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China's Counter-Strategy to American Export Controls in Integrated Circuits

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This article examines China's efforts to counter American sanctions against Huawei that in effect try to weaponize the silicon supply chain. While China has taken tentative steps to try to decouple from the American semiconductor industry, it faces three continuing challenges. First, the areas of technological dependence that the Huawei Entity List sanctions highlighted, fabrication capital equipment and electronic design automation (EDA) software, are areas in which China has very weak capabilities. Second, the wider the scope of the sanctions is, the more likely local and foreign firms will be willing to cooperate with Chinese efforts to create substitutes for controlled American technologies. But the scope of the sanctions appears to be in stasis and may even narrow during the Biden administration. Finally, the progressive expansion of China's silicon ambitions has elicited foreign industrial policies to counter China's own policies. This expanding market outside of China will lessen the effectiveness of Chinese policy and at the same time make a certain level of controls over IC technology palatable to American partners as Chinese customers are replaced by others.

Techno-nationalist concerns about technological independence have always been a motivating factor for the PRC government. However, outside of the defense industry, these concerns have frequently been due to two factors. First, the obvious wide gap between China's technological capabilities and international technological frontiers in many areas made eschewing foreign technology difficult or even impossible. Second, the global availability of many technologies for commercial use continually undermined the appeal of employing existing or developing new Chinese alternatives that would be inferior and more costly in the short term.

Several developments have served to dampen these restraints on techno-nationalist gambits. The growth and development of China's economy has narrowed or even erased the gap with international technological frontiers in many areas. Equally important, Xi's confidence in China's rise spurred ambitious foreign and industrial policies[1] that in turn eventually provoked a strong policy reaction in Washington. In the integrated circuit (IC)[2] industry, the ultimate American policy backlash against what American policy circles now widely perceive to be China's state-driven and state-controlled technological rise was the use of the Entity List against Huawei. This American attempt to drive Huawei out of the 5G

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[1] Many explicitly techno-nationalist industrial policies, such as the 2006 Medium-to-Long-Term Plan for Indigenous Innovation, and, to a lesser extent, more confident and even confrontational foreign policies emerged under the Hu-Wen leadership preceding Xi. However, it was not until the second Obama administration that Washington began to become disillusioned with relatively accommodationist policies toward China.

[2] This report will use the terms ICs, chips, and semiconductors when referring to ICs.

telecommunication equipment industry marked a turning point for China toward a much greater emphasis on building domestic alternatives across the IC supply chain. Prior to the Huawei export controls, the Chinese government made appropriate nods to building domestic capabilities across the supply chain, but its spending priorities focused on design and fabrication.

Renewed Chinese enthusiasm to displace reliance on foreign production in order to counter American sanctions offers no guarantee of success. There are three continuing constraints on China's silicon techno-nationalism. The areas of technological dependence that the Huawei Entity List sanctions highlighted – fabrication capital equipment and electronic design automation (EDA) software – are areas in which China has very weak capabilities. The scope of the sanctions matters as well. The wider the scope, the more likely local and foreign firms will be willing to cooperate with Chinese efforts to create substitutes for controlled American technologies. A second Trump administration might have embraced ever-expanding sanctions against a broader swathe of Chinese industry that in turn would have forced domestic firms and multinationals to scramble to collaborate in finding ways around this widening net. In contrast, the Biden administration's maximalist strategy appears to be something akin to the status quo and it is more likely to pursue some level of loosening of the current controls. In such a situation where a wide array of firms would not be negatively impacted in a significant way, cooperation with China's industrial policies to displace foreign production or even individual corporate maneuvers to evade these controls would plummet. Finally, the progressive expansion of China's silicon ambitions has elicited foreign industrial policies to counter China's own ambitions. With the Europeans and Americans joining the already activist Korean and Taiwanese states in promoting IC production at home, the leverage China has over foreign firms is somewhat diminished. This incentive structure will lessen the effectiveness of Chinese policy and, at the same time, make a certain level of controls over IC technology palatable to American partners since Chinese customers will be replaced by others.

This article will first explain the Huawei Entity List action and analyze its potential effectiveness in light of the global position of American, Chinese, and third country firms in the global industry. It will then consider Chinese government policy and Chinese and foreign firm strategies to cope with the sanctions. In the concluding section, we will explore how foreign industrial policy in ICs will temper the effectiveness of China's techno-nationalist counter-strategy.

The War on Huawei: Impact on the IC Industry

This article focuses on the US government's campaign to hobble Huawei because other Entity List moves by the US government have affected marginal participants in the industry,[3] such as the various firms placed on the Entity List for selling to Xinjiang government entities. The one exception is SMIC, China's largest IC foundry (a type of firm that manufactures but does not design chips), but the US government undertook that action in reaction to SMIC

[3] Huawei entities account for 144 of the 200-plus Chinese entities on the Entity List (Abrams *et al*. 2021), and alongside SMIC (11 SMIC-related entities included on the Entity List), Huawei, through its Hisilicon division, is the only major IC industry participant. Drone-maker DJI is also now on the Entity List, but it only began ramping up its chip design operations in recent years.

allegedly engaging with China's military industrial complex.[4] The American actions against Huawei were much broader and threatened to affect a wide swathe of US and foreign IC companies in addition to undermining Huawei's ability to design its own chips and ultimately its telecommunication infrastructure business.

In order to place the actions against Huawei in context, a brief explanation of the supply chain in ICs is in order. The semiconductor value chain can usefully be viewed as consisting of three large blocks of activities (excluding marketing and distribution) (Figure 1):[5]

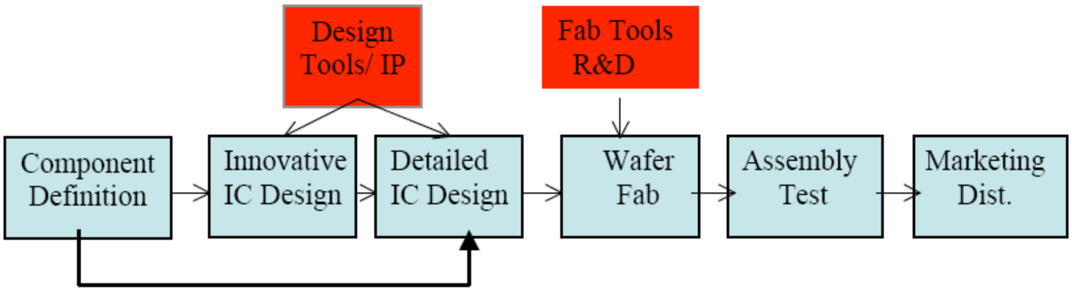
- **Design:** Execution of a design idea into code (typically a GDSII file) that serves as the blueprint for the integrated circuit (IC) in the fabrication stage.
- **Fabrication**: Guided by the design code, inscribing circuitry onto physical materials (typically with a type of silicon as the main material) using lithography and treating the physical materials with chemicals. The three main processes repeated in fifty or more iterations are deposition (of materials onto the wafer), lithography, and etching (removal of unwanted materials from the treated wafer). The result of this fabrication process is the bare, unpackaged, and thus unprotected, IC die. Generations of fabrication are measured by the lithography widths of the circuitry with smaller widths representing more advanced fabrication processes. The current most advanced process in mass production has lithography of 5 nm. One nm is approximately one ten thousandth the thickness of household plastic wrap.
- **Assembly and Testing (A&T):** The IC die undergoes (1) assembly of its packaging, which protects it and allows it to connect to other electronic components and devices, and (2) testing to determine whether it works properly, resulting in the final IC chip.

Each segment of the IC supply chain has key technological inputs. The critical input for design are EDA software tools to write the design code. The most critical input for fabrication and A&T are various pieces of capital equipment. The critical role of these inputs would loom large in the American strategy against Huawei.

Figure 1. IC Value Chain

[4] See https://www.federalregister.gov/documents/2020/12/22/2020-28031/addition-of-entities-to-the-entity-list-revision-of-entry-on-the-entity-list-and-removal-of-entities for the reasoning behind SMIC's placement on the Entity List. The US has also limited the controls on SMIC to relatively advanced process technologies, 10 nm and below technologies (Abrams, Tseng, and Pitzer 2021).

[5] The following explanation of the IC supply chain is drawn from Fuller (2020).



Source: Fuller, Akinwande, and Sodini 2013, p. 77.

1. *The Evolution of American Export Controls 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,[6] there were still rising concerns about Huawei's global presence and its emerging position as the leader of 5G telecommunications equipment. The fundamental motivating concern appears to be that the US military does not want to have to rely on "dirty networks" potentially compromised by the Chinese state while conducting overseas military operations (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. Even South Korea, a close American ally and located in close proximity to China, has decided to allow Huawei 5G infrastructure equipment into its market.[7] 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 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 its export controls in April 2018 after discovering ZTE had violated the 2017 agreement.[8] These export controls effectively cut off

[6] The final nail in the coffin for Huawei's access to the American market was the June 30, 2020 Federal Communications Commission's naming of 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).

[7] See the following article on continued American pressure to convince South Korea to change its mind:
http://english.chosun.com/site/data/html_dir/2020/12/07/2020120701614.html

[8] 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

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).[9] Given the hue and cry over ZTE's imminent demise in the spring of 2018, it 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 as ZTE had been.

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 trailed Huawei technologically and commercially for almost the entire first two decades of the 21st century (Fuller 2016, Ch. 3). Consequently, Huawei 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 (Strumpf2018; 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.

Those pushing the anti-Huawei policy were principally from the national security side of the government and were not lawyers well acquainted with the Bureau of Industry and Security (BIS) regulations (Interview, December 2019) so 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 any entity on the Entity List without a license from BIS. If the American hardware was produced offshore, then such hardware could be sold to the entity on the Entity List without the approval of the American government 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 overseas foundries, such as Taiwan Semiconductor Manufacturing Corporation (TSMC), allowing Huawei in turn to be able to legally purchase the Qualcomm chip.

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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-year exporting probation). Denial Orders issued by the Department of Commerce's Bureau of Industry and Security (BIS) prevent the companies or persons receiving the Denial Orders from any export privileges for items subject to the Export Administration Regulations. 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.

[9] 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).

The immediate implications for Huawei of its having been placed on the Entity List in May 2019 were thus primarily software-related. 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 to 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[10] 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.[11] 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.

2. *The Entity List Sanctions in the Context of the Global Industry*

The US government had cleverly chosen areas, EDA tools and capital equipment, where America had strong leverage and China had minimal capabilities. The EDA tool industry is effectively an American triopoly consisting of Cadence, Synopsys, and Mentor Graphics, which is now a division of Siemens[12]. The German ownership of Mentor Graphics does not allow it to claim that it does not fall under the jurisdiction of American export controls because the vast majority of Mentor Graphics' technology is of American origin. American semiconductor capital equipment is also in a strong global position as it accounted for 52 percent of the industry in 2018, and it was particularly strong in capital equipment for fabrication.

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[10] Huawei only has to be a purchaser, end-user, intermediate consignee, or ultimate consignee. In other words, Huawei only has to somehow be involved in the relevant product's supply chain.

[11] This point was confirmed by a legal expert on the Entity List via email on September 14, 2020. The preceding two sentences are from Fuller (2020), p. 8.

[12] Mentor Graphics officially changed its name to Siemens EDA in January 2021, but this report will use the former name as it is better known within the industry.

Modern EDA tools for chip design did not emerge until the 1990s. Since that time, the same three American firms have dominated the industry with 73 percent of the global market in 2018.[13] EDA tools have to do a variety of different tasks along the whole design process (typically referred to as the design flow),[14] and firms that can offer tools to cover the complete design flow are more competitive. At the same time, the pace of technological change is rapid in this sector. Thus, firms that have developed a suite of tools to cover the whole design flow are at a distinct advantage. They enjoy first mover advantages and have constructed significant barriers to entry by spending large amounts of revenue on R&D. The two largest firms, Cadence and Synopsys, each spend 30 percent or more of their respective revenue on R&D (Ader *et al.* 2019).

Two other aspects of the EDA industry serve to cement the leadership position of the Big Three tool vendors. Given the fast pace of technological change, venture capital has supported entrepreneurship in new tool creation. However, these start-ups typically can only afford to concentrate on one innovative tool rather than building a new suite of tools to cover the entire design flow. Taking advantage of the lack of competitive positioning of these starts-ups across the whole design flow, the Big Three have also stayed ahead by acquiring these innovative start-ups to keep their entire set of tools at the cutting edge (Henkel, Ronde, and Wagner 2015). The other aspect is the historical co-evolution of advanced foundry and the Big Three has served to enhance the position of the Big Three tool vendors. EDA vendors derive a lot of their expertise at the design–foundry interface[15] from their favored position as the firms working with the foundries early on for each new process node (a node in chip fabrication terms means a new process generation).

As of 2018, American firms monopolized production of four fabrication capital equipment areas: optical mask-making lithography (not IC lithography), bevel edge removal (dry), gate stack tools, and ultra-high-dose doping equipment. In other areas, such as etch, metrology, and inspection, American firms maintain a monopolistic position in certain high-end products (Fuller 2020). This position may appear to be nearly unassailable and thus another point of leverage that can be used against Chinese firms, but the American position is weaker than it first appears. Interviews with American capital equipment vendors attest to the fact that

[13] American EDA firms plus America-based Mentor Graphics accounted for approximately 73 percent of market revenue in 2018. This calculation is based on Boston Consulting Group's report of US EDA vendors being 60 percent of total revenue (Varas and Varadarajan 2020) added to Ader *et al*.'s calculation of Mentor representing 13 percent of total revenue (Ader *et al*. 2019).

[14] The design flow for digital design generally takes the following path. The path goes from a conception of how the chip will operate within a larger electronics system (architecture stage) through to the use of various design languages to define the circuitry moving from greater to lesser levels of abstraction (behavioral to register transfer level [RTL] to gate level design) in the process. These processes along with the architectural level are commonly referred to as front-end design. The back-end design consists of the processes of implementation of these abstract designs into a design for real physical components and connectors embedded in silicon (Fuller, Akinwande, and Sodini 2013).

[15] The design-foundry interface is the point at which EDA tool vendors and foundries work together to ensure that the software tools effectively transmit the information needed to fabricate the chip design correctly.

Japanese vendors are a competitive threat or a potential threat in virtually all areas of American dominance (Interviews, July 2019). Past history from the capital equipment sector suggests that firms can fall behind in certain products and then regain a competitive position, whether it is the American industry as a whole in the 1990s (Browning and Shelter 2000) or Applied Materials regaining competitiveness in conductor etch equipment during the last decade (Fuller 2020). Moreover, in the critical lithography equipment area, two Japanese firms, Canon and Nikon, and the Netherlands' ASML are the only firms of any competitive scale. ASML monopolizes the high-end extreme ultraviolet (EUV) lithography equipment needed to manufacture at the most advanced nodes below 7 nm.[16] Thus, the US would need substantial cooperation from its allies to wield export controls effectively.

Turning to China, Chinese industrial policy has in the past focused primarily on building up capabilities in chip design and fabrication (Fuller 2019). Today, these two areas plus the generally less technologically advanced A&T segment are the areas in which China has a most extensive industrial presence.[17] China's fabless design[18] sector accounts for 15 percent of the global sector (Abrams, Tseng, and Pitzer. 2021) and China's fabrication capacity is 12–13 percent of global fabrication capacity (Fuller 2020). However, in fabrication, much of the capacity remains in foreign hands (Abrams, Tseng, and Pitzer 2021; Fuller 2019). In both EDA tools and fabrication capital equipment, China lags far behind the global leaders.

Today, Chinese producers are generally not producing critical equipment for fabs. Across the categories of important wafer fabrication equipment, they never rate as major producers and competitors according to the global majors (Interviews, July 2019). Most of the Chinese equipment produced does not go into wafer fabs but rather into solar panel, IC A&T, and flat-panel display manufacturing. China's domestic producers accounted for only 5 to 10 percent of chip equipment expenditures in China in 2018.[19] Moreover, as chip manufacturers rely on the chip equipment manufacturers to provide quality equipment and decades of experience to help them improve their production, price competition is ineffective. Indeed, due to the proven track records of the established international chip equipment firms, some estimate that the quality of Chinese equipment would have to offer the promise of a 10 percent or greater yield advantage to induce customers to switch from the established firms (Abrams, Tseng, and Pitzer 2021). The largest Chinese producers thus have insignificant market shares compared to the global majors, as shown in Table 1 below.

Chinese EDA vendors also do not appear to pose any competitive threat. Huada Empyrean is the only local firm with a suite of tools that can cover the whole design flow for some analog chips. Huada also offers EDA tools for LCD driver chips[20] (Technode 11.13.2019; 科技日报 11.20.2017). The other Chinese EDA firms concentrate on narrow sets of tools as is typical

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[16] In lithography, the smaller the node, the more advanced the technology.

[17] China's 2019 production was US$109 billion, comprising 39 percent fabless, 28 percent foundry/IDM (fabrication), and 33 percent from A&T (Chang *et al.* 2020).

[18] Fabless design are those firms that design but do not fabricate their own chips. For example, Huawei and Qualcomm are fabless design firms, but Intel, which owns its own fabrication facilities, is not.

[19] Teng *et al.* 2020.

[20] These are the chips used in flat-panel/liquid-crystal displays.

of EDA start-ups worldwide.[21] Industry insiders whom I interviewed expressed skepticism that even Huada, which has its own baggage as an old state-run company, could compete with the Big Three, let alone the other, much smaller Chinese EDA firms.[22] Local tool vendors in 2019 collectively generated a paltry US$77 million in sales, which represented 10 percent of China's market (Ramani and Arcuri 2020).

Table 1 **2019 Market Shares for Major Domestic and Foreign Wafer Fabrication Equipment Vendors**

		Leading Global Suppliers						**Chinese Suppliers**		
Equipment Category	**2019 US$ (bln)**	**ASML (NL)**	**Applied Materials (USA)**	**Lam Research (USA)**	**KLA Tencor (USA)**	**Tokyo Electron (Japan)**	**Screen (Japan)**	**AMEC**	**NAURA**	**ACM**
Deposition	12.0		43.6%	19.1%		10.4%		1.1%	0.9%	0.1%
Lithography	11.7	83.3%	0.3%*							
Etch	10.8		18.1%	44.7%		28%		1.1%	0.8%	
Process Control	6.2	4.9%	11.3%		53.6%					
Material removal/clean	3.7		18.3%	34%		24.1%	9.7%	0.7%	0.8%	0.6%
Automation	2.9		4.7%							
Photoresist Processing	2.1					91.3%	5.6%			
Chemical Mechanical Polishing (CMP)	1.4		66.1%							
RTP	1.4		40.4%			20.3%	3.8%		1.7%	
Ion Implant	1.2		60%							
Total Market**	**55.5**	**18.1%**	**18.7%**	**13.9%**	**6.5%**	**13.6%**	**3.1%**	**0.5%**	**0.5%**	**0.2%**

Source: Credit Suisse.
*The amount listed for Applied Materials is probably for optical mask-making lithography, which is different from the lithography equipment used in the main lithography step of fabrication. Applied Materials had a monopoly on optical mask-making lithography as of 2018 (Fuller 2020).
**Some small categories are not in this table but are included in total market revenue and total market shares.

Corporate and Chinese Government Counter Strategies

How have the Chinese government, Huawei, and other firms in this global industry, responded to the disruption US policy has presented? While America's war on Huawei has clearly roused the Chinese government to greater action in fostering the development of domestic capital equipment and EDA tools, Trump's defeat in the American election has complicated these Chinese efforts and potential parallel strategies to de-Americanize the silicon supply chain by changing the interest calculus of many corporate actors.

[21] For example, the other firms often mentioned as promising EDA tool vendors have quite narrow foci: Avatar (physical implementation tools), Xpeedic (signal integrity, packaging, and RF solutions), and Pro-Plus (simulation and yield enhancement).

[22] These sentiments were echoed by Tsinghua's Professor Liu Leibo at a recent industry forum (财新 1.1.2020).

1. *China's Policy Response*

To understand the centrality of Huawei's Entity List designation to changes in China's IC industrial policy, one can look to what the larger trade spat between China and the US did not do. The US government actually imposed 25 percent tariffs on Chinese semiconductors on June 15, 2018. Despite the tariffs and the brief if grave threat that ZTE faced from the Entity List at the same time, China did not retaliate in kind (Bown 2020), nor did it begin a renewed push for decoupling in ICs at that time.

Only after Huawei was placed on the Entity List did the Chinese government provide more resources for capital equipment and EDA tools via the July 2019 second tranche of its Big Fund, the pool of money backing the 2014 IC Megaproject. For capital equipment, the plans are to spend far more than the paltry 4.2 percent of the first tranche of the Big Fund spent on capital equipment and semiconductor materials. Furthermore, the plan is to target these funds rather than to spread them over 14 different equipment and semiconductor materials firms, as was the case in the first tranche (Li and He 2020). In EDA, the Big Fund invested 20 times more in EDA tool vendor Giga-da than it had previously invested in the EDA tool vendor, Huada Empyrean, during the first tranche (Ramani and Arcuri 2020).[23] At the CCP's Central Economic and Financial Working Group meeting in April 2020, Xi Jinping called for secure supply chains, which was widely understood as a call to end dependency on foreign, particularly American, technology (Sutter and Sutherland 2021).

Following the toughening of the American stance against Huawei in May 2020, the Chinese government has become even more ambitious. Following two decades of promotional policies encompassed in State Circulars No. 18 (2001) and No. 4 (2011), in August 2020 the Chinese government released State Circular No. 8 (2020), promising new tax breaks for IC capital equipment producers that were not included in the No. 18 and No. 4 circulars, and calling on local governments to prioritize IC equipment, IC materials, and EDA tools alongside high-end chips.[24] For the 14th Five-Year Plan (FYP) (2021–2025), China has included US$1.4 trillion in spending on high-technology industries, including the semiconductor supply chain (Sutter and Sutherland 2021), with an emphasis on fostering de-Americanization of the supply chain, in a marked departure from the 13th FYP when the focus was on domestic production of chips rather than indigenizing the entire supply chain (Digitimes 1.8.2021).

2. *Huawei's Response*

[23] Beyond the Big Fund itself, additional and more substantial funds were available from other local state investment funds during the time of the first tranche of the Big Fund (2014–2018) (Fuller 2020). However, the larger share of the second tranche of Big Fund investment going to EDA and IC capital equipment will probably lead to commensurate greater investment by local state funds.

[24] State Council No. 8, downloaded on August 5, 2020, http://www.gov.cn/zhengce/content/2020-08/04/content_5532370.htm. Compare to the discussion of Circulars No. 18 and No. 4 in Fuller (2016). Note that Circular No. 8 was not publicly released until August 4, 2020, even though the document was dated July 27, 2020.

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[25] in the short term unless it managed to disguise the origin of its orders through shell companies. A longer-term alternative would be to use de-Americanized foundry production that would not fall under American export controls.

For EDA, Huawei has tried several mechanisms to develop alternatives, but none of them are likely to solve the problem any time soon of gaining legal access to quality EDA tools for the complete design flow. 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 even be successful.

The most promising option is not to develop alternatives at all, but instead to find ways to access the American EDA tools that 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 that they suspect of engaging in such activities. 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 of undertaking this challenging task (Fuller 2020).

[25] 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 10 percent of SMIC's production is at 28 nm and below, and its most advanced node, 14nm, will not reach 15,000 wafers per month until this year, whereas TSMC already offers 120,000 wafers at 7nm and 50,000 wafers at 5 nm (Abrams, Tseng, and Pitzer 2021).

With the support of the Chinese government, Huawei has now embarked on a bid to create a de-Americanized fab with Chinese equipment vendors. The fab will be run by the state-owned Shanghai IC R&D Center, and the plan is to be able to ramp up to 28 nm chips by the end of 2021 and to 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). This is a bold and optimistic claim. There could be significant quality trade-offs that make such equipment uncompetitive outside of Chinese government procurement channels. Furthermore, the plan is a bit vague regarding how much of the new fab will comprise foreign equipment. One recent analysis predicts that it would take until 2026 at the earliest to develop even a 90 nm fab using only Chinese equipment (Abram, Tseng, and Pitzer 2021).

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 EUV equipment, which is the only lithography that works at the newest sub-7-nm nodes, covered by the Wassenaar Arrangement, the US government has invoked the Wassenaar Arrangement to pressure allies to stop selling lithography equipment to China.[26] However, Wassenaar is not binding so there are no automatic compliance guarantees. Local lithography alternatives, such as SMEE, are at the lab rather than the fab stage. In other words, they are far from ready for mass production.[27]

3. *Foreign Corporate Responses*

Non-Chinese corporations, both American 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 beginning from May 2020, or even earlier in the case of EDA firms.

The election of Biden has changed the calculus of corporations. Another term for Trump might have featured widening controls affecting large swathes of the global IC industry. For instance, Republicans in Congress introduced a bill in September 2020 that proposed to cut off China from technology inputs for 45 nm and below.[28] In contrast, Biden's nominee for Secretary of Commerce, Gina Raimondo, has already got into trouble with Republicans in the Senate for criticizing the decision to place Huawei on the Entity List. While Raimondo has walked back her comments, her nomination and reported nominations of lower-level officials within Commerce are indicative of the Biden administration's reluctance to widen export controls to cover more of China's IC industry, and they even hint at a policy of

[26] ASML did in fact sell EUV lithography equipment to SMIC, but at the request of the Trump administration, delivery of that equipment has been put on hold by the Dutch government with neither approval nor refusal of permission to export forthcoming. This is a classic example whereby the US has taken a much stricter line on export controls to China than its allies under the nearly 25 years of the Wassenaar Arrangement.

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

[28] H.R. 8329 introduced to the House of Representatives on September 21, 2020.

loosening the Entity List controls by granting many licenses to sell to Huawei.[29] Sensing an opportunity, Huawei's Ren Zhengfei himself appealed to the US government to loosen its various restrictions against his company; in addition, Huawei went to court to ask that the FCC ruling declaring the company a security threat be overturned.[30]

Prior to the Biden administration coming to power, there were a number of corporate moves and scenario plans that should be understood 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 also 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 (Fuller 2020).

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.[31] American industry insiders also informed me of business war-gaming done by the American industry to determine how quickly it could build up a cutting-edge fab without American equipment. The plan was to primarily use 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.

With Trump gone and the prospect of widening controls affecting more and more of the global IC industry receding, such evasion measures become increasingly unappealing. To the extent that Huawei's business declines, it is likely to be replaced by other companies that will require chips designed using American EDA tools and fabricated using American capital equipment. If you are TSMC or a major American capital equipment manufacturer, re-building an entire separate supply chain to serve one declining customer fails any cost-benefit test.

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[29] See FT 2.6.2021 and https://chinatechtales.wordpress.com/2020/11/10/brief-note-on-a-biden-appointment-and-us-semiconductor-controls/. Another recent report suggests the lower-level nomination to be in charge of BIS will either be Kevin Wolf, amenable to looser export controls, or a China tech hawk, James Mulvenon (WSJ 2.12.2021). Even if Mulvenon were to get the post, ultimately the head of BIS serves at the behest of the Secretary of Commerce and the President so it is unclear how much leeway a China tech hawk would have to maintain a hard line on Huawei.

[30] https://www.sohu.com/a/450352839_465270.

[31] "KLA Corporation (KLAC) CEO Rick Wallace on Q1 2020 Results - Earnings Call Transcript." https://seekingalpha.com/article/4343405-kla-corporation-klac-ceo-rick-wallace-on-q1-2020-results-earnings-call-transcript?part=single

Conclusion: Foreign Responses to China's Silicon Ambitions

The declining importance of Huawei's business to foreign IC companies is reinforced by foreign governments' own industrial policies. These foreign government industrial policies also partially offset Chinese industrial policies that have made the Chinese marketplace increasingly important to foreign firms, a point of leverage Xi Jinping highlighted in his April 2020 speech.

ASML, the monopoly producer of EUV lithography equipment, would be very concerned about losing the Chinese market if foreign IC makers were sitting pat – except they are not. TSMC's capital expenditure for 2021 will range from US$ 25 to US$ 28 billion (Abrams, Tseng, and Pitzer 2021). Korean companies are planning to spend US$ 18.9 billion on IC fabrication capacity in 2021 (Business Korea 1.6.2021). However, not only are Taiwan and Korea still pouring tens of billions of dollars of investment into advanced fabrication each year, after decades of neglect, the US and the EU are beginning to move forward with more aggressive spending plans (Fuller 2020). The EU has proposed spending up to 35 billion Euros on advanced fabrication. With such aggressive spending outside of China, ASML and other companies will have their hands full fulfilling their non-Chinese orders.

With onerous export controls limited to one major company, the American industry will also likely not suffer much stigma in the eyes of foreign users of its products. If the US were to adopt wide controls covering a large swathe of Chinese industry, foreign firms as well as Chinese firms would work to find replacements for American technology. Now the most likely scenario is that to the extent Huawei declines, other firms filling its place in chip orders will be relatively unaffected by American export controls and, correspondingly, the risk of American-origin technology will dissipate.

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