that takes into account firm strategies (Sako and Zylberberg 2019) help to answer remaining questions concerning

WI that a network approach often cannot answer, especially for supply chains involving physical goods which are less amenable to a network topography approach. The WI approach assumes network hubs must be replaced with network hubs, but this assumption does not always hold for physical goods. GVC linkage characteristics provide information on the level of difficulty of replacing one node/hub with another (Table 1 below). For market linkages, replacing the incumbent lead firm or supplier on either side of the transaction is relatively easy given the low complexity of the tasks. For modular linkages, the technology-intensity is higher so even if the ability to codify information is high, the ability to switch firms is slightly more difficult than for market linkages. The ability to displace firms at the node is hardest for relational and hierarchical linkages because the mutual dependence inherent in relational linkages and the internalization of capabilities in hierarchical linkages. For captive linkages, it is easy for the lead firm to switch suppliers, but very hard for dependent suppliers to switch lead firms.

<insert Table 1>

Corporate strategies to conform to or undermine weaponization tactics are underspecified because the weaponization of interdependence literature can only determine value of a given hub by the access it provides, which may not be an accurate measure of the value firms place on that hub. Characterizing the type of linkage clarifies two things. First, the linkage type provides information on the likelihood of duration based on the likelihood of switching/displacement of a firm at the key node. Second, the linkage type gives us an approximate idea of the value of that linkage for a particular firm. Relational linkages have high value for both participants. Market and modular nodes have lower value for both participants. Captive nodes have low value for the dominant firm but high value for the captive supplier. The hierarchical linkage only has one participant, so the value placed on that node is indeterminant other than the firm has chosen to internalize the node for some reason. Fully hierarchical linkages are typically not relevant to weaponization since state actors have difficulty denying firms access to their own internal capabilities/activities.

The drivenness/polarity of GVCs also has implications for weaponization. The more firms are involved in leading/driving a GVC the harder it will be for a state to weaponize interdependence for any significant duration. With more than one substantial firm leading the GVC, the ability of a state to prevent these additional lead firms from coordinating a working around a chokepoint increase as the number of lead firms increase.

3. American Weaponization of Interdependence Targeting Huawei

Although the American telecommunications equipment market had been relatively closed to Huawei for years and the Trump administration effectively closed off the market to all Huawei 5G equipment[1], there were still rising concerns about Huawei's global presence and its emerging position as the leader of 5G telecommunication equipment (Segal 2021). The two main motivating concerns were China's own weaponization through a Huawei-provided panopticon for intelligence gathering and trade secret theft (Segal 2021; Fuller and Triolo 2019) and the potential of reliance on "dirty networks" during military operations. The US military does not want to have to rely on "dirty networks" potentially compromised by the Chinese state while conducting overseas military operations and

[1] The final nail in the coffin for Huawei's access to the American market was the Federal Communications Commission on June 30, 2020 naming Huawei and ZTE as national security threats in order to prevent these firms from competing in the admittedly small, rural broadband equipment market in the US. In 2019, the FCC had already voted unanimously to block subsidies for rural broadband to any firms deemed to be threats to national security, and it was understood that this vote was targeted at these two Chinese firms (NYT 6.30.2020).

feared Huawei's dominant position in 5G equipment would spread this equipment globally (Donahue 2020; Fuller and Triolo 2019; Triolo 2020). The US government tried to dissuade third countries from purchasing Huawei equipment, but foreign adoption of this policy has been uneven. With such policies proving ineffective in halting the imminent spread of Huawei 5G infrastructure equipment around the world, the US government placed Huawei on the Entity List in May 2019.

It took time for the Trump administration to learn how limited the original Entity List regulations were for the purpose of decimating Huawei. The US government had originally designed the Entity List to deal with firms violating American trade sanctions. Indeed, in March 2016 the US government had placed Huawei's competitor and second biggest telecommunications infrastructure equipment vendor, ZTE, on the Entity List for violating American trade sanctions on Iran and North Korea. ZTE settled with the US government in March 2017, but the US government renewed the export controls in April 2018 after discovering ZTE had violated the 2017 agreement.[2] These export controls effectively cut off ZTE from American chips and threatened its very survival (Sina Tech 4.22.2018). The issue was quickly resolved in part because of Trump's enthusiasm to reach a trade deal with China (Bown 2020)[3]. Given the hue and cry over ZTE's imminent demise in the spring of 2018, it

[2] The US placed ZTE on the Entity List in March 2016 because of ZTE's sales of American technology to North Korea and Iran. In March 2017, ZTE settled with the US, agreeing to enhanced compliance protocols including end-user protocols in return for lifting the Entity List with a suspended Denial Order lasting seven years (in effect a seven years' exporting probation). Denial Orders issued by the Department of Commerce's Bureau of Industry and Security prevent the companies or persons receiving the Denial Orders from any export privileges of items subjected to the Export Administration Regulations (BIS). After being notified by ZTE of violations, BIS activated the Denial Orders against ZTE and ZTE executives on April 15, 2018. Subsequently, a second agreement was reached with ZTE to lift the Denial Orders in June with the final lifting of the orders coming on July 13, 2018.

[3] Perhaps relevant to any future Biden administration rollback of Huawei sanctions is the fact that four senators, two Democrats (Schumer and Van Hollen), and two Republicans (Rubio and Cotton), sponsored a bill to reinstate the sanctions, but the Republican caucus supported President Trump and this effort was thus defeated (Reuters 7.20.2018).

was understandable that some within the US government assumed that they could easily leverage the Entity List to level Huawei in a similar manner. The aim was simply to cut off Huawei from chips just like ZTE.

There were two problems with this strategy. The first problem was Huawei 's technological capabilities far exceeded ZTE's. The second was the way the Entity List operated.

While Huawei and ZTE are often discussed as peer competitors, ZTE has trailed Huawei technologically and commercially for almost the entire first two decades of the 21st century (Fuller 2016, Ch. 3). Consequently, Huawei had developed a formidable chip design subsidiary, Hisilicon, whereas ZTE's chip design capabilities remained quite weak. When facing American export controls, ZTE did so as a firm desperately reliant on foreign, especially American, chips (WSJ 5.18.2018; Sina Tech 4.22.2018). It is very likely that ZTE would have seen a precipitous decline in its overseas business if it had not reached a quick settlement with the United States.

Due to the fact that those pushing the anti-Huawei policy, who were principally from the national security side of the government, were not lawyers well acquainted with Bureau of Industry and Security (BIS) regulations (Interview December 2019), they learned the wrong lesson from ZTE's near demise in 2018. They assumed that utilizing sanctions to undermine other Chinese companies would be easy, but they did not realize the loopholes within the Entity List regulatory framework. The original Entity List regulations only prevented software with a given level of American content and American-produced hardware with a given level of American content from being sold to the Entity List entity. If the American hardware were produced offshore, then such hardware could be sold to the Entity List entity because the regulations were written prior to the era of fragmented global value chains. For ICs, this loophole was particularly large because it meant that an American firm, such as Qualcomm, could design a chip entirely in the US and then arrange for the manufacturing to be done by one of the large foundries, such as Taiwan Semiconductor Manufacturing Corporation (TSMC), overseas allowing Huawei in turn to be able to legally purchase the Qualcomm chip.

The immediate implications of placing Huawei on the Entity List in May 2019 were thus primarily software-related for Huawei. Huawei's smartphones faced the serious problem of being cut-off from Google's app store, which was critical for Android phones outside of China. More threatening still was the inability to legally use American EDA software tools to design chips once the then-current licenses expired. Without American EDA tools, it would be basically impossible for Huawei to design chips.

The Trump administration hawks were still not satisfied. With Huawei still able to use TSMC to fabricate advanced chips that Huawei had already designed prior to the ban, Huawei's own design needs for new chips to replace those in production would be two years out. In other words, as long as Huawei could still access foundries outside of the US, blocking Huawei from supplying competitive 5G equipment around the world would at least be two years out. To make matters worse, even if Huawei could not design its own chips later, the loophole around fabrication abroad meant that Huawei could revert to its earlier and still very successful model (Fuller 2016) of relying on external chip suppliers for its telecommunications equipment.

Thus, the Trump administration decided to revise the Entity List rules for Huawei to close the legal loopholes. On May 15, 2020, the US government proposed revised regulations to restrict Huawei's access to American capital equipment used in chip fabrication and tighten existing restrictions concerning EDA tools. The final rule on Huawei's

Entity List order issued on August 17, 2020 offers an either–or clause, where either knowledge on the part of the provider of the good or service (e.g., EDA software) to Huawei is required, or Huawei and its affiliates "touching" the product (e.g., EDA software) somewhere along the supply chain[4] is sufficient to make the product controlled. However, to be legally liable, a firm still has to have knowledge that it supplied Huawei or dealt with a Huawei-touched supply chain.[5][6] Furthermore, this final version of Huawei's order revised the Export Administration Regulations' (EAR) Foreign Direct Product Rule to forbid the use by third parties of American capital equipment when manufacturing chips for Huawei.

As Figure 1 shows, the export controls the US pursued have been targeted at the key technology inputs, electronic design automation (EDA) tools and capital equipment, into the IC industry's two most technology-intensive segments, design and fabrication. EDA tools are the critical software tools needed to design chips. Similarly, a wide range of technically sophisticated capital equipment is necessary to fabricate chips.

<insert Figure 1>

Working within the WI framework, Segal (2021) deemed American weaponization to be successful. Farrell and Newman (2021b) agreed but also posited that the durability of these chokepoints would erode over time. They speculated that Huawei and China would find workarounds for these chokepoints. In the next section, we will use GVC analysis to better answer the question of the durability of these chokepoints examining both GVC structures and the critical role of incentives of corporate actors in determining durability.

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[4] Huawei just must be a purchaser, end user, intermediate consignee, or ultimate consignee. In other words, Huawei just must somehow be involved in the relevant product's supply chain.

[5] This point was confirmed by a legal expert on the Entity List via email on September 14, 2020.

[6] The preceding two sentences are from Fuller (2020), p. 8.

4. GVCs and Durability of Chokepoints

The question of the duration of this chokepoint turns on the nature of the linkages for the two chokepoints and, secondarily, on the polarity within this industry.

EDA tools have a strong relational linkage with the foundries even while they have a more distant, modular relationship with the designers of chips (Sangiovanni-Vencentelli 2003; Fuller 2020). The modular links with the designers would indicate that the designers could switch EDA tool vendors. Unfortunately for Huawei, there are only three vendors (Cadence, Synopsys and Mentor Graphics) capable of supporting the full panoply of design functions, all American[7] and subject to the export controls. More distressing still for Huawei, as a modular linkage between design firms and EDA tool vendors, there is little knowledge generation within the interaction between EDA tool vendors and chip designers, such as Huawei, so there is little value placed by the EDA vendors on preserving this link to specific designer customers. With this incentive structure, the EDA tool vendors would be very unlikely to try to undermine the chokepoint in order to preserve these links to Huawei.

Turning to the linkage between EDA tool vendors and the major foundries, such as TSMC and Samsung, there is a strong relational linkage because there is a richer interaction featuring co-iterative exchanges of information for the purpose of ensuring the design-for-manufacturing process for each new fabrication process. The foundries only want to work with a few EDA tool vendors for these new processes, and they have continually chosen the Big Three tool vendors since they are the most prominent. As the preferred partners in design-for-manufacturing for new processes, these EDA tools have had a structural advantage over would-be rivals which will naturally lag in rolling out EDA tools for the latest

[7] Mentor Graphics was acquired by Germany's Siemens in 2017, but its technology activities are heavily based in the US so its EDA tools are still deemed American technology content that is subject to export controls.

processes offered by the foundries (Fuller 2020). This structural advantage conforms to idea that incumbents in relational networks will be harder to displace. However, the analysis of this specific value chain also suggests that the EDA vendors are more dependent on the benefits of this co-development than the foundries. The leading foundries have other scale and scope economies to ensure the continuation of the current duopoly of advanced process technology. Thus, if the foundries perceive American export controls involving the EDA tool vendors as too onerous, they might begin to cultivate new EDA partners at the design-for-advanced manufacturing node.

Turning to capital equipment, fabrication production requires numerous processes.[8] Today, typically one supplier is dominant (more than 50 percent of the market share) for each type of equipment. Today, American firms represent 52 percent of global revenue in IC capital equipment compared to Japan’s 27 percent and Europe’s 17 percent. In the narrower relevant category of wafer fab equipment, three of the five largest firms, comprising 71 percent of 2018 revenue, are American: Applied Materials, Lam Research, and KLA (see Figure 2). Applied Materials is the largest firm with 18 percent of revenue. Nevertheless, going forward, ASML of the Netherlands is likely to be the largest firm because it monopolizes high-end lithography and extreme ultraviolet (EUV) lithography and dominates lithography generally (Ramel and O’Connor). America withdrew from the lithography market in 2001 when ASML acquired SVG, the last American lithography equipment producer.

<insert Figure 2>

[8] The following paragraph draws upon Fuller 2020.

The interactions between the capital equipment vendors and their customers, the foundries and other chipmaking firms, tend to be between modular and weakly relational (Fuller 2020). This suggests that replacing American equipment in much of the fabrication process would be relatively easy to do.

The interaction of the GVC of semiconductor capital equipment and the semiconductor chip GVC sheds light on why Huawei was successfully cut-off from access to chip fabrication facilities. The interaction between foundries and capital equipment makers is somewhere between modular and relational in character and thus suggests that there might be some opening for outside equipment producers to displace American equipment. However, the semiconductor capital equipment GVC itself is somewhere between captive and hierarchical in character and thus this value chain characteristic presents high barriers for would-be competitors to displace an incumbent.

What is more critical for the capital equipment industry than the mere GVC linkage characteristics is the fact that there are capable capital equipment makers across all of the different machines with the exception of advanced lithography where ASML has built a monopoly (Fuller 2020). In other words, the capital equipment is characterized by multipolarity with a multitude of firms capable of organizing the industry with the goal of exploiting other industry participants for outsized gains. Each one of these firms may manage a relatively hierarchical (i.e., vertically integrated) value chain with at best some captive suppliers, but each firm also faces established competitors with their own supply chains.

There are two implications following from these industry characteristics. First, the combination of at best weakly relational linkages between foundries and capital equipment makers and the multipolarity among capital equipment makers means the foundries ultimately are not reliant on American equipment. Thus, any chokepoint based on denial of American equipment is unlikely to be durable unless the chokepoint inflicts minimal or no costs on the advanced foundries. Second, the firms likely to be able to displace incumbent American capital equipment firms are the existing competitors rather than new ones that would find entry difficult based on the GVC linkage characteristics. These existing firms also happen to be from allies of the US, Japan and the Netherlands. However, compliance with US sanctions is far from guaranteed. In order to maintain the chokepoint, the US will also have to take care not to force large costs on these allied firms (Fuller 2022) rather than worrying about potential Chinese competitors (Fuller 2020, 2021). Expanding use of the chokepoint to a wide swathe of Chinese semiconductor customers, as has been broached by some in the American government (Nellis 2022), would push firms in allied countries closer to working to undermine the chokepoint by ignoring American controls when at all possible. A similar point about the sustainability of the chokepoint can be made for the intersection of the semiconductor value chain and semiconductor capital equipment value chain. Farrell and Newman (2021b) recognized that they had not really addressed the intersection of different networks. One could argue capital equipment and semiconductors are an intersection of two GVCs or both part of a larger GVC. Indeed, the fungible boundaries of GVCs is a recognized problem in the literature (Gereffi 2018). Whether one large or two intersecting GVCs, the semiconductor industry is rife with multipolarity. On the hand, this situation could suggest that China would be able to find ways to overcome the chokepoint. On the other hand, these GVC-driving firms are all in countries allied to the US or in the US itself: Samsung (Korea), TSMC (Taiwan), ASML (the Netherlands), Tokyo Electron (Japan), Intel (US) and Applied Materials (US). Thus, as long as the US can keep its allies on board, it would be very hard for China to leverage these various GVC-driving MNCs to create ways to undermine the chokepoint.

In the following sub-sections, we explore the strategies of Huawei, the Chinese government and foreign corporate actors in depth in order to highlight how the GVC structures and particular WI strategies of governments shape corporate incentives that in turn help or hinder the durability of chokepoints.

Huawei's Response to Chokepoints[9]

As a firm that has increasingly relied on internal chip design at advanced production nodes for use in its telecommunications products, Huawei faced dire consequences when cut off from EDA tools (a threat since May 2019) and especially foundry services to produce its chips (a threat since May 2020). When the threat was limited to EDA tools, Huawei faced the choice of hacking the license keys to gain access to the major EDA vendors' tools, trying to gain access to EDA tools through intermediaries or turning to buy chips from others once its internal stockpiles ran out. With the reinforced rules of May 2020 preventing foundries from using American capital equipment to fabricate chips for Huawei, Huawei faced the choice of being unable to secure international foundry services for advanced fabrication nodes[10] in the short-term unless it managed to disguise the origin of its orders through shell companies. Longer term an alternative would be to use de-Americanized foundry production which would not fall under American export controls.

[9] The following two subsections are revised and updated versions of sub-sections from Fuller 2021.
[10] Only TSMC and Samsung offer such advanced nodes with both fabs offering 5 nm mass production. The most advanced Chinese foundry, SMIC, is several generations behind at 14 nm mass production. Moreover, only ten percent of SMIC's production is at 28 nm and below, and its most advanced node, 14nm, will only reach 15,000 wafers per month this year whereas TSMC already offers 120,000 wafers at 7nm and 50,000 at 5 nm (Abrams *et al*. 2021).

For EDA, Huawei has tried several mechanisms to develop alternatives, but none of them are likely to solve the problem of gaining legal access to quality EDA tools for the complete design flow any time soon. Huawei first explored partnering with the large Franco-Italian firm, ST Micro, in a bid to access ST Micro's EDA licenses under the guise of "joint development". Given that EDA licenses are clear that such sharing is illegal, this gambit was a non-starter. Huawei has since used its investment arm to invest in Chinese EDA start-ups, but the process of developing a full set of substitutes will take far too long assuming it could be successful at all.

The most promising option is not to develop alternatives at all, but instead find ways to access the American EDA tools Huawei currently uses. The downside to hacking beyond the heightened uncertainty surrounding the success of the hacking itself is that foundries may avoid servicing firms they suspect of engaging in such activity. Far better to set up a series of shell companies without clear direct links to Huawei to access EDA tools. A representative for a foreign EDA tool vendor stated that at least one Entity List company had set up a shell company with no apparent links to the Entity List–designated firm to serve as a legal front for EDA licenses (Correspondence July 13, 2020). Better still, such corporate maneuvering could be aided by foreign EDA vendors pursuing similar options (see below).

As for access to fabrication, Huawei front-loaded orders with TSMC before the Entity List came into full effect in September 2020 so it has stockpiled a substantial quantity of chips. Such stockpiles for certain chips may last up to eighteen months starting from September 2020 (Fuller 2020). De-Americanizing a fab with advanced nodes is not impossible, but even the most optimistic scenarios estimate such a project would take more than three years to get up and running. Critically, such optimistic scenarios are predicated upon a variety of corporations and governments outside of China being willing to undertake the great upfront expense to undertake this challenging task (Fuller 2020).

There were optimistic reports that state-owned Shanghai IC R&D Center would create a fab for Huawei and the plan was to be able to ramp up to 28 nm chips by the end of 2021 and 20 nm chips by the end of 2022. One analyst, Bernstein's Mark Li, claims that the critical chips for 5G telecommunications infrastructure equipment, typically made on 14 nm and below process lines, could be made at the 28 nm process node (FT 10.31.2020). Others have been much more skeptical. One analysis predicted that it would take until 2026 at the earliest to develop even a 90 nm fab using only Chinese equipment (Abram *et al*. 2021). Indeed, the reported Shanghai has not been built and at Huawei's last annual investor forum in the spring of 2022, the company denied it had any plans to build fabs with or without partners.

With older process nodes, lithography equipment from Japan and the Netherlands is readily available. The newer the node the more likely that the US will pressure Japan and the Netherlands not to sell to China. With the newest nodes (below 7 nm), the US government has successfully cajoled allies to adapt the Wassenaar Agreement to forbid the selling of EUV lithography equipment to China. Local lithography alternatives, such as SMEE, are at the lab rather than the fab stage. Similarly, the reports of the Chinese firm, SMIC, producing 7 nm chips with older deep ultra-violet (DUV) lithography equipment have yet to demonstrate that such chips were made without disastrously inefficient low yields (the number of good chips per wafer) as experts would generally expect from using DUV equipment for a task requiring higher-end EUV equipment. In other words, they are far from ready for mass production.[11]

Foreign Corporate Responses

Non-Chinese corporations, both American ones and other foreign firms affected by the export controls, regarded the progressively stricter export controls against Huawei with corresponding increasing alarm. From May 2020, it became much more likely that the Trump administration would take a very hard line. This hard line was confirmed with the finalizing of the controls in August 2020. Affected corporations began to consider quite radical contingency plans from May 2020 or even earlier in the case of EDA firms. The Biden administration has taken some incremental moves to tighten the export controls, but has as yet not pursued a radical broadening of the controls except for EDA tools (see below).

There have been a number of corporate moves and scenario planning that should be seen as ways to escape the burden of American export controls. At the same time, such corporate moves if fully implemented would have allowed China to radically decrease its technological dependence on the United States.

American EDA vendors were beginning to set up JVs in China in the wake of the export controls. For example, Synopsys set up a JV with a Chinese firm, AMEDAC, in September 2019 and there were persistent rumors of another Big Three setting up a JV in China. These JVs potentially could be used as the first in a string of intermediary companies to allow Entity List-designated firms to access EDA tools from American EDA tool providers

[11] See discussion of SMEE here: https://chinatechtales.wordpress.com/2020/10/19/sprouts-of-silicon-supply-chain-grandeur-chinas-chipmaking-equipment-industry/.

(Fuller 2020). The US government in April 2022 began to investigate Synopsys for possible violation of American export controls.[12]

On the fabrication side, with the prospect of enhanced equipment controls that would affect even major non-American foundries, such as TSMC, looming over the industry, the CEO of KLA, the third largest American capital equipment producer, on May 5, 2020 bluntly stated on an investor call that KLA would consider de-Americanizing its own equipment by moving more production offshore to Southeast Asia.[13] American industry insiders also informed me of business wargaming done by the American industry to determine how quickly it could build up a cutting edge fab without American equipment. The plan was to use primarily equipment produced entirely overseas by American capital equipment producers in addition to ASML lithography equipment. The projected timeframe for this de-Americanized fab would be four to six years (Fuller 2020). Such a fab, if ever built, would be able to fabricate for Huawei and direct suppliers to Huawei without the long arm of the US government being able to reach it.

To the extent that the prospects for radically widening controls affecting more and more of the global IC industry are receding, such evasion measures became increasingly unappealing. Furthermore, Huawei's collapsing chip orders up until now have been replaced by other companies that will require chips designed using American EDA tools and American capital equipment. If you're TSMC or a major American capital equipment manufacturer, re-building a whole separate supply chain to serve one declining customer fails any cost-benefit test. Thus, lead firms in this highly multipolar GVC still are not going to

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[12] https://www.tomshardware.com/news/synopsys-probed-for-allegedly-supplying-eda-tools-to-chinese-entities.

[13] "KLA Corporation (KLAC) CEO Rick Wallace on Q1 2020 Results - Earnings Call Transcript."

undermine the durability of these chokepoints until such time as their bottom lines are seriously threatened.

5. Conclusion

The basic model of weaponization of interdependence has a hub (high network centrality point), latent or realized control of the hub by the weaponizer and the institutions to enact the weaponization of the hub. This theoretical framework works well with information networks, such as the internet or SWIFT, but less well for the world of physical goods. First, hubs of network centrality do not really describe the chokepoints in real cases Farrell and Newman cite as examples of weaponization, including the Huawei case. Rather than network centrality, in the world of physical goods, the chokepoint is best conceived as a point at which the weaponizer has leverage over on input without which this task cannot continue. It is plausible that some of these chokepoints in the world of physical goods have network properties, such as Google's Android platform, which was also weaponized against Huawei, but the two main points of attack, capital equipment and EDA tools, did not.

Farrell and Newman (2021b) posit that network robustness relies on the existence of self-reinforcing mechanisms and relative imperviousness to strategies to undermine them. However, to their credit, they recognize that their theory is underdeveloped on these points. GVC analysis provides analytic leverage on precisely these points. On self-reinforcing mechanisms, chokepoints relying on platform effects or nodes with relational GVC characteristics will be self-reinforcing. Furthermore, platforms are hard to displace/replace so will be quite impervious to efforts to undermine them e.g., Huawei's mobile handset failures without Google Android in the global market (Osawa 2019). Similarly, relational nodes make would-be rivals without such relational access very unlikely to displace them. For example, the relationship between the main EDA vendors and major foundries presents a very high structural barrier to China substituting the American EDA vendors with Chinese ones.

The interaction of the GVC of semiconductor capital equipment and the semiconductor chip GVC sheds light on why Huawei was successfully cut-off from access to chip fabrication facilities. The interaction between foundries and capital equipment makers is somewhere between modular and relational in character and thus suggests that there might be some opening for outside equipment producers to displace American equipment. However, the semiconductor capital equipment GVC is somewhere between relational and hierarchical in character and this value chain characteristic presents high barriers for would-be competitors to displace it.

The number of powerful lead firms within a given GVC also provides insight into durability of chokepoints. The more lead firms (the greater the GVC multipolarity), the more likely breakers of chokepoints can find powerful and capable corporate allies willing to help them create a solution for a given checkpoint. The semiconductor GVC has a number of such lead firms from the largest capital equipment makers (e.g., ASML, Applied Materials and Tokyo Electron) to the largest foundries (e.g., TSMC and Samsung) and integrated chipmakers (e.g., Samsung and Intel). However, the sheer level of multipolarity is not a sufficient explanation. One must examine the incentives provided these lead firms.

There are strong economic reasons under the current American weaponization policy for lead firms to be uninterested in engaging Huawei and China to break these chokeholds. Although the weaponization of interdependence scholars emphasize that weaponization is in pursuit of security rather than pure economic gains, they ignore that economic considerations may loom large in determining robustness of these chokeholds.

Multiple state and non-state actors may play a role in creating alternatives that undermine the chokehold, but unlike the weaponizer, these other actors may be mainly calculating on the basis of economic gains and losses. Huawei alone could be displaced in the foundries by other firms. Indeed, TSMC has been in rude financial health and with constrained capacity even after it no longer produced chips for Huawei. Thus, there has been no strong motivation for foundries to try to de-Americanize fabrication lines nor to develop key relational partners in terms of EDA tool vendors. The economic benefit given the limited potential market would not be worth the economic cost and risk.

Similarly, the current and most potent latent rivals to displace American capital equipment producers have little interest to create de-Americanized lines because business is booming for Huawei-eschewing foundries. Also, the key linchpin of lithography equipment, ASML, is not interested in contesting these American export controls as its backlog for orders is immense. Without ASML, it is near impossible to build a functioning advanced fab.

Thus, market considerations convinced many important firms to not adopt moves to undermine the weaponization moves by the US. This factor is important because it suggests that the much broader sanctions aimed at a very large swathe of China's chip industry pushed by some in the Trump and Biden administrations probably would be much less durable. With much larger revenues under threat, not only Japanese and Dutch firms might reconsider compliance with American export controls. American firms might re-ignite their own efforts to escape American jurisdiction for their technologies as some of them openly discussed in the wake of the tightening of restrictions against Huawei.

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Table 1 GVC Linkages and Likelihood of Displacement of Incumbents

Linkage type	Complexity of transactions	Ability to codify transactions	Capabilities in the supply base	Possibility of displacement of incumbent
Market	Low	High	High	High
Modular	High	High	High	Medium-High
Relational	High	Low	High	Low
Captive	High	High	Low	High (supplier) Low (lead firm)
Hierarchy	High	Low	Low	Low

Figure 1 IC Value Chain

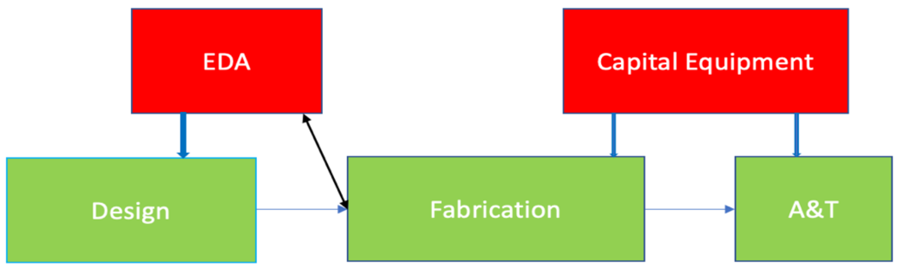
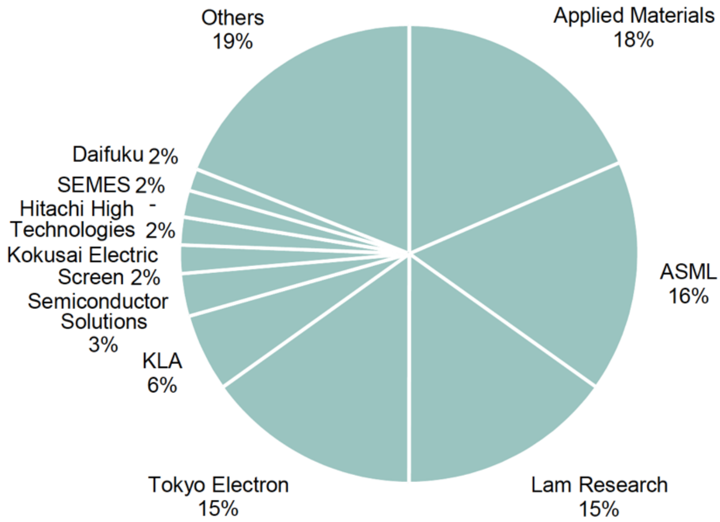


Figure 2 Top Global Wafer Fab Equipment Providers, 2018



Source: Ramel and O'Connor, "Entering the EUV Era."