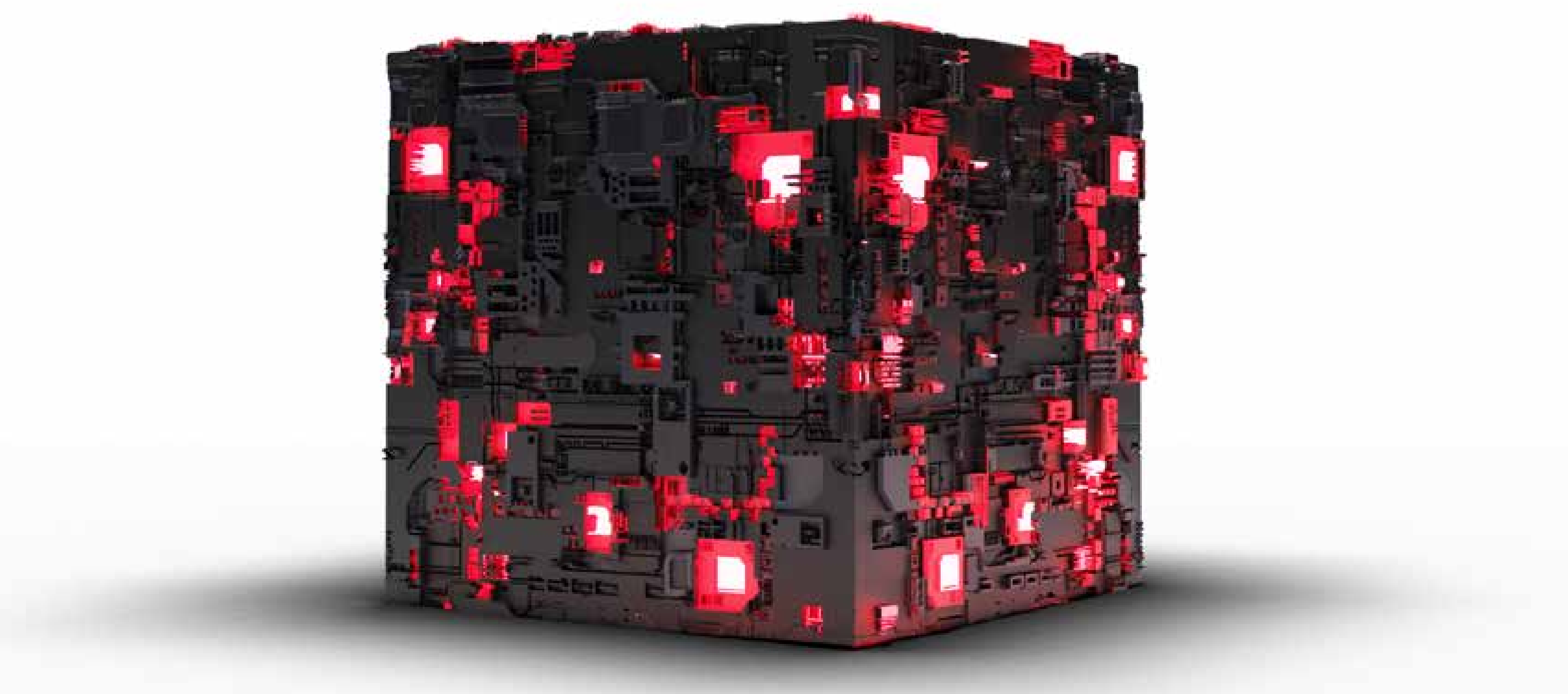
Centre for International
Governance Innovation

CIGI Papers No. 256 — August 2021

Supply Chain Regulation in the Service of Geopolitics

What's Happening in Semiconductors?

Dieter Ernst



Centre for International
Governance Innovation

CIGI Papers No. 256 — August 2021

Supply Chain Regulation in the Service of Geopolitics

What's Happening in Semiconductors?

Dieter Ernst

About CIGI

The Centre for International Governance Innovation (CIGI) is an independent, non-partisan think tank whose peer-reviewed research and trusted analysis influence policy makers to innovate. Our global network of multidisciplinary researchers and strategic partnerships provide policy solutions for the digital era with one goal: to improve people's lives everywhere. Headquartered in Waterloo, Canada, CIGI has received support from the Government of Canada, the Government of Ontario and founder Jim Balsillie.

À propos du CIGI

Le Centre pour l'innovation dans la gouvernance internationale (CIGI) est un groupe de réflexion indépendant et non partisan dont les recherches évaluées par des pairs et les analyses fiables incitent les décideurs à innover. Grâce à son réseau mondial de chercheurs pluridisciplinaires et de partenariats stratégiques, le CIGI offre des solutions politiques adaptées à l'ère numérique dans le seul but d'améliorer la vie des gens du monde entier. Le CIGI, dont le siège se trouve à Waterloo, au Canada, bénéficie du soutien du gouvernement du Canada, du gouvernement de l'Ontario et de son fondateur, Jim Balsillie.

Credits

Managing Director of Digital Economy Robert Fay
Program Manager Aya Al Kabarity
Senior Publications Editor Jennifer Goyder
Publications Editor Susan Bubak
Graphic Designer Sami Chouhdary

Printed in Canada on Forest Stewardship Council® certified paper containing 100% post-consumer fibre.

67 Erb Street West
Waterloo, ON, Canada N2L 6C2
www.cigionline.org

Table of Contents

About the Author

Senior Fellow Dieter Ernst joined CIGI in May 2016. At CIGI, Dieter's research explores unresolved challenges for the global governance of trade, intellectual property (IP) and innovation, addressing three issues in particular: finding out what adjustments are needed in the development and use of IP, especially patents and trade secrets, to cope with the requirements of increasingly complex and diverse global corporate networks of production and innovation; dealing with the effects of the proliferation of strategic patenting behaviour on the organization and governance of these global networks; and assessing US-China technology competition in information technology.

Based in Hawaii, Dieter is an adjunct senior fellow at the East-West Center. He has served as a member of the US National Academies' Committee on Global Approaches to Advanced Computing, as a senior adviser to the Organisation for Economic Co-operation and Development in Paris and as a research director of the Berkeley Roundtable on the International Economy at the University of California, Berkeley.

Previously, Dieter was a professor of international business at the Copenhagen Business School and served as a scientific adviser to governments, private companies and international institutions, including the World Bank, the UN Conference on Trade and Development and the UN Industrial Development Organization.

He holds a Ph.D. in economics from the University of Bremen.

Acronyms and Abbreviations

5G	fifth-generation
AI	artificial intelligence
BCG	Boston Consulting Group
BIS	Bureau of Industry and Security, US Department of Commerce
CCP	Chinese Communist Party
CESI	China Electronics Standardization Institute
CHIPS	Creating Helpful Incentives to Produce Semiconductors
CNAS	Center for a New American Security
CRS	Congressional Research Service
CSET	Center for Security and Emerging Technology
CTA	Communications Technology Association
DoD	Department of Defense
EDA	electronic design automation
GAO	Government Accountability Office
ICT	information and communications technology
ICTS	information and communications technology and services
IP	intellectual property
IPR	intellectual property rights
IT	information technology
MIIT	Ministry of Industry and Information Technology
MOFCOM	Ministry of Commerce
NICSTC	National Integrated Circuit Standardization Technical Committee
nm	nanometre
NPC	National People's Congress
NSC	National Security Council
NSCAI	National Security Commission on Artificial Intelligence
NSF	National Science Foundation
R&D	research and development
SAMR	State Administration for Market Regulation
SIA	Semiconductor Industry Association
SIAC	Semiconductors in America Coalition
SiP	system-in-package
SME	semiconductor manufacturing equipment
SMIC	Semiconductor Manufacturing International Corporation
TSMC	Taiwan Semiconductor Manufacturing Co.
USTR	United States Trade Representative
WTO	World Trade Organization

Executive Summary

Supply chain regulation can be a formidable tool to protect a country's resilience against unexpected disruptions of trade, investment and the supply of skilled labour. Its utility, however, may erode when geopolitics rather than economics becomes the primary objective.

This paper examines the implementation problems and the unintended consequences of a new supply chain doctrine in the service of geopolitics. The analysis is focused on US President Joe Biden's Executive Order on America's Supply Chains to protect US technological leadership and national security against China. With semiconductors as a primary target, America's supply chain controls are designed to exploit China's most glaring weaknesses as supply chain chokepoints that the US Commerce Department can block, thus impeding timely and cost-effective access to essential products, services and technologies. The paper also highlights a second defining characteristic of America's supply chain doctrine — regulatory supply chain controls are combined with a big push in domestic semiconductor manufacturing.

The paper presents three propositions as guideposts for further research. First, "asymmetric interdependence" defines US-China semiconductor supply chain linkages. The United States is well ahead across all research and development (R&D)-intensive stages. Despite all its efforts, China continues to lag behind. Both countries differ in how they perceive policy implications. For China, US dominance provides a powerful signal that both the government and industry now need to strengthen the country's innovation capabilities in semiconductors.

In the United States, the defence and security community argues that China threatens US leadership in semiconductors, undermining military superiority. On the other side are US semiconductor and information technology firms that need continuous access to the huge China market. An important finding is that the complexity of US government policy making constrains America's response to China's semiconductor industrial policy. Simply copying China's reliance on subsidies will not pass the checks and balances imposed by US Congress.

Second, US efforts to block supply chain chokepoints face substantial implementation problems, both internationally and at home. An important finding is that with rising supply chain complexity, it becomes more difficult and costly to implement effective regulatory supply chain controls against China. Domestically, the US government will need to create new processes to improve the transparency of regulatory processes, strengthen interagency coordination and address legal enforcement loopholes, recruitment problems and budgetary requirements. In addition, as semiconductor supply chains are strained by multiple bottlenecks, giving rise to severe chip shortages, this is arguably the worst time to experiment with discriminatory supply chain controls against a geopolitical rival.

Third, America's supply chain controls against China are imposing substantial collateral damage on industry, public research labs and universities in the United States and in partner countries. This has eroded trust across multiple layers of the semiconductor supply chain. Without trust, knowledge sharing and innovation will suffocate. Hence, US discriminatory supply chain controls may well erode the global semiconductor innovation system.

The paper concludes with a brief discussion of the implications for future US supply chain control against China: Will the quest for improved supply chain resilience succeed in mobilizing enough forces to shift the focus of US policy away from supply chain regulation in the service of geopolitics?

Introduction

This paper addresses supply chain regulation, and its interactions with technology competition and innovation. Specifically, it will focus on a new supply chain doctrine: regulatory supply chain controls are used as weapons for technology competition against companies or countries that are perceived to be geopolitical rivals.

The US government is at the forefront of this massive expansion of supply chain regulation in the service of geopolitics. On February 24, 2021, President Biden signed the Executive Order on

America's Supply Chains[1] to review and assess the strengths and weaknesses of supply chains, in order to protect US technological leadership and national security. The National Security Council and the National Economic Council were tasked to coordinate a 100-day supply chain survey. Drawing on this review, the White House published a 250-page report to guide US supply chain regulation on June 8, 2021.[2] Almost one-third of the report assesses threats to semiconductor supply chains, culminating in a detailed list of policy recommendations.[3]

America's supply chain regulation is directed primarily against China, with semiconductors as the main target. An important objective is to obstruct China's capacity to import advanced semiconductor technology that is needed to address the country's most glaring weaknesses, in particular in leading-edge semiconductor manufacturing equipment (SME) and electronic design automation (EDA) tools for high-end processors. These Chinese weaknesses are supply chain chokepoints that the US Commerce Department seeks to block, denying China timely and cost-effective access to essential products, services and technologies. Both the Pentagon and the National Security Council (NSC) play a central role in shaping US semiconductor supply chain control against China.[4]

A fundamental assumption is that regulatory supply chain controls can only succeed if they are combined with a big push in domestic semiconductor manufacturing. Supply chain regulation is complemented by the Creating Helpful Incentives to Produce Semiconductors (CHIPS) for America Act, the Endless Frontier Act and other related legislation.[5] Together, these policies signal a return "toward the kind of economic nationalism that has, over the decades, found support across the ideological spectrum" (Scheiber 2021). A new digital grand strategy is gaining momentum:[6] "The first priority should be advancing U.S. interests by spreading the U.S. digital innovation policy system and constraining digital adversaries, especially China. This will entail working with allies when possible — and pressuring them when necessary....The overarching goal of U.S. strategy should be to limit China's global dominance and manipulation of markets in the IT and digital space" (Atkinson 2021a).

A broad consensus exists in the US Congress, and among the country's defence and business elites, that this unified "whole of government" semiconductor strategy against China will sustain US leadership in semiconductor innovation and technological competitiveness. These claims need to be taken with a grain of salt.

This paper argues that supply chain regulation in semiconductors faces a challenge of as yet unknown proportions — the deepening entanglement of geopolitics with trade and innovation policy. The damage caused by rising protectionism and the US-China technology war is huge and rising.[7] It is difficult to see how the United States can elegantly square the semiconductor industry requirements with any geopolitical desires for supply chain separation. This is an industry in turmoil, as it struggles with a severe global chip shortage, while at the same time trying to cope with massive disruptions in the global economy imposed by the coronavirus disease 2019 pandemic, by major changes in technology and by the US-China technology war.

Regulatory supply chain controls against China will further increase uncertainty and risk. This raises a question: How will rising unpredictability affect competition and innovation? The paper presents three propositions that could serve as guideposts for further research.

The first part of the paper addresses the impact of "asymmetric interdependence" on the security and stability of supply chain linkages between the US and Chinese semiconductor industries. Trade

1 *America's Supply Chains*, 86 Fed Reg 11849 (2021).

2 See The White House (2021a).

3 For the details of the White House 100-day supply chain review report, *Building Resilient Supply Chains, Revitalizing American Manufacturing, and Fostering Broad-Based Growth*, see the section "The White House Supply Chain Review Report" in the first part of the paper.

4 On the NSC's role, see Allen-Ebrahimian (2021). On the Department of Defense's (DoD's) China Task Force, see Garamone (2021). See also DoD (2020).

5 On the CHIPS for America Act, see Moore (2021). On the Endless Frontier Act, see www.congress.gov/bill/116th-congress/senate-bill/3832. For details, see the section "The Endless Frontier Act: A Difficult Birth" below. In the US Senate, legislation has been proposed to establish within the Commerce Department a well-funded "Office of Supply Chain Preparedness" to oversee new efforts to bolster US manufacturing (Inside U.S. Trade's World Trade Online 2021a).

6 As described in Atkinson (2021a).

7 By 2025, geopolitics is projected to lead to a loss of $4 trillion in trade value for Group of Twenty countries (Boston Consulting Group [BCG] 2021). All dollar figures are in US dollars.

theory and geopolitical analysis both provide a framework for analyzing unequal distribution of assets and capabilities. There is ample evidence that the United States continues to hold a substantial overall lead across all R&D-intensive stages of the semiconductor supply chain. China continues to lag far behind. The idea that the United States could lose its edge in advanced semiconductors is simply not supported by evidence.

It is important, however, to emphasize that the United States and China differ in how they perceive policy implications from asymmetric supply chain interdependence in semiconductors. Resolving these conflicting perceptions will not be easy.

The second part examines implementation problems that US efforts to block supply chain chokepoints are facing, both internationally and at home. US supply chain regulations are no doubt hurting China's semiconductor industry. However, the above implementation constraints are raising doubts about the effectiveness of US supply chain regulation against China.

Finally, the third part highlights collateral damage that America's supply chain regulation is imposing on industry, public research labs and universities in the United States and in partner countries. This has eroded trust across multiple layers of the semiconductor supply chain. Without trust, knowledge sharing and innovation will suffocate; therefore, discriminatory supply chain controls may well erode the global semiconductor innovation system.

Conflicting Perceptions of Asymmetric Supply Chain Interdependence

Semiconductor supply chain linkages are viewed very differently in the United States and China, resulting in different approaches to supply chain regulation. The concept of asymmetric interdependence can help to cut through the maze of conflicting perceptions.

This section first looks at what trade theory and geopolitical analysis have to say about asymmetric interdependence and the resulting unequal distribution of assets and capabilities. Next, it looks at empirical research that shows the United States dominates global semiconductor supply chains in the most R&D-intensive activities, while China lags far behind. The conflicting perceptions that persist in both countries about the policy implications of asymmetric supply chain interdependence in semiconductors are then highlighted.

What Theory Has to Say

Let us first look at trade theory. As Peter A. Petri has emphasized in his 1984 study on Japanese-American trade, understanding the structure of interdependence is crucial for understanding the policy conflicts that shape trade competition between trading partners (Petri 1984, 3). As a result of differences in the structures of the two economies, their interdependence is sharply asymmetric, with economic events in the United States having a greater impact on Japan than vice versa. Petri argues that the roots of bilateral conflict can be traced to asymmetric interdependence, which may have increased the incentives for protectionism. In short, unequal distribution of assets and capabilities gives rise to unequal distribution of gains from trade.

Equally important is the dimension of geopolitics. Albert O. Hirschman, in his path-breaking 1945 study *National Power and the Structure of Foreign Trade*, finds that relationships of dependence, of influence and even of domination can arise out of trade relations (Hirschman 1945). Unequal distribution of economic and military power enables the stronger country to create conditions that make the interruption of trade of much graver concern to its weaker trading partners than to itself. Recent research has argued that asymmetric interdependence can be exploited in order to deny an adversary access to technology for strategic purposes (Farrell and Newman 2019). This would allow "states with (1) effective jurisdiction over the central economic nodes and (2) appropriate domestic institutions and norms to weaponize these structural advantages for coercive ends" (ibid.).

Both the trade and geopolitical impacts of asymmetric interdependence indicate that policies to enhance supply chain security and stability may face serious challenges.

Empirical Research

There is ample evidence that supply chain linkages between the US and Chinese semiconductor industries are characterized by asymmetric interdependence. The United States dominates the global semiconductor supply chain in the most R&D-intensive activities, while China lags far behind.

According to the Center for Security and Emerging Technology (CSET), "the U.S. semiconductor industry contributes 39 percent of the total value of the global semiconductor supply chain. U.S.-allied nations and regions — Japan, Europe (especially the Netherlands, the United Kingdom, France, and Germany), Taiwan and South Korea — collectively contribute another 53 percent" (Khan, Mann and Peterson 2021, 3). Together, the United States and its allies account for roughly 92 percent of the total value of the global semiconductor supply chain. By contrast, China is contributing only six percent of the total value of the global semiconductor supply chain (ibid.).

US firms collectively account for more than a 90 percent share in advanced logic semiconductor products that power mobile communications, PCs, data centre servers, artificial intelligence (AI) analytics and automotive advanced driver assistance systems. Despite massive efforts, China remains a marginal player (Semiconductor Industry Association [SIA] 2020, 7 ff).

The United States holds a commanding lead in semiconductor research — $39.8 billion in 2019, almost 60 percent of global semiconductor R&D spending. By comparison, Chinese semiconductor firms spent only $2.6 billion in semiconductor R&D in 2018 (less than four percent) (Khan, Mann and Peterson 2021, 33 ff.).

The United States, Japan and the Netherlands (which hosts ASML, the world leader in leading-edge extreme ultraviolet lithography technology[8]) together dominate the production of SME, the most severe chokepoint in China's chip supply chains. These countries also enjoy an overwhelming dominance in intellectual property (IP) and world-class teams of engineers, making it exceptionally difficult for newcomers to the SME industry to catch up to the leading edge. "Whether China will manage to reduce this gap, will depend on its access to a range of complex components, which SME firms often buy from third party suppliers and then assemble into finished SME. Just as chipmakers cannot make chips without access to SME, firms cannot make SME without access to these specialized components" (Hunt, Khan and Peterson 2021, 42).

Three US-based firms — one of which now has a European parent company — have a combined 85 percent share in the EDA software tools essential to design semiconductors. US firms also dominate specialized EDA tools needed for AI chip design, such as application-specific integrated circuit layouts (The White House 2021a, 32). EDA tools are used by the US government as chokepoints to block China's progress in chip design. China's EDA industry is small. In late 2019, only 300 engineers were working in Chinese EDA firms. This compares with 1,500 EDA engineers in China-based foreign multinationals, and with Synopsys's EDA engineering workforce of more than 5,000.[9]

China heavily depends on foreign experienced semiconductor engineers, especially from Taiwan, Province of China. Mark Li, a Hong Kong-based analyst at the investment bank Bernstein, estimates that "'easily hundreds, maybe thousands, and if you include semiconductor design, maybe even tens of thousands'" of Taiwanese staff now work in China's chip industry" (Li, quoted in Hille and Yang 2021). "China needs that expertise to help it run fabrication plants and develop more advanced process technology, which Taiwan has perfected" (Hille and Yang 2021).

In July 2021, SIA had this to say about China's semiconductor capabilities: "Despite China's whole-of-government push for semiconductor localization, the Chinese semiconductor industry is likely to...lag in leading-edge logic foundry process technology (just like the United States, China relies on Taiwan and South Korea for the production of 100% of advanced below 10nm chips), general purpose high-end logic (i.e., CPU/GPU/FPGA), advanced manufacturing equipment and materials (i.e., photoresist, photolithography etc.), in addition to EDA software and IP relevant for cutting-edge logic chips" (SIA 2021b).

8 See www.asml.com/en/products/euv-lithography-systems.

9 See Randall (2019). However, China seeks to recruit top EDA tool engineers. Chinese EDA firms typically are founded or are run by former employees of US EDA firms.

In short, the United States continues to hold a substantial overall lead across all R&D-intensive stages of the semiconductor supply chain. Despite all its efforts, China has not significantly reduced the technology gap in semiconductors between itself and the United States. The idea that the United States could lose its edge in advanced semiconductors is not supported by empirical evidence.

China's Perception

From China's perspective, asymmetric interdependence constrains China's ability to catch up, as it allows the US government to impose stifling technology restrictions against China. America's technology export restrictions have seriously damaged Chinese semiconductor companies, such as Huawei's HiSilicon affiliate and the Semiconductor Manufacturing International Corporation (SMIC), the country's leading foundry.[10]

The extensive reach of US technology control is codified in the interim final rule Securing the Information and Communications Technology and Services Supply Chain.[11] Under this rule, the Department of Commerce has broad discretion to investigate, modify, block or unwind covered transactions involving certain identified foreign adversaries on national security grounds.

The six product categories delineated in the interim rule cover major building blocks of the information and communications technology (ICT) industry. They include:

> Those designated as critical infrastructure; software, hardware or any other product or service integral to connecting to the internet; software, hardware or any other product or service integral to data hosting or computing services; internet-enabled end-point surveillance or monitoring devices, home networking devices, or unmanned aerial systems with more than 1 million units sold to U.S. persons in the last year; software designed to connect or communicate with the internet that has been in use by more than 1 million U.S. persons in the prior year; and products integral to artificial intelligence, quantum key distribution, quantum computing, drones, autonomous systems or advanced robotics. (Inside U.S. Trade's World Trade Online 2021b)

In response to US technology restrictions, Chinese President Xi Jinping, in a speech to the Chinese Communist Party's (CCP's) Central Economic and Financial Working Group in April 2020, called for building "independent, controllable, secure, and reliable supply chains to ensure industrial and national security with access to at least one alternative source for important products" (Xi, quoted in Congressional Research Service [CRS] 2021). China should "use existing global dependencies on China as a counterweight to pressures to shift manufacturing out of China" and "use the pull of China's market to attract global resources and deepen global dependence on China" (ibid.). China thus needs to find ways to reduce asymmetric interdependence by strengthening its position in semiconductor manufacturing equipment, electronic design automation and, most importantly, in semiconductor research.

A review of China's 14th Five-Year Plan suggests that "Chinese leaders plan to expand the state's role in the economy and advance national economic security interests; use market restrictions and its *One Belt, One Road* global networks to foster Chinese-controlled supply chains; and sharpen the use of antitrust, intellectual property (IP), and standards tools to advance industrial policies" (ibid.). Specifically, China's leadership seeks to expand inward foreign investment, while simultaneously pushing for self-reliance.

China Moves to Attract Foreign Investment to Bolster High-Tech Sectors

China's Ministry of Industry and Information Technology (MIIT) argues that China's semiconductor market must remain open to foreign investors. When asked what the government will do about China's semiconductor chip shortage, an MIIT spokesperson told reporters that the department will "promote the free flow of factor resources, create a fair and just market environment, support domestic and foreign companies to increase investment, and continue to

10 On Huawei, see Chen (2021) and Sherman (2021). On the SMIC, see Ting-Fang and Li (2021b).

11 *Securing the Information and Communications Technology and Services Supply Chain,* 86 Fed Reg 4909 (2021) (to be codified at 15 CFR § 7) [*Securing*]. See WilmerHale (2021).

improve the supply capacity of integrated circuits" (Inside U.S. Trade's World Trade Online 2021c).

China's Ministry of Commerce (MOFCOM) seeks to attract foreign investment in high-tech sectors (Inside U.S. Trade's World Trade Online 2021d). MOFCOM's "Five-Year Plan for the Utilization of Foreign Capital" lays out incentives to attract foreign investment, technology and talent in high-tech sectors as a means to strengthen its supply chains, including tax concessions and the expansion of free-trade zones but notes that all investments must fit China's national strategy. Investment promotion activities are to be increased in Japan, South Korea, Singapore, the United Kingdom, the Netherlands and Denmark, MOFCOM specified (quoted in Inside U.S. Trade's World Trade Online 2021d).

Specifically, China is searching for new ways to obtain foreign technology through trade and investment flows that are not yet restricted by the US government. This includes "partnerships in open technology and basic research, the establishment of research and development (R&D) centers overseas, and talent programs for foreign experts to work in China" (CRS 2021). MOFCOM expects that these ties may allow China to develop capabilities in priority areas, such as semiconductor design (ibid.).

Strengthen Self-Reliance

At the same time, other Chinese officials have outlined plans to promote investment in semiconductor research and production. For instance, Jiang Jinquan, the director of the CCP's Central Policy Research Office, argues that China's technology sector is too vulnerable to disruptions that can result from policy decisions made by other countries — "as a result, China has to rely on imports to meet over 80 per cent of domestic demand for semiconductor products" (quoted in Pan 2021). Jiang said the United States was "imposing a technology blockade" on China, forcing it into "an inevitable choice to seek a self-dependent and self-empowerment strategy in the technology sector" (ibid.). To achieve breakthroughs in key science and technology projects, China must pool its resources to overcome chokepoints in core technologies, Jiang said. Breakthroughs in science and technology will allow China to avoid "being strangled by others at the neck," Jiang wrote, borrowing a phrase used by Chinese President Xi (ibid.).

China's New Approach to Standardization and Competition Policy

Standards development, as well as intellectual property rights (IPR) and antitrust enforcement are now gaining in importance in China's new push in industrial policy for semiconductors. "In 2018, China consolidated market competition, IP, and standards authorities in a powerful new regulator — the State Administration for Market Regulation (SAMR) — that is poised to play a key role in implementing the 14th FYP. Since then, China's Academy of Engineering and SAMR have been developing *China Standards 2035*, a plan to set standards...on new technologies where China is likely to have greater influence in the absence of existing rules" (CRS 2021).

On January 28, 2021, the MIIT announced its intent to launch the National Integrated Circuit Standardization Technical Committee (NICSTC) (Inside U.S. Trade's World Trade Online 2021e). Its secretariat will be housed in the MIIT's China Electronics Standardization Institute (CESI). A preliminary list of members includes leading Chinese technology companies and research institutions, such as SMIC, ZTE, Alibaba, Huawei, Tencent, China Mobile, China Unicom, the National Defense University, Tsinghua University and the MIIT's Fifth Institute of Electronics.

This MIIT standardization initiative is still at an early stage.[12] Its immediate purpose is to bring order

12 According to interviews in April 2021with industry experts, the focus of the NICSTC appears to be on the following standards:

- Improve the relevant standards for the assessment of integrated circuit products, including conducting research on the assessment requirements.
- Standardize the development of emerging packaging technologies, such as high-density flip chip-ball grid array (FC-BGA) packaging, wafer-level 3D rewiring packaging, through silicon via (TSV) packaging, system-in-package (SiP) radio frequency packaging and ultra-thin chip 3D stacked packaging technologies. And solidify the results into the assessment procedures and requirements for flip-chip bonding, chip-scale packaging (CSP), wafer-level packaging (WLP) and SiP.
- Conduct research and standard formulation in response to the performance, reliability and information security requirements of integrated circuits in emerging applications, such as the mobile internet, cloud computing, Internet of Things, big data and so on.
- Prepare detailed specifications for integrated circuit products and ensure that product parameter indicators can fully meet the performance requirements, reliability requirements and information security of integrated circuits in the above application fields.
- Improve the standard system of testing methods, as well as mechanical and environmental testing methods to ensure that they — and the testing of various parameter indicators — have standards to be followed.

to the chaotic expansion of China's semiconductor industry caused by the rampant growth of investment. In addition, an important motivation is to win more influence over international standards by strengthening domestic capacity. In addition, specialized AI chips, which are quoted in the CESI application, are developed today without common standards. This is anathema to the controlled top-down approach favoured by Beijing. It will take time to define and implement a focused Chinese strategy for semiconductor standardization. A major drawback, of course, is that US and most European companies are unlikely to offer their input to the Chinese committee, as the United States has sanctioned many of the expected Chinese participants.

It is somewhat ironic that US regulatory supply chain controls may push China to strengthen its innovation capabilities and technological competitiveness. It was only after US export controls revealed China's potentially devastating dependence on imports of US chips and semiconductor equipment that Chinese technology firms began aligning with their government's desire for chip self-sufficiency (Wang 2021). Reacting to US technology restrictions provides greater focus to China's technology investment and development. China's leaders are taking cues from American technology restrictions to guide the country's technology indigenization strategy (Tang 2020). Chinese leaders, for example, point to US policies toward Huawei as the impetus for doubling down on the country's technology indigenization goals (Ting-Fang and Li 2020).

Under pressure from US export restrictions, the powerful State-owned Assets Supervision and Administration Commission of the State Council is now searching for ways to strengthen China's innovation system in semiconductors and advanced computing. US technology export restrictions may thus accelerate an overdue reform of China's innovation policy. It remains to be seen, however, whether these efforts will be sufficient to reduce the huge technology gap that continues to separate China's semiconductor industry from the still-dominant US semiconductor industry. US fears that China could overtake the United States any time soon in semiconductors are clearly overblown.[13] As the author's CIGI colleague Alex He has demonstrated, the top-down approach to policy making in China may well stifle China's ambitions to become a technology leader in advanced semiconductors (He 2021).

Conflicting Perceptions in the United States

In the United States, policy debates about asymmetric semiconductor supply chain interdependence with China are divided into two camps. On the one side are those who argue that China threatens US leadership in semiconductors, and that this threat will materialize sooner rather than later. On the other side are proponents of a more pragmatic approach, emphasizing that the main concern is the unequal geographic distribution of semiconductor manufacturing, which could easily disrupt the supply of critical chips.

The first position is driven by stakeholders in the defence and security community around the Department of Defense, the intelligence agencies and the Department of Homeland Security. It also draws persistent support from large global US information technology players that are suppliers to these agencies. The overriding concern is security, which is broadly defined in terms of America's geopolitical grand strategy.[14] This requires expanding the exterritorial reach of US law — a long-established US policy of pursuing certain foreign policy goals through export restrictions and of related sanctions (Editors 1984). The second position represents stakeholders in the US semiconductor and information technology industries that depend on continuous access to the huge China market.

Playing the Fear Card: China Threatens US Leadership in Semiconductors

In its 2021 Interim National Security Strategic Guidance, the White House emphasizes the increasing technological and geopolitical threat from China:

> [China] is the only competitor potentially capable of combining its economic, diplomatic, military, and technological power to mount a sustained challenge to a stable and open international system.

13 See Ernst (2020).

14 As laid out in O'Hanlon (2021). See also Art (2009).

> We will ensure that America, not China, sets the international agenda, working alongside others to shape new global norms and agreements that advance our interests and reflect our values.
>
> When the Chinese government's behavior directly threatens our interests and values, we will answer Beijing's challenge. We will confront unfair and illegal trade practices, cyber theft, and coercive economic practices that hurt American workers, undercut our advanced and emerging technologies, and seek to erode our strategic advantage and national competitiveness. *We will ensure that our supply chains for critical national security technologies and medical supplies are secure*. (The White House 2021b, 8, 20; emphasis added)

In its extreme form, this position gives rise to a "China regime change" doctrine. A typical example is Senator Tom Cotton (R), who refers to US businesses that profit from economic integration with Beijing as "the China lobby" and openly questions their political allegiance (quoted in Inside U.S. Trade's World Trade Online 2021f). Such language may tempt the reader to recall the "political vindictiveness" during the McCarthy period (as described in Kennan [2020, 115])[15] — creating such reminiscences may not be unintended.

America's new industrial policy doctrine is focused primarily on strengthening the US defence innovation system (Atkinson 2021b).[16] According to Robert D. Atkinson, "the new innovation system needs to be focused on making U.S. advanced technology leadership — in both innovation and production — the central organizing principle of U.S. economic and national security policy while embracing an all-of-government approach to achieve that. Unparalleled U.S. leadership in advanced technology innovation and production — commercial and defense — is the best insurance against Chinese aggression....The key question [is]: does the Chinese system enable it to progress in ways that hurt U.S. national security and global techno-economic leadership?" (ibid., 59, 61).

To cope with the threat from China, incrementalism is no longer acceptable:

> It is time to think big, establishing a new system grounded in two principles. First, policymakers can no longer be indifferent to U.S. industrial structure. They need to articulate that there is a set of industries "too critical to fail" — such as aerospace, biopharmaceuticals, sophisticated computers and semiconductors, advanced machinery and equipment, software, and artificial intelligence. Second, while business must lead, government has to play a strong supporting role.
>
> The most important step to get to a new innovation system is for elites and policymakers to agree to this new national mission and then ensure an all-of-government approach to implementing it. (ibid., 69)

Along similar lines, the National Security Commission on Artificial Intelligence (NSCAI) argues that "bold action" is needed to re-establish America's supply chain resilience in semiconductors: "We do not want to overstate the precariousness of our position, but given that the vast majority of cutting-edge chips are produced at a single plant separated by just 110 miles of water from our principal strategic competitor, we must reevaluate the meaning of supply chain resilience and security," the report states, in a clear reference to Taiwan Semiconductor Manufacturing Co. (TSMC) (NSCAI 2021, 3).[17]

Semiconductors are the key bottleneck. According to the NSCAI report, bold action is needed to ensure access to state-of-the-art semiconductors. "Without several U.S.-based fabrication facilities, both U.S. industry and U.S. national security face risks from competitive pressures and supply chain shortages" (ibid., 218).

According to the CRS, the United States should counter China's state-led industrial policies by expanding the exterritorial reach of US trade law, "including potentially sharpening U.S. authorities and strengthening the U.S. role

15 See also www.senate.gov/about/powers-procedures/investigations/mccarthy-hearings/have-you-no-sense-of-decency.htm.

16 See also Segal (2019).

17 Created by the 2019 National Defense Authorization Act, the NSCAI is composed of commissioners from Oracle, Microsoft, Amazon Web Services, Google, academia and other tech-focused companies. See also the presentations during NSCAI's Global Emerging Technology Summit on July 13, 2021 (www.nscai.gov/all-events/summit/).

in global technical bodies to counter China's policies" (CRS 2021). Supply chain regulation needs to be strengthened to enhance supply chain security and trade and technology collaboration among US allies and partners. In addition, the US government should extend supply chain controls to block "China's access to U.S. open-source technology and basic research" (ibid.).

In addition, the CRS recommends US Congress "examine China's complex structuring of government industrial subsidies that make it difficult to determine the state's role and subsidization under global rules; respond to China's unconventional use of antitrust, IP, and standards tools, including potentially sharpening U.S. authorities and strengthening the U.S. role in global technical bodies to counter China's policies; examine the implications of China's access to U.S. open source technology and basic research and whether export controls should be tightened; and consider how trade policy might enhance supply chain security and trade and technology collaboration among U.S. allies and partners" (ibid.).

A Pragmatic Approach: Expand US Semiconductor Manufacturing to Reduce Heavy Regional Concentration

An alternative US perception on asymmetric interdependence is less concerned with China's threat to US technology leadership. The main concern is the unequal geographic distribution of semiconductor manufacturing, which could easily disrupt the supply of critical chips. While the United States dominates R&D-intensive layers of the semiconductor supply chain, it is heavily dependent on East Asia for semiconductor manufacturing. In fact, the US share of global chip production drastically declined from 37 percent in 1990 to 12 percent today (SIA 2021a).

The proposed CHIPS for America legislation frames US chip manufacturing as an issue of US national security (Moore 2021). A Boston Consulting Group (BCG) report, *Strengthening the Global Semiconductor Supply Chain in an Uncertain Era*, commissioned by the SIA, provides the following data points:

- Currently almost 75 percent of the global installed capacity is concentrated in East Asia (Japan, South Korea and Taiwan) and mainland China, "a region significantly exposed to high seismic activity and geopolitical tensions" (Varas et al. 2021, 5).
- "East Asia is at the forefront in wafer fabrication, which requires massive capital investments supported by government incentives as well as access to robust infrastructure and highly skilled production engineers with a long experience in leading-edge process technology" (ibid., 4).
- The geographic concentration is even higher for advanced technologies: "100% of the global capacity in the leading 7- and 5-nanometer nodes is currently in East Asia" (ibid., 40), with 92 percent in Taiwan (primarily TSMC), and eight percent in South Korea (i.e., Samsung) (ibid., 29, 47). "Taiwan has 40% of the world's logic chip production capacity and leads in the most advanced nodes at 10 nanometers or below that are required to manufacture chips such as application processors, CPUs [central processing units], GPUs [graphics processing units] and FPGAs [field-programmable gate arrays] for smartphones, PCs, data center servers, and autonomous vehicles" (ibid., 40). Advanced semiconductor production facilities thus are critical supply chain chokepoints that could be disrupted by natural disasters, infrastructure shutdowns or international conflicts, and may cause severe interruptions in the supply of chips. As semiconductors are of critical importance for all industries, such an extreme geographic concentration of advanced semiconductor fabrication is a major headache not just for the United States, but for all countries, including Canada.
- "A high degree of geographic concentration of supply also exists for critically important semiconductor materials, such as silicon wafers, photoresist, some chemicals such as packaging substrates, or specialty gases. While each specialty material accounts for only a tiny portion of the industry's total value added, semiconductors cannot be fabricated without them" (ibid., 41). To illustrate how vulnerable semiconductor value chains are to secure access to materials, the BCG report highlights the example of C4F6, "a critical process gas used to make 3D NAND memory and some advanced logic chips. It is essential for the etching process during chip fabrication, allowing etching to be completed 30% faster than the nearest alternative. Furthermore,

once a manufacturing plant is calibrated to use C4F6, it cannot be substituted" (ibid.).[18]

According to the BCG report, the solution to these challenges is not the pursuit of complete self-sufficiency, which would come at a staggering cost and questionable execution feasibility. Instead, the US semiconductor industry "needs nuanced targeted policies that strengthen supply chain resilience and expand open trade, while balancing the needs of national security. To address the risk of major global supply disruptions, governments should enact market-driven incentive programs to achieve a more diversified geographical footprint, which should include building additional manufacturing capacity in the US, as well as expanding the production sites and sources of supply for some critical materials" (ibid., 6).

Specifically, the BCG report recommends that the United States should invest in a "minimum viable capacity" strategy for semiconductors that are essential for national security and critical infrastructure. Defence and aerospace together account for about three percent of US semiconductor consumption. This would clearly be insufficient to justify a cost-effective big push into domestic semiconductor manufacturing. However, by adding critical infrastructure to defence and aerospace, the total would add up to around 27 percent of US semiconductor consumption, which might be considered to be a more realistic minimum viable capacity metrics in terms of demand justification.[19] Critical infrastructure covers a broad range of semiconductor-consuming products and services, such as medical equipment, health care, energy, transportation, carrier core networks and wireless infrastructure, government data centres, and servers and storage and networking equipment for essential industries, such as telecommunications, energy, transport and banking.

In order to ensure a resilient supply of leading-edge semiconductors, SIA has further narrowed down its minimum viable capacity strategy to advanced logic chips at or below 7 nanometres (nm). This would account for around nine percent of total US semiconductor consumption. On the demand side, this raises an important question: Is nine percent of US semiconductor consumption sufficient to provide the minimum economies of scale necessary for a cost-effective big push into domestic semiconductor manufacturing?

On the supply side, keeping up with producing leading-edge integrated circuit technology has become increasingly expensive. The numbers are massive (more than $15 billion for initial investment), and huge additional investments are needed to stay at the leading edge (multiples of up to $20 billion).[20] These high investment thresholds have now driven out all but three companies — Samsung, TSMC and Intel — from the leading-edge portion of the market. Moreover, of these three manufacturers, only two can truly be considered to be at the leading edge (Samsung and TSMC), both with in volume production of 7nm and 5nm integrated circuits.

The SIA calculates that a $20 billion incentive program over 10 years would yield 14 new fabs in the United States for logic, memory and analog semiconductors and attract $174 billion in investment versus nine fabs and $69 billion without the federal incentives (Varas et al. 2020, 26). A $50 billion program would yield 19 fabs and attract $279 billion.[21] It is argued that this new capacity would be instrumental to address major vulnerabilities in the US semiconductor supply chain.

An expansion of US semiconductor production thus faces challenges from both the demand and the supply side. Relying on government procurement to ensure demand has its drawbacks, according to Commerce Department Senior Policy Adviser Sree Ramaswamy (2021): "There are some concerns here in some parts of the semiconductor value chain about [whether] we have enough defense demand to be able to sustain those investments." However,

18 "Sales of C4F6 gas were approximately $250 million in 2019, with the top three suppliers located in Japan (40% of global supply), Russia (25%), and South Korea (23%). If any of these top three producers were severely disrupted, the loss of $60–100 million in C4F6 supplies, could lead to about $10 to $18 billion of lost revenue for NAND alone downstream in the semiconductor chain — almost 175 times higher than the direct impact. If such disruption in a portion of C4F6 supply were to become permanent, NAND production levels would potentially be constrained for two to three years until alternative locations could introduce new capacity ready for mass production" (Varas et al. 2021, 41).

19 Email from Jimmy Goodrich, vice president of global policy, SIA, April 9, 2021.

20 Peter Hanbury of Bain & Company (quoted in Hille 2021) said: "If you want 3nm, that is going to cost you $15bn, and then two years later, you are going to have to spend another $18bn, and after that, another $20bn."

21 See www.semiconductors.org/wp-content/uploads/2020/10/Incentives-Infographic-2020.pdf.

as the United States accounts for 25 percent of global ICT end product demand, SIA expects this to provide the minimum economies of scale necessary for domestic production supported by the incentive program described in the BCG study.[22]

On the supply side, there are signs that the race is on for lavish subsidies — all three global players in advanced semiconductor production are seeking huge taxpayer-subsidized incentive packages.[23] Opposition to such subsidies, perceived to be "corporate welfare," has emerged in the US Congress across party lines (Inside U.S. Trade's World Trade Online 2021g). To overcome such resistance, a cross-sector alliance of semiconductor companies and downstream users of semiconductors announced on May 11, 2021, the formation of the Semiconductors in America Coalition (SIAC)[24] and called on Congress to appropriate $50 billion for the bipartisan CHIPS for America Act. The focus is on domestic chip-manufacturing incentives and research initiatives, but no operational definition is provided on how to enhance the resilience of the semiconductor supply chain. In addition to SIA member companies,[25] SIAC members include Amazon Web Services, Apple, AT&T, Cisco Systems, General Electric, Google, Hewlett Packard Enterprise, Microsoft and Verizon.[26] However, in light of the current shortage of car semiconductors, it is noteworthy that no car companies have joined SIAC.

In the end, the US move to incentivize the construction of semiconductor fabs is just one among a series of manoeuvres taking place globally as countries and regions seek to build up or regain chip-making capabilities. China has led the way through its Made in China 2025 plan.[27] In December 2020, Belgium, France, Germany and 15 other EU nations agreed to jointly bolster Europe's semiconductor industry, including moving toward 2nm node production.[28] The money would come from the €145 billion portion of the European Union's pandemic recovery fund set aside for "digital transition." And in March 2021, the Japanese industry ministry proposed to boost semiconductor production in the country as part of efforts to address a shortage of chips (Nippon.com 2021). The proposals call for joint chip development and production in Japan with Taiwan's TSMC and other foreign companies to improve the country's status as a maker of advanced semiconductors.

As all of these initiatives are motivated primarily by geopolitical concerns, it is unclear how economically viable the resultant expansion of semiconductor production will be. The United States, China, Taiwan, South Korea, Japan and Europe are all pursuing a massive expansion of semiconductor production on national security grounds. At some stage, the current chip shortage may well give way to disruptive and extremely costly overcapacity. After all, the semiconductor industry has been famous for its cyclical nature since its early days (Ernst 1983).

US Congress Deliberations

These policy debates have set in motion the wheels of legislative action in the US Congress. As always, the pathways to law and regulations have been twisted. Much of the effort initially has been focused on the Endless Frontier Act, which has experienced a difficult birth. The Endless Frontier Act bill, introduced in the Senate on May 21, 2021, redesignates the National Science Foundation (NSF) as the National Science and Technology Foundation and establishes a Directorate for Technology within the foundation.[29] Specifically, the act seeks to create a supply chain resiliency program and expand the Commerce Department's Manufacturing USA program.

Initially, the legislation was aimed to fund the NSF Technology Directorate with $100 billion over five years to strengthen US leadership in critical technologies through fundamental research in technology focus areas, such as AI, high-performance computing and advanced manufacturing; enhance US competitiveness

22 Email from Jimmy Goodrich, vice president of global policy, SIA, June 21, 2021.

23 For instance, Samsung is seeking a taxpayer-subsidized incentives package worth more than $1 billion to choose Austin, Texas, for its next big facility — a 7 million sq. ft. next-generation chip fabrication plant that would be valued at more than $17 billion and create 1,800 jobs, according to documents filed with the state (see https://assets.comptroller.texas.gov/ch313/1554/1554-manor-samsung-app.pdf) (Carlson and Sechler 2021).

24 See www.chipsinamerica.org/.

25 See www.semiconductors.org/about/members/.

26 See www.chipsinamerica.org/about/#members.

27 See https://en.wikipedia.org/wiki/Made_in_China_2025.

28 See https://digital-strategy.ec.europa.eu/en/library/joint-declaration-processors-and-semiconductor-technologies.

29 US, Bill S, *Endless Frontier Act*, 116th Cong, 2020, online: <www.congress.gov/bill/116th-congress/senate-bill/3832>.

in the focus areas by improving education in such areas and attracting more students to such areas; and foster the impact of federally funded R&D through accelerated translation of advances in the focus areas into processes and products that help achieve national goals.

The act is defined by a strong focus on geopolitics. The Office of Science and Technology Policy, Commerce, the National Security Council and other relevant federal agencies shall review the national security strategy and programs and resources pertaining to US national competitiveness in science, research and innovation to support such strategy; and develop a strategy for the federal government to improve such competitiveness to support the national security strategy.[30]

For quite some time, funding for the act was left hanging in the air. As summarized in the newsletter *China Trade & Tech* of May 14, 2021, "The Endless Frontier Act is coming. We just don't know what it will look like, or where it's headed" (Inside U.S. Trade's World Trade Online 2021h). In the Senate, the Commerce, Science and Transportation Committee drastically cut the proposed funding for a new technology directorate within the NSF, arguing that it might duplicate efforts led by the Energy Department's National Laboratories (Inside U.S. Trade's World Trade Online 2021i).

In addition, IT and auto companies have been at odds over the potential funding of the CHIPS for America Act, with auto groups urging the administration to give mature semiconductor manufacturing preference for funding in response to the current shortage of car semiconductors. Ironically, the Endless Frontier Act faces opposition in the House from Republicans who claim that it copies China's industrial strategy. On May 21, 2021, Congress.gov showed that more than 400 amendments have been submitted to the Endless Frontier Act, including Senate Majority Leader Chuck Schumer's (D-NY) own substitute amendment bringing together legislation from Senate committees and renaming the endeavour the American Innovation and Competitiveness Act.[31]

On June 8, 2021, the Senate passed (68–32) the American Innovation and Competition Act, a wide-ranging China-focused legislative package that includes various trade provisions, such as the renewal of the Generalized System of Preferences and a new Miscellaneous Tariff Bill, as well as funding for domestic semiconductor manufacturing incentive programs with labour-wage provisions (Inside U.S. Trade's World Trade Online 2021j).[32] Cooperation with allies also plays an important role — the Foreign Relations Committee's Strategic Competition Act bill[33] offers the administration a host of recommendations for how to work with the European Union on trade, technology, export controls, investment screening and more.

Senator Schumer, in remarks immediately before the final vote on the bill, said the passage of the American Innovation and Competition Act was "the moment when the Senate lays the foundation for another century of American leadership," and added that it "could be the turning point for American leadership in the 21st century" (ibid.). In contrast to such grandiose declarations, the bill still faces an uncertain path, as the House is considering several bills that differ widely from their Senate-passed counterparts. For instance, the House bill does not include the Endless Frontier Act's $10 billion regional technology hub program, nor does it include the Senate's $1.2 billion authorization of annual funding for Commerce's Manufacturing USA program. The House bill also lacks authorization for funding the National Institute of Standards and Technology's Hollings Manufacturing Extension Partnership, which is included in the Senate legislation (Inside U.S. Trade's World Trade Online 2021l). In short, deep partisan divisions persist over how Congress should craft its approach to China's rise; there is also a considerable chasm between the House and the Senate's legislative approaches.

Again, this underlines the huge implementation barriers that the United States is facing, as it seeks to come up with its own version of a Chinese-style semiconductor industrial policy. After all, the decentralized, market-driven US government policy making is worlds apart from the top-down Chinese approach. For the United States, moving toward a more government-driven industrial policy will therefore not be easy.

30 Ibid.

31 See www.congress.gov/bill/117th-congress/senate-bill/1260/amendments?searchResultViewType=expanded&pageSize=100&page=5.

32 The bill is a compendium of legislation from a variety of Senate committees.

33 See Inside U.S. Trade's World Trade Online (2021k).

China's response to the American Innovation and Competition Act followed immediately, which indicates how much US-China relations have further deteriorated under the Biden administration. The Foreign Affairs Committee of China's National People's Congress (NPC) issued a statement on June 9, 2021, claiming the Senate bill "attempts to exaggerate the so-called 'China threat' to maintain the U.S. global hegemony" (informal translation quoted in Inside U.S. Trade's World Trade Online 2021m). On June 10, a new "Anti-Foreign Sanctions" law was passed by the NPC and approved by President Xi.[34] This new law permits Chinese agencies to impose countermeasures on persons or organizations directly or indirectly involved with sanctions levied on China. It is unclear whether and for how long the United States can win this vicious circle of US sanctions followed by Chinese retaliation.

The White House Supply Chain Review Report

As a culmination of all these activities, June 8, 2021, saw the release of the White House 100-day supply chain review report that lays out America's supply chain regulation strategy against China (The White House 2021a). Semiconductors receive by far the most detailed discussion. The report highlights the fragility of America's semiconductor supply chain and the resultant threat of unpredictable disruptions. This is in line with the aforementioned pragmatic US approach to asymmetric interdependence, which focuses on the unequal geographic distribution of semiconductor manufacturing. The report states: "U.S. companies, including major fabless semiconductor companies, depend on foreign sources for semiconductors, especially in Asia, creating a supply chain risk. Many of the materials, tools, and equipment used in the manufacture of semiconductors are available from limited sources, semiconductor manufacturing is geographically concentrated, and the production of leading-edge semiconductors requires multi-billion-dollar investments" (ibid., 22).

Overall, however, the White House report codifies a techno-nationalist strategy shaped by security and defence concerns. In contrast to the Trump era, the Biden administration seeks to engage with allies and partners on semiconductor supply chain resilience, "by encouraging foreign foundries and materials suppliers to invest in the United States and other allied and partner regions to provide a diverse supplier base, pursuing R&D partnerships, and harmonizing policies to address market imbalances and non-market actors" (ibid., 23). The report culminates in a laundry list of "Opportunities & Challenges" (ibid., 66–74) that, however, fails to provide an analysis of feasibility. At the top of the list of opportunities is public investment in support of domestic semiconductor manufacturing. Little attention is focused on the threat of a subsidy race that may result from attracting TSMC, Samsung, Intel and GlobalFoundries to invest in US chip production (ibid., 66).

As for critical challenges, the report identifies high labour cost (relative to Taiwan and other Asian competitors) together with insufficient tax incentives. In line with suggestions from the SIA, the report assumes that "the 10-year cost of a new fab in the United States may be 30 percent — $6 billion on average — higher than building the same fab in Taiwan, South Korea or Singapore, and up to 50 percent higher than in China. Much of the cost differential (estimated 40–70 percent) is specifically due to government incentives" (Varas et al. 2020, quoted in ibid., 68).

As for domestic implementation constraints, the report points to interagency rivalries as a major challenge, emphasizing the need to "ensure coordination among the various federal players (and private sector participants) to minimize duplication of effort and maximize potential return on investments" (ibid., 69).

The report also contains well-intentioned suggestions to "Support Domestic Semiconductor Jobs along the Supply Chain," but fails to address head-on the disruptive effects of US visa restrictions on the recruitment and retainment of foreign talent. Finally, the report emphasizes the importance of critical infrastructure projects, such as high-speed broadband, that are needed to "provide an "'anchor'" for leading edge semiconductor technology and production" (ibid., 73). According to the report, "this will be beneficial for the DoD and national security, as defense needs alone are small compared with commercial markets" (ibid.).

34 For a detailed analysis, see Lovely and Schott (2021). These rules supplement a string of actions taken by the Chinese government to deter compliance with foreign governments' extraterritorial measures deemed to harm Chinese interests. Related actions are China's unreliable entity regulations, issued in October 2020, and laws implemented in March 2020 prohibiting parties in China from unilateral cooperation with foreign civil and criminal investigations.

Arguably, an important weakness of the report is its neglect of the considerable implementation constraints that America's supply chain controls against China are facing (as discussed in the following part of the paper). An equally important shortcoming is that the report fails to address head-on the collateral damage caused by these supply chain regulations against companies and research institutions, both in the United States and in partner countries (as discussed in the final part of the paper).[35]

Blocking Supply Chain Chokepoints Faces Serious Implementation Problems

We saw that in the United States, it is widely assumed that asymmetric interdependence allows the US government to impose stifling technology restrictions against China. The prevailing policy doctrine is to expand such supply chain controls. In principle, China's weaknesses in semiconductors are robust supply chain chokepoints because these technologies are tangible and difficult to steal or copy; expensive; dependent on scarce talent requiring tacit knowledge and experience; and produced by a small number of suppliers, in particular because of high barriers to entry and economies of scale (Khan 2021, 48, note 4).

The reality, however, is a bit different. Attempts to block supply chain chokepoints face serious implementation problems, both internationally and at home. In the short term, US supply chain regulations no doubt are hurting China's semiconductor industry. The quite substantial implementation constraints, however, are raising doubts on how effective such policies will be over the longer term.

International Constraints

Global semiconductor supply chains have become longer and deeper, involving a greater diversity of stakeholders on multiple supply chain layers.[36] Over time, an increasing diversity of global semiconductor supply chains has emerged, bringing together companies that differ drastically in size, business model, market power, location and nationality. Participants also differ in their capacity to bypass the extraterritorial reach of US technology restrictions (Ernst 2020, 27 ff.). With rising complexity, it becomes more difficult and costly to implement effective regulatory supply chain controls against China.

The semiconductor equipment industry chain provides an illustrative example (see Figure 1). Focusing on the 10 stages of semiconductor fabrication, the industry association SEMI[37] identifies 48 leading companies from the United States, Japan, Europe and China. These companies differ in their exposure to US supply chain controls. They also differ in their resources and capabilities, and therefore will respond quite differently to those controls.

Due to the proliferation of machine learning/AI technologies, the complexity of global semiconductor supply chains has surged substantially.[38] The architecture and the governance of these new supply chains are still emerging, little is fixed and there is a lot of experimentation. As a result, supply chain vulnerability to external disruptions has further increased, and stakeholders are facing conflicting interests.

Limits to US-Allied Cooperation against China

America's China policy creates dilemmas for its allies. US allies welcome the return of the United States to multilateralism, but most of them are not interested in an intensified technology war between the United States and China. According to David Dollar (2021) at the Brookings Institution, "this was evident in Blinken's visit to South Korea, initial discussions with European allies, and the visit of Japanese Prime Minister Suga to Washington. Our allies have deeper trade and investment relations with China than we do; and, in fact, since Biden's

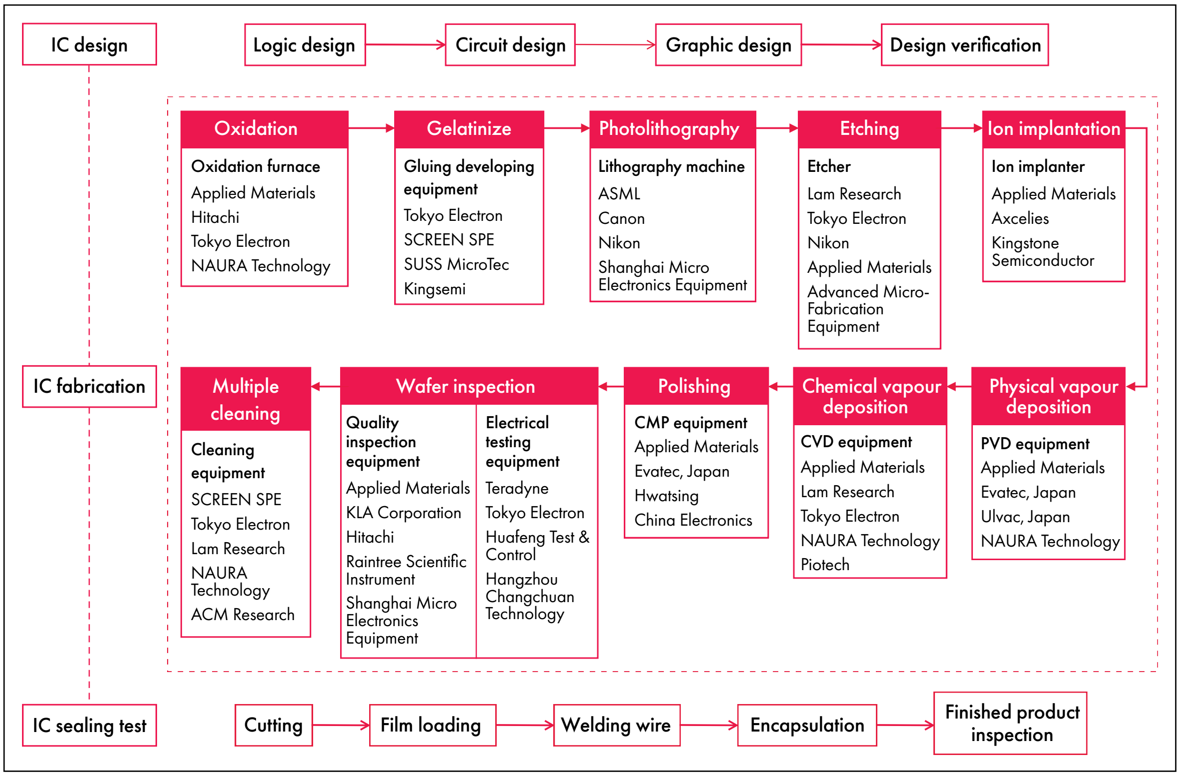
35 What matters for the United States is that US semiconductor sales to China in 2019 were valued at $70.5 billion, about 36 percent of all US chip sales. See data in Goodrich and Su (2020).

36 For an early analysis of this process, see Ernst (2009).

37 See www.semi.org/en.

38 As demonstrated in Ernst (2020). See also Ciuriak (2020).

Figure 1: Semiconductor Equipment Industry Chain



Sources: SEMI, company websites and Ping An Securities Research Institute.
Note: CMP = chemical-mechanical polishing; CVD = chemical vapour deposition; PVD = physical vapour deposition.

election, the EU, Japan, South Korea, Australia, New Zealand, and ASEAN [Association of Southeast Asian Nations] have all signed new economic agreements with China....[In short]...there is some contradiction between the U.S. confronting China and working multilaterally, so it is likely that over time Biden's China policy will have to become either less confrontational or more unilateral."

Take the challenges faced by Taiwan and South Korea, which are among the closest geopolitical allies of the United States. Both countries are also by far America's main suppliers of advanced semiconductors. Partnering with the United States is thus a high priority for Taiwan's TSMC and South Korea's Samsung. At the same time, however, both companies heavily depend on the China market, and their governments can ill afford to openly provoke China. As Taiwan will be at the centre of US-China technology competition, it is especially vulnerable to Chinese retaliation: "China will likely leverage its economic influence through trade restrictions, talent recruitment, and cyber to attack key companies in order to obtain core semiconductor intellectual property (IP) needed to bolster its domestic industry" (FP Analytics 2021). In fact, Taiwanese suppliers to Apple are starting to lose out against Chinese competitors, as Apple is adjusting its list of suppliers in response to pressure from China (Ting-Fang and Li 2021a). As for South Korea, while Samsung is a powerful leader in semiconductors, the Korean government critically depends on friendly relations with China in order to contain the North Korea threat.

In short, these two close US allies are caught in the middle of the US-China technology war. They are thus unlikely to embrace without reservations joint supply chain controls directed against China.

Limits to US-EU Cooperation against China

The idea that the Biden administration will be able to create a unified bloc of allies to counter China may face headwinds, because some allies are more heavily reliant on trade with China than others. According to the University of California, San Diego's Susan Shirk, commercial considerations dominate Europe's thinking in crafting a China policy much more than they do in the United States. For that reason, the prospect of working with Europe on China has probably been exaggerated (Shirk, quoted in Inside U.S. Trade's World Trade Online 2020).[39]

In 2020, China was the main external trade partner for the European Union. This explains why Europe is reluctant to link arms with the United States against China. In fact, on December 30, 2020, the European Union and China concluded in principle the negotiations for a Comprehensive Agreement on Investment. This deal followed a call between Chinese President Xi and European Commission President Ursula von der Leyen, European Council President Charles Michel and German Chancellor Angela Merkel on behalf of the presidency of the EU Council, as well as French President Emmanuel Macron. The US government clearly expressed displeasure. In the meantime, European Parliament ratification talks for the EU-China Comprehensive Agreement on Investment (CAI) are frozen while sanctions imposed by Chinese authorities on European individuals and entities remain in place (Emmott 2021).

The most recent EU-US summit, held on June 15, 2021, has launched a Trade and Technology Council to boost coordination on fifth-generation (5G) semiconductors, supply chains, export controls and technology rules and standards.[40] Yet, given the complexity of the relevant supply chains, it would seem unrealistic to expect tangible results any time soon.[41] Nevertheless, the overwhelming interest of Germany and France in expanding their access to the China market through an investment pact is likely to prevail (Thomas, quoted in Lee 2021).

In any case, "Europeans want a more balanced relationship, with more dialogue and less diktat.... If by 'leadership' Mr. Biden means a return to the traditional American assumption — we decide and you follow — many Europeans feel that that world is gone, and that Europe must not behave like America's junior wingman in fights defined by Washington....China may be a peer rival for the United States, but it has long been a vital trade partner for Europe. And while European leaders see Beijing as a systemic rival and competitor, they also see it as a partner, and hardly view it as an enemy" (Crowley and Erlanger 2021).

According to former US Trade Representative Charlene Barshefsky, the European Union may "fall short" in cooperating with the United States to counter China (Inside World Trade's World Trade Online 2021n). During a US Chamber of Commerce event, Barshefsky argued that the United States might not always be able to count on the European Union in efforts to combat China due to political pressures and priorities within the bloc. The United States thus needs a "plan B" in working with allies such as the European Union to counter China (US Chamber of Commerce 2021).

"Europe does not feel a security risk from China," she said. "Europe is not positioned in the Pacific the way the United States is. And the result is that Europe does not feel a sense of imminent threat as the United States might feel and indeed many Europeans believe indirectly there is no threat from China." Most importantly, "Europe is not going to fight with China in order to preserve America's unique role in the world," she said. "That's a US interest" (ibid.).

In light of these fundamental dilemmas, it is hardly surprising that the global technology industry is hedging its bets. A recent Brookings Institution survey polled 158 senior business executives working for American, Chinese, European, Japanese, Taiwanese and Korean global high-tech firms about the impact of US-China tensions on their industry (Thomas and Wu 2021). Its main finding is that global high-tech companies do not plan to pick sides. Rather, they pragmatically aim to compete in both Chinese and US ecosystems regardless of the extra cost and complexity involved. While these executives regard as inevitable that American and Chinese technological spheres of influence will to some extent separate, they also expect Chinese systems and solutions suppliers to continue to rely on globally sourced (rather than Chinese-developed) technologies. In addition, these executives expect multinational companies of all stripes to double down on their efforts to keep competing in the Chinese market.

The Chip Shortage

Global semiconductor supply chains are strained by multiple bottlenecks, giving rise to severe chip shortages. Supply chain controls against China are likely to add further to these

39 Susan Shirk is research professor and chair of the 21st Century China Center at the University of California, San Diego.

40 See www.consilium.europa.eu/en/meetings/international-summit/2021/06/15/.

41 See also Sevastopulo, Fleming and Peel (2021).

disruptions. They are also likely to expose more sharply conflicts of interest with US partners. In the author's view, this is arguably the worst time to experiment with discriminatory supply chain controls against geopolitical rivals.

Automakers around the world are shutting down assembly lines because of a global shortage of semiconductors. The shortage stems from a confluence of factors as auto manufacturers compete against the sprawling consumer electronics industry for chip supplies. During the pandemic, consumers have stocked up on laptops, gaming consoles and other electronic products, creating tight chip supplies since 2020. This has encouraged inventory hoarding along semiconductor supply chains, widening the gap between expanding demand and stagnant supply. The shortage has been exacerbated by the Trump administration's policies aimed at curtailing technology transfers to China (Automotive News 2021).[42] Some automakers have tried to move chip production from China's SMIC, which was hit with US government restrictions in December, to Taiwan's TSMC, which is overbooked.

Research by the IT consulting company Gartner finds that the car chip shortage started primarily with devices, such as power management, display devices and microcontrollers, fabricated on legacy nodes at 8 in. foundry fabs, which have limited capacity (Shen 2021). The shortage has now extended to other devices, and there are capacity constraints and shortages for substrates, wire bonding, passives, materials and testing, all of which are parts of the semiconductor supply chain. This has resulted in severe disruptions across the supply chains of many types of electronic equipment, including mobile communications and consumer electronics. In response, semiconductor foundries are increasing wafer prices, and, in turn, chip companies are increasing device prices.

Accumulated shortages imply that chips are hard to come by right now, both for advanced and mature technology. According to Gartner (2021), the present shortage will be deep and long-lasting, and is expected to last until the second quarter of 2022. Flex,[43] the world's third-largest electronics contract manufacturer, which sits at the heart of supply chains for the car, medical devices and consumer electronics industries, projects shortages will last into 2022 (Dempsey 2021). The severity of the current chip shortage is prompting stunning levels of investment in new production facilities, both for advanced semiconductors (i.e., 7nm and below), and trailing-node semiconductors (i.e., 14nm and above). As a result, the risk of excess chip factory capacity has risen across a broad spectrum of the semiconductor industry. For advanced semiconductors, we have seen that the United States, China, Europe and Japan are all pursuing self-sufficiency on national security grounds. Given the huge investments projected for new advanced fabrication lines, there is a real risk of excess capacity. Driven by the needs of the car industry, investments are also rapidly expanding for trailing-node semiconductors. Excess capacity is thus likely to be broad-based.

Given these powerful industry trends, US government efforts to reduce the chip shortage through better collaboration on supply chain regulation are likely to face substantial obstacles

During a White House CEO Summit on Semiconductor and Supply Chain Resilience on April 12, 2021, industry representatives discussed ways to reduce the chip shortage through better collaboration and more efficient semiconductor supply chains (The White House 2021c). In their view, supply chain transparency is the critical issue. Timely access to data across the chip supply chain is necessary to react more nimbly to fluctuations in demand, supply and capacity.

In short, government-centred supply chain regulation would need to be complemented by industry-driven digital supply chain management (Maroney and Howell 2021). It remains to be seen whether and how the government's geopolitical objectives can be matched with the industry focus on supply chain transparency. It is unclear as well whether the United States can balance conflicts of interest with Germany, Japan and Korea. Industry sources, for instance, have argued that the United States is "worried about being outflanked by allies" for prioritization to access chips (Inside U.S. Trade's World Trade Online 2021o). In fact, German carmakers and suppliers (including Continental and Bosch) are searching for ways to link up with specialized suppliers of electronic vehicle chips

42 See also Ewing and Clark (2021).

43 See https://flex.com/company/our-story.

(Tyborski 2021). There are also rumours that German carmakers might invest in chip foundries in China.[44]

Domestic Implementation Constraints

America's supply chain controls against China also face substantial domestic implementation constraints. The US government will need to improve the transparency of regulatory processes, strengthen interagency coordination, and address legal enforcement loopholes, recruitment problems and budgetary requirements.

A new report by the US Government Accountability Office (GAO) documents a serious lack of transparency in the processes used by the Office of the US Trade Representative (USTR) to review tariff exclusion requests and extensions for Section 301 tariffs on products from China: "From 2018 to 2020, U.S. stakeholders submitted about 53,000 exclusion requests to USTR for specific products covered by the tariffs....[However,]... USTR did not document how reviewers should consider multiple requests from the same company, and GAO's case file review found USTR performed these steps inconsistently" (GAO 2021).

US supply chain regulations are facing similar quality issues. For instance, a recent study by the Center for a New American Security (CNAS) finds that the US government will need to create new processes to develop, implement and monitor and evaluate supply chain controls as part of its national technology strategy. The government will "need to optimize existing processes in new ways, as bureaucratic foundations in this space have so far been uncoordinated, under-resourced, and undervalued. Institutions such as the National Security Council (NSC), National Economic Council (NEC), and Office of Science and Technology Policy (OSTP) are, in their current structure and partitions, not fully equipped to meet the challenge of creating and executing a coherent response to this challenge" (Shulman and Riikonen 2021, 4). The same is true for the Commerce Department, which, according to the US Chamber of Commerce, "is not equipped" to carry out supply chain regulation directed against China "with sufficient staff and resources." Managing such supply chain controls is "overwhelming" for the department (US Chamber of Commerce, quoted in Inside U.S. Trade's World Trade Online 2021p).

Specifically, the following implementation constraints have been identified in informal background interviews:[45]

- Legal complexity: The enforcement of "Entity List" licensing[46] against Huawei and other Chinese firms has had to struggle with seemingly never-ending loopholes. An army of specialized trade attorneys in global law firms is working hard to multiply such loopholes.
- Fragmentation in decision making: The implementation of export controls has been plagued by conflicts of interest and turf battles between and within different government agencies, such as Commerce, Treasury and the Defense Department. Supply chain regulation is likely to face similar conflicts within and across relevant government agencies.

The Commerce Department's Bureau of Industry and Security (BIS) has recruitment and retainment problems, in particular for experts on export controls and secure telecommunications. Earlier recruitment drives under the Trump administration were hastily executed, resulting in quality and motivation issues.[47]

It remains to be seen whether the budget requirements for effective supply chain regulation will be met. The Biden administration's 2022 budget request calls for a $2.5 billion increase in funding for Commerce, specifically to provide "adequate funding for staffing to support export controls and secure telecommunications." On July 13, 2021, President Biden nominated a former Defense Department official to lead the BIS and a long-time trade lawyer to serve as assistant Commerce secretary for enforcement and compliance (Inside U.S. Trade's World Trade Online 2021q). However, no details are provided on funding or staffing levels for Commerce's BIS, which administers the US export control regime.

44 Interview with industry experts on March 4, 2021, who have requested anonymity.

45 Phone and email interviews conducted in the spring of 2021 with industry experts who requested anonymity.

46 See www.bis.doc.gov/index.php/policy-guidance/lists-of-parties-of-concern/entity-list.

47 Phone and email interviews conducted in the spring of 2021 with industry experts who requested anonymity.

The Biden administration's leeway for reform is likely to be limited: "Facing an aggrieved opposition loyal to the Trump brand, Biden will find it more difficult to govern than under the 'normal' conditions of split government" (Bremmer and Kupchan 2021, 4). Current battles in US Congress about funding for the Endless Frontier Act and related initiatives demonstrate that overdue reforms face substantial barriers.[48] In short, not even "the most powerful nation on Earth" (Obama 2016) can mobilize all the public assets and capabilities needed to implement effective supply chain controls against China.

As recognition of these implementation barriers begins to sink in, the search for less costly alternative strategies is on. For instance, the House Armed Services Committee Chairman Adam Smith (D-WA) argues that the United States must accept competition with China, not aim for dominance: "The U.S. should forge a realistic plan to compete with China in developing new technologies and move away from trying to dominate or rein in the country's rise....Being the dominant power in the world actually has a pretty big downside and that downside is everyone expects you to fix every freaking problem in the world....The U.S. must accept it must compete with China globally and focus its policy making on how to best develop technologies rather than on trying to suppress China's rise" (Smith, quoted in Inside U.S. Trade's World Trade Online 2021r).

Smith suggests that the United States commit to a concept of "selective supply chain cooperation": "Making all — or even just the best — key technologies in the U.S. is unrealistic in a global economy," contending that a "straight Buy America" approach would not work. "We definitely prefer that if we need to rely on a technology that wasn't primarily made in the U.S., we'd rather buy it from Europe or Taiwan than we would then have China be the leader in that technology" (ibid.).

Defense Innovation Unit Director Michael Brown (2021) points in a similar direction: "Even when it is not the driving force behind an area of innovation, the U.S. — and particularly the Pentagon — must learn how to keep up....I think DOD has to learn a different motion for these commercial technologies, which is how to be the fast follower....DOD must learn how to adapt those technologies to ensure it doesn't fall behind."

48 See earlier discussion in "Conflicting Perceptions of Asymmetric Supply Chain Interdependence."

The dirty little secret of technology competition between the United States and China is aptly summarized by Richard J. Danzig, a former secretary of the navy under US President Bill Clinton. Danzig and Lorand Laskai (2020, 5, 14) argue that because "the inadequacies of instruments available for charting and effectuating changes in Sino-American technological interdependencies...are so imperfectly understood, tentative restraint is the right posture as governments experiment with their use."

For the United States, it is no longer possible to execute a broad technology blockade against China. The politicization of trade and technology transfer has dramatically increased the complexity of technology competition. Under these conditions, it is unclear which country, China or the United States, can better cope with the conflicting requirements of supply chain regulation, which some observers have compared to "three-dimension chess."[49]

All of this indicates that a "Cold War"-like technology war with China is unsustainable. This view is shared by one of the protagonists of the Cold War between the United States and the Soviet Union. Henry Kissinger argues that "'endless' competition between the world's two largest economies risks unforeseen escalation and subsequent conflict" (Brennan 2021).[50] Neither country could win a Cold War-like technology war. Hence, they both need to find a way to coexist.

Outside the tightly knit Washington, DC, beltway community, there is a broad consensus that America can no longer stop China's rise, and that discriminatory supply chain controls are unlikely to produce the expected results. Daniel Gros, the director of the Centre for European Policy Studies, argues that "the US is haunted by the specter of a technologically dominant China — and keen to ensure it never materializes. And yet, given China's fundamentals, there is little the US could do to hamper, let alone arrest, its progress" (Gros 2020). The *Financial Times*' chief economics

49 Email from Richard J. Danzig to the author, September 11, 2020.

50 In Kissinger's view, the United States and China today are almost equally powerful, while the Soviet Union in the Cold War era was relatively weaker than the United States and was not integrated into the global economy.

commentator, Martin Wolf, also does not believe that containing China would still be a feasible option today: "Many Americans argue that a form of containment is feasible. Indeed, this is one of the few points on which Joe Biden's administration and its predecessor tend to agree. One can also see the political advantage: common enemies may unify a divided country. But is this really a feasible policy? I believe the answer is: no" (Wolf 2021).

To summarize, supply chain regulation in high-technology industries such as semiconductors is orders of magnitude more difficult to execute than assumed by the fashionable concepts of "geoeconomic strategy" or "weaponized interdependence."[51] A hands-on knowledge of sector- and country-specifics is required to develop valid policy suggestions. The United States needs to do its homework first, in order to create new ideas and run faster.[52] Only then would the United States have enough leverage to "impede the rival," let alone to learn from it.

This interpretation is in line with observations by the renowned Oxford University historian Sir Michael Howard. In his memoirs, he describes the dominant role played by abstract wargaming exercises in US diplomacy. During a visit to the United States in the spring of 1960, just before the US role in the Vietnam War began to expand, Howard found in the Pentagon "a people who, in spite of the Second World War and Korea, had not really experienced war, and who found the prospect an invigorating challenge. It was in just such an atmosphere, I thought, that wars began" (Howard 2006, chapter 9).[53]

In short, supply chain regulation against a geopolitical rival requires a realistic appraisal of factors such as national interest, public support, economic and social stability, and technological advantages — and what those factors look like from the opponent's perspective. Abstract war gaming exercises are no substitute. As for the prospects of supply chain regulation against China, the United States still has a long way to go to improve the institutional knowledge and administrative capacity of the government required for successful implementation.

Despite all the international and domestic implementation constraints that this paper has highlighted, there is little evidence that this has reduced the support in the United States for discriminatory supply chain controls against China. The deeply entrenched fear of China's threat to US technology leadership continues to dominate policy making in the US Congress. Rather than a fact-based analysis of asymmetric bilateral interdependence, a narrowly defined concept of geopolitics is bound to shape America's supply chain control against China for quite some time.

Collateral Damage, Trust and Innovation

Finally, let us address the substantial collateral damage that may be caused by supply chain controls against China, and explore possible implications for trust and innovation.[54]

Supply chain regulation can be a formidable tool to protect a country's resilience against unexpected disruptions of trade, investment and the supply of skilled labour (Terblanche 2021).[55] However, its utility is eroding, especially if supply chain regulation is used in the service of geopolitics. Recent research on US export controls has documented unintended negative consequences: "U.S. export controls were designed for an era when the United States enjoyed overwhelming technological dominance. U.S. policymakers often wield export controls as if that is still the case. As a result, current export control implementation often compounds unintended consequences that harm U.S. economic and technological competitiveness" (Rasser 2020).

While the United States is still the world's technology leader in semiconductors, it is now facing new challenges. As China is gradually

51 As propagated, for instance, by Blackwill and Harris (2016). See also, more recently, Farrell and Newman (2019).

52 As argued, quite a few years ago, in Ernst (2011).

53 Howard became even more alarmed after attending a lecture on nuclear warfighting given by Herman Kahn at the RAND Corporation in Santa Monica, California. Some RAND researchers whom he met were debating how long it might take Los Angeles to get back to "normal" after a nuclear attack.

54 The role of standard-essential patents and open-source communities will be discussed in a follow-on paper.

55 For an in-depth analysis, see Pettit, Fiksel and Croxton (2010).

catching up in important technologies, "opportunities for effective export controls are growing scarcer....[Hence,] applying export controls with inadequate consideration of the shifts in the global technology landscape means amplifying unintended consequences that can cause lasting damage to U.S. firms and industries and pose avoidable hurdles to technology cooperation with allies and partners" (ibid.).

In short, US semiconductor supply chain regulations that are targeting China need to address three fundamental questions: How much collateral damage to US technology developers and manufacturers is tolerable in the service of US national security? To what degree might this erode US technological capabilities? And what disruptions might this impose on the global semiconductor innovation system?

Collateral Damage

There is ample evidence that America's regulatory supply chain controls are imposing collateral damage on industry, public research labs and universities in the United States and in partner countries. US suppliers will suffer, as compliance with complex administrative procedures is costly and time-consuming, so that market opportunities are lost to foreign competitors.

Industry Fights against Collateral Damage

When the Commerce Department's information and communications technology and services (ICTS) supply chain rule was released in January 2021,[56] the US Chamber of Commerce argued that it could cost "billions" for companies to comply with the rule amid uncertainty about whether their transactions could be "unwound or amended (quoted in Inside U.S. Trade's World Trade Online 2021p). The chamber singled out Commerce's non-specific definition of a "foreign adversary" as one of the rule's many characteristics that will prevent it from being effective. "This aspect of the rule undermines a central goal to 'protect our country against critical national security threats,'' the Chamber of Commerce said in its comments, quoting from the May 2019 order. "'Walling off' certain countries from providing ICTS means that foreign adversaries know to concentrate their efforts on facilities outside their borders — which this rule does not address. Vigilance to specific threats, irrespective of geography, is preferable to geography-based barriers" (ibid.).

Disrupted Transactions

According to the Communications Technology Association (CTA), the ICTS supply chain rule "threatens to call into question potentially millions of routine transactions that CTA's members and their business partners rely on to sustain and advance global supply chains" (quoted in Inside U.S. Trade's World Trade Online 2021p). And Microsoft warns that supply chain controls could lead to crippling uncertainty that ultimately could stifle US competitiveness in the technology sphere. "The rule's sheer breadth and lack of clear criteria for when companies may be subject to a review — even for transactions already completed — will make it more difficult and expensive for U.S. companies to develop cutting edge technology" (ibid.). Regulatory uncertainty created by the rule's broad scope could lead the United States to lose its technological leadership, the software company claimed. "For example, companies developing certain critical 5G technologies currently lack a cost-effective way to source key components either domestically or from allies. Developing alternative supply sources will take time and investment. If U.S. companies lose access to critical components before alternative supply sources exist, their businesses will be disrupted, and U.S. technology leadership will suffer" (ibid.).

Compliance Costs

The Commerce Department has released an analysis of the costs that businesses could face in trying to comply with the supply chain interim final rule for the ICT sector. The "Regulatory Impact Analysis" breaks down administrative costs into four areas: learning about the rule, developing a compliance plan, implementing that plan and compliance with investigations. For instance, "prohibiting a transaction may entail very high costs involved with unwinding a transaction, finding a new supplier, and negotiating a new contract, as necessary. Even mitigation agreements may result in additional costs for a transaction since they may involve new negotiations for goods or services" (Inside U.S. Trade's World Trade Online 2021p).[57]

56 *Securing, supra* note 11.

57 *Securing, supra* note 11.

Small and medium-sized enterprises are expected to shoulder a large part of the collateral damage. The US Commerce Department estimated that more than 4.5 million companies have imported significant amounts of goods and services potentially subject to review under the supply chain rule. The overwhelming majority — 99.6 percent — of those are small businesses with fewer than 500 employees (ibid.). "Small firms downstream of impacted industries are likely to face increases in the prices of ICT products they use as inputs and either absorb the increase in cost and/or raise their prices," the draft notice says. "Given this situation, it is possible that the rule will have a more substantial adverse impact on small firms relative to larger firms" (Inside U.S. Trade's World Trade Online 2021b).

Small businesses "may not have the same ability to deal with the burdens, both direct and indirect, associated with the Rule....Faced with the various costs associated with compliance, firms will have to absorb those costs and/or pass them along to their consumers in the form of higher prices...Either action will reduce the profits of firms. Due to their lack of market power, and their lower profit margins, small firms may find it difficult to pursue either or both of those responses while remaining viable" (ibid.).

In addition, US suppliers will further suffer, due to China's response to the US technology ban. As we saw, China is redoubling its efforts to become self-reliant by sourcing components from suppliers based in Europe and elsewhere in Asia. Chinese electronics companies will oust US chip suppliers by sourcing components from Asian or European companies if that alternative is at all viable. According to Bill McClean, a leading semiconductor industry observer, "If there is an alternative, they... [the Chinese system suppliers]...are going to pick it. I guarantee that. The trust is gone....The gloves are off now" (quoted in McGrath and Jorgenson 2019).

US supply chain controls are also damaging leading foreign suppliers in US partner countries, such as Taiwan's TSMC or ASML in the Netherlands, which are losing important Chinese customers. Sooner or later, these foreign suppliers will find ways to circumvent the US origin restrictions. And they will attempt to design out US content altogether. Research by the CNAS finds that foreign entities impacted by US export controls often find ways to sidestep US origin restrictions or seek ways to design out US content altogether (Rasser 2020). For example, during an earnings call on October 14, 2020, Peter Wennink, CEO of Dutch photolithography manufacturer ASML, noted that the firm was looking at non-US alternatives for metrology process tools to sidestep export restrictions (Reuters 2020). CNAS also finds that "export controls can incentivize end users to manipulate the value of non-U.S. inputs, such as by increasing the cost of foreign labor or materials. It also could prompt U.S. companies to move operations abroad" (Rasser 2020).

Trust and Innovation

In short, discriminatory supply chain regulation has eroded trust across multiple layers of the semiconductor supply chain. However, trust is the essential prerequisite for innovation within complex multi-layered global semiconductor supply chains. Trust is the glue that has kept supply chains growing. Most importantly, trust is the lifeblood of innovation.

This is so because innovation involves exploring unknown territory, which gives rise to uncertainty and risk. According to Bart Nooteboom (2013) at Groningen University, "One needs trust under uncertainty and in innovation uncertainty is high. If one were certain about conditions, conduct and outcomes one would no longer talk about trust." Trust is even more critical for innovation within complex multi-layered global supply chains. Innovation within global supply chains increases risk even further. As we saw, this is due to the diversity of stakeholders, and the increasing length and depth of these supply chains in the semiconductor industry.

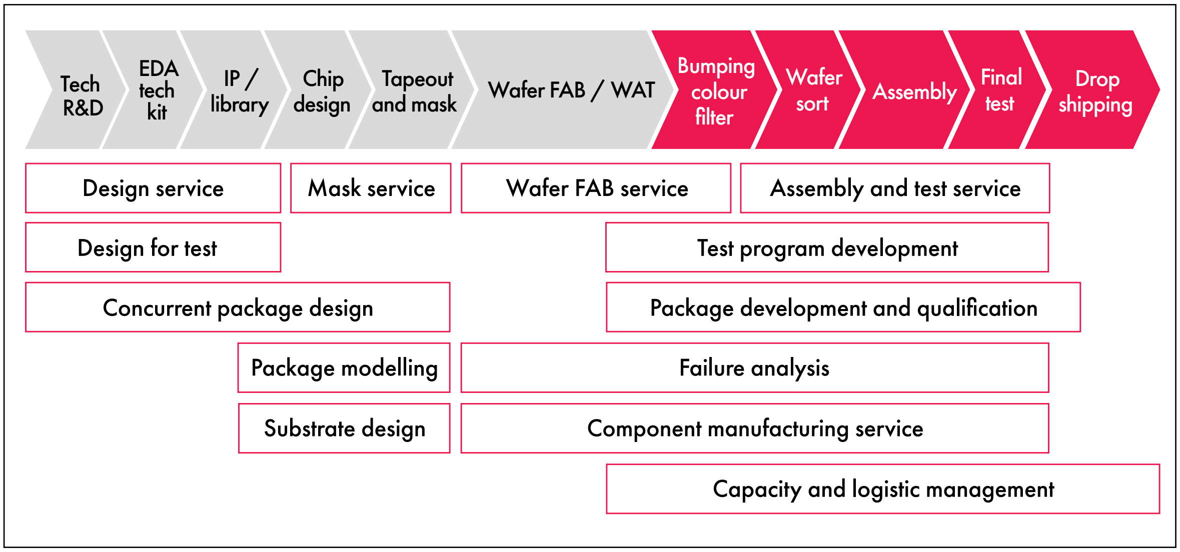
Trust Is Critical for Chip Design

Chip design provides an important example of the supply chain complexity challenge. Figure 2 identifies 13 different types of chip design support services. These services can be provided by individual specialized service providers. Or they can be consolidated in one chip design service package provided, for instance, by a foundry such as TSMC.

Knowledge exchange across the chip development cycle has experienced far-reaching changes, increasing uncertainty and the need for trust-based interactions.[58] Based on standard interfaces

58 For a detailed analysis, see Ernst (2005). See also, more recently, Ernst (2018a).

Figure 2: Integrated Circuit Development Cycle Stages



Source: Ernst and Naughton (2012).
Note: FAB = fabrication; WAT = wafer acceptance testing.

and design rules, the division of labour was reasonably simple during much of the 1990s. Engineers designed chips and handed the definition to the mask makers, who then sent the masks to the semiconductor manufacturers (the silicon foundries such as TSMC). And (most of the time, at least) the result of having this modular division of labour was a chip that could be manufactured at an acceptable yield.

However, this easy phase of knowledge exchange between integrated circuit design and fabrication has vanished permanently. As process technology has dramatically increased in complexity, intense interactions are required across all stages of the semiconductor value chain, and it is no longer possible to work with standard interfaces and design rules. Chip design teams now must share data and exchange knowledge with mask makers and wafer fabricators, i.e., foundries.[59] But implementing such knowledge exchange across multi-layered supply chains is a tortuous process, due to rising uncertainty and dwindling trust. Discriminatory supply chain controls against China have been an important impediment, as they disrupt long-established ways of person-to-person knowledge exchange.

In the end, without trust, knowledge sharing and innovation within global supply chains will suffocate. As a result, discriminatory supply chain controls may fundamentally distort the semiconductor innovation system. The aforementioned Brookings Institution survey of global technology executives concludes that technology competition is an "ecosystem game," which critically constrains the scope for innovation policy shaped by geopolitics (Thomas and Wu 2021). Under such conditions, "U.S. policies will be unlikely to convince the CCP not to pursue building a Chinese-dominated tech ecosystem and will be unlikely to convince multinational companies to avoid investing in such a Chinese ecosystem" (ibid.).

Conclusions

This paper has examined implementation problems and unintended consequences of a new supply chain doctrine in the service of geopolitics. The analysis is focused on President Biden's Executive Order on America's Supply Chains to protect US technological leadership and national security against China. With semiconductors as a primary target, America's supply chain controls are designed to exploit China's most glaring weaknesses as supply chain chokepoints that

59 As a result, knowledge sharing across global supply chains has raised new challenges for the management of IP, in particular standard-essential patents. These issues will be discussed in a separate paper.

the US Commerce Department can block, thus impeding timely and cost-effective access to essential products, services and technologies.

The paper also highlights a second defining characteristic of America's supply chain doctrine — regulatory supply chain controls are combined with a big push in domestic semiconductor manufacturing. Supply chain regulation thus is complemented by US Congress legislation, such as the CHIPS for America Act, the Endless Frontier Act and other related laws.

Three propositions are presented as guideposts for further research.

First Proposition

The concept of asymmetric interdependence can help to cut through the maze of conflicting perceptions of US-China semiconductor supply chain linkages and its impacts. There is ample evidence that the United States continues to hold a substantial overall lead across all R&D-intensive stages of the semiconductor supply chain. Despite all its efforts, China has not significantly reduced the technology gap in semiconductors between itself and the United States. The idea that the United States could lose its edge in advanced semiconductors is simply not supported by evidence.

It is time to acknowledge that the United States and China differ in how they perceive policy implications from asymmetric supply chain interdependence in semiconductors.

For China, US dominance provides a powerful signal that both the government and industry now need to strengthen the country's own innovation capabilities in semiconductors. Attracting foreign technology and talent continues to matter. Increasingly, however, standards development, as well as IPR and antitrust enforcement, will need to move to the centre of China's industrial policy for semiconductors.

In the United States, policy debates about asymmetric semiconductor supply chain interdependence with China are divided into two camps. On the one side are those in the defence and security apparatus who argue that China threatens US leadership in semiconductors, and that this threat will materialize sooner rather than later. The overriding concern is security, which is broadly defined in terms of America's geopolitical grand strategy. On the other side are proponents of a more pragmatic approach, emphasizing that the unequal geographic distribution of semiconductor manufacturing focused on East Asia could easily disrupt the supply of critical chips. The main proponents are US semiconductor and IT firms that need continuous access to the huge China market.

In short, while a broad consensus exists across US policy elites that China poses a threat to US leadership, the implementation of US supply chain controls against China is hampered by conflicting interests between the government's focus on geopolitics and industry's commercial interests. This raises an important question for further research: Is supply chain regulation in the service of geopolitics creating frictions within America's "iron triangle" that used to unite business, government and large sections of academia in the pursuit of IP protection?[60]

An important finding is that the fragmented policy setting in US supply chain controls constrains America's response to China's semiconductor industrial policy. Simply copying China's reliance on subsidies will not pass the checks and balances imposed by the US Congress, especially in the Senate. This is highlighted by the difficult birth of the American Innovation and Competition Act, which — after months of haggling — is still searching for ways to bring together the Endless Frontier Act, the CHIPS for America Act and several other pieces of China legislation.

In addition, the suggested "minimum viable capacity" strategy for expanding US semiconductor production is facing considerable problems from both the demand and the supply side. On the demand side, it is unclear whether nine percent of US semiconductor consumption is sufficient to provide the minimum economies of scale needed for cost-effective production. On the supply side, there are signs that the race is on for lavish subsidies. Opposition to such subsidies, perceived to be "corporate welfare," has emerged in the US Congress across party lines.

A global race to expand domestic semiconductor production on national security grounds is rapidly gaining momentum among the United States, China, Taiwan, South Korea, Japan and Europe. While much of these investments are focused on

60 On America's "iron triangle" see Balsillie (2020).

leading-edge devices, investments in trailing-node chips are also increasing, driven by the needs of the car industry. It is unclear how economically viable the resulting capacity expansion will be. At some stage, the current chip shortage may well give way to disruptive and extremely costly overcapacity.

Second Proposition

The paper has explored in quite some detail implementation problems for US efforts to block supply chain chokepoints, both internationally and at home. As global supply chains in semiconductors have become longer and deeper, this involves a greater diversity of stakeholders at multiple supply chain layers. An important finding is that with rising supply chain complexity, it becomes more difficult and costly to implement effective regulatory supply chain controls against China. Domestically, the US government will need to create new processes to improve the transparency of regulatory processes, strengthen interagency coordination and address legal enforcement loopholes, recruitment problems and budgetary requirements.

US supply chain regulations no doubt are restraining China's semiconductor industry. Nevertheless, the above implementation constraints are raising doubts about the effectiveness of US supply chain regulation against China. America's strategy to block supply chain chokepoints against China are constrained by persistent limitations to cooperation between the United States and its allies. There is little evidence, however, that this has changed US policy. The deeply entrenched fear of China's threat to US technology leadership continues to place geopolitics at the centre of America's supply chain controls against China.

In addition, as semiconductor supply chains are strained by multiple bottlenecks, giving rise to severe chip shortages, this is arguably the worst time to experiment with discriminatory supply chain controls against a geopolitical rival. As chip demand exceeds supply, this has prompted stunning levels of investment in new supply. The United States, China, Europe and Japan are all pursuing self-sufficiency in IC on national security grounds. This significantly increases the risk of excess chip factory capacity.

Third Proposition

Supply chain regulation can be a formidable tool to protect a country's resilience against unexpected disruptions of trade, investment and the supply of skilled labour. It could help to correct the heavy regional concentration of semiconductor manufacturing. However, the utility of supply chain regulation is eroded when geopolitics rather than economics become the primary objective.

While the United States is still the world's technology leader in semiconductors, it is now facing new predicaments. To the degree that China is gradually catching up in important technologies, America will face fewer opportunities for imposing supply chain controls against that country. Once new additional capacity comes on stream outside the United States, China can access critical technologies from other non-American sources in Japan and Europe. America's regulatory supply chain controls against China are thus imposing collateral damage on its own industry, public research labs and universities.

Small and medium-sized US suppliers will suffer, in particular, as compliance with complex administrative procedures is costly and time-consuming. Business will be lost to foreign competitors.

Most importantly, US supply chain controls against China have eroded trust across multiple layers of the semiconductor supply chain. Without trust, knowledge sharing and innovation will suffocate, distorting the global semiconductor innovation system.

In light of the findings of this paper, how will this affect future US policy on the control of semiconductor supply chains against China? Will the logic of geopolitics continue to dominate, resulting in a big push to obstruct China's capacity to import advanced semiconductor technology? Or are we going to see a gradual mellowing of such policies, as the attention begins to shift to the real issue — the unequal geographic distribution of advanced semiconductor manufacturing that may easily disrupt global semiconductor supply chains?

All we can say at this stage is that the current widespread shortage of semiconductors may act as a catalyst for change. Companies and governments around the world face increasing pressure to improve the resilience of global semiconductor supply chains. Practically every industry today depends on secure access to semiconductors. Reducing the heavy regional concentration of chip manufacturing is of critical importance for many countries, not just for the United States.

This raises an important issue. Instead of each country trying to become self-sufficient, a better way to deal with supply chain vulnerabilities caused by geographic concentration would be to negotiate (for instance within the World Trade Organization [WTO]) a plurilateral trade agreement similar to the Information Technology Agreement (Ernst 2018b) that would help to stabilize access to semiconductors for member countries. In today's world of rising economic nationalism, it may take quite a while to work out such a solution. But other second-best solutions might exist that could help to facilitate progress to such a WTO trade agreement. For instance, an industry-led approach to increase diversification could be implemented through the World Semiconductor Council. This organization has a proven record in bringing together industry leaders from the United States, Korea, Japan, Europe, China and Taiwan to address issues of global concern to the semiconductor industry.[61]

In the end, however, it is unclear whether the quest for improved supply chain resilience will mobilize enough forces to shift the focus of US policy away from supply chain regulation in the service of geopolitics. Too powerful is the cross-party consensus in US Congress that China now poses an existential threat to US leadership in advanced technology, and that this will erode America's security and military strength. At the same time, the vicious circle of US sanctions and Chinese countermeasures seems to have silenced voices for reconciliation in both countries.

61 See www.semiconductorcouncil.org/.

Works Cited

Allen-Ebrahimian, Bethany. 2021. "Biden's whole-of-National Security Council strategy." Axios, February 2. www.axios.com/bidens-whole-of-national-security-council-strategy-431454bb-43dc-45ef-9ccc-8a3f229ba598.html.

Art, Robert. 2009. *America's Grand Strategy and World Politics*. New York, NY: Routledge.

Atkinson, Robert D. 2021a. *A U.S. Grand Strategy for the Global Digital Economy. Information Technology & Innovation Foundation*. January. https://itif.org/sites/default/files/2021-us-grand-strategy-global-digital-economy.pdf.

———. 2021b. "Time for a New National Innovation System for Security and Prosperity." *Prism* 9 (2): 59–75. www2.itif.org/2021-PRISM-9-2-new-national-innovation-system.pdf?_ga=2.62925423.1764265543.1616441978-149779233.1616441978.

Automotive News. 2021. "Trump's China tech policy hits automakers as chips run short." January 15. www.autonews.com/manufacturing/trumps-china-tech-policy-hits-automakers-chips-run-short.

Balsillie, Jim. 2020. "Long-awaited Patent Collective's arrival one small step for Ottawa, one giant leap for Canada's innovation economy." *The Globe and Mail*, December 4. www.theglobeandmail.com/business/commentary/article-long-awaited-patent-collectives-arrival-one-small-step-for-ottawa/.

BCG. 2021. "Achieving Supply Chain Resilience in a Volatile World." PowerPoint Presentation. July. https://media-publications.bcg.com/BCG-Executive-Perspectives-Supply-Chain-Resilience-in-Volatile-World.pdf.

Blackwill, Robert D. and Jennifer Harris. 2016. *War by Other Means: Geoeconomics and Statecraft*. 1st ed. Cambridge, MA: Belknap Press.

Bremmer, Ian and Cliff Kupchan. 2021. *Top Risks 2021*. New York, NY: Eurasia Group. www.eurasiagroup.net/files/upload/top-risks-2021-full-report.pdf

Brennan, David. 2021. "Endless U.S.-China Contest Risks 'Catastrophic' Conflict, Henry Kissinger Warns." *Newsweek*, March 26. www.newsweek.com/endless-us-china-contest-catastrophic-conflict-henrykissinger-1579010.

Brown, Michael. 2021. "The Next 5 Years of Defense Innovation with Eric Schmidt, Michael Brown and Dr. Amy Zegart." Defense Innovation Unit webinar, March 16. www.diu.mil/latest/the-next-5-years-of-defense-innovation-with-eric-schmidt-michael-brown-and.

Carlson, Kara and Bob Sechler. 2021. "Samsung wants $1 billion tax incentive for new Austin plant that would create 1,800 jobs." *Austin American-Statesman*, February 4. www.statesman.com/story/business/2021/02/04/samsung-austin-expansion-chip-plant-seeks-1-billion-taxpayer-incentives/4309503001/.

Chen, Celia. 2021. "Huawei under no 'illusion' about US lifting sanctions but will keep chip-making unit as it fights for survival." *South China Morning Post*, April 12. www.scmp.com/tech/big-tech/article/3129254/huawei-under-no-illusion-about-us-lifting-sanctions-will-keep-chip.

Ciuriak, Dan. 2020. *Economic Rents and the Contours of Conflict in the Data-driven Economy*. CIGI Paper No. 245. Waterloo, ON: CIGI. www.cigionline.org/publications/economic-rents-and-contours-conflict-data-driven-economy.

Crowley, Michael and Steven Erlanger. 2021. "Biden's Plan to Link Arms with Europe Against Russia and China Isn't So Simple." *The New York Times*, February 18. www.nytimes.com/2021/02/18/us/politics/biden-europe-russia-china.html.

CRS. 2021. "China's 14th Five-Year Plan: A First Look." January 5. https://crsreports.congress.gov/product/pdf/IF/IF11684.

Danzig, Richard J. and Lorand Laskai. 2020. *Symbiosis and Strife: Where Is the Sino–American Relationship Bound?* An Introduction to the APL Series "Measure Twice, Cut Once: Assessing Some China–US Technology Connections." www.jhuapl.edu/assessing-us-china-technology-connections/dist/4c1e745c6c71b0fea0e5224d9bca4b03.pdf.

Dempsey, Harry. 2021. "Chip shortage to last until at least mid-2022, warns manufacturer." *Financial Times*, June 6.

DoD. 2020. *Fiscal Year 2020 — Industrial Capabilities: Report to Congress*. Washington, DC: DoD. https://media.defense.gov/2021/Jan/14/2002565311/-1/-1/0/FY20-INDUSTRIAL-CAPABILITIES-REPORT.PDF.

Dollar, David. 2021 "What does Biden's first 100 days tell us about his approach to China?" *FixGov* (blog), April 26. www.brookings.edu/blog/fixgov/2021/04/26/what-does-bidens-first-100-days-tell-us-about-his-approach-to-china/.

Editors. 1984. "Extraterritorial Application of United States Law: The Case of Export Controls." *University of Pennsylvania Law Review* 132. https://scholarship.law.upenn.edu/cgi/viewcontent.cgi?referer=https://www.google.com/&httpsredir=1&article=4628&context=penn_law_review.

Emmott, Robin. 2021. "EU parliament freezes China deal ratification until Beijing lifts sanctions." Reuters, May 20. www.reuters.com/world/china/eu-parliament-freezes-china-deal-ratification-until-beijing-lifts-sanctions-2021-05-20/.

Ernst, Dieter. 1983. *The Global Race in Microelectronics: Innovation and Corporate Strategies in a Period of Crisis.* Frankfurt, Germany: Campus Verlag.

———. 2005. "Limits to Modularity — Reflections on Recent Developments in Chip Design." *Industry and Innovation* 12 (3): 303–35.

———. 2009. *A New Geography of Knowledge in the Electronics Industry? Asia's Role in Global Innovation Networks.* Policy Studies, No. 54. August. Honolulu, HI: East-West Center.

———. 2011. "China's Innovation Policy is a Wake-Up Call for America." *Asia Pacific Issue*, Analysis from the East-West Center No. 100. May. http://papers.ssrn.com/sol3/papers.cfm?abstract_id=2770063.

———. 2018a. "Beyond Value Capture — Exploring Innovation Gains from Global Networks." In *Megaregionalism 2.0: Trade and Innovation within Global Networks*, edited by Dieter Ernst and Michael G. Plummer. World Scientific Studies in International Economics. Vol. 67. Singapore: World Scientific Publishing.

———. 2018b. "The Information Technology Agreement, Manufacturing and Innovation — China's and India's Contrasting Experiences." In *Megaregionalism 2.0: Trade and Innovation within Global Networks*, edited by Dieter Ernst and Michael G. Plummer. World Scientific Studies in International Economics. Vol. 67. Singapore: World Scientific Publishing.

———. 2020. *Competing in Artificial Intelligence Chips: China's Challenge amid Technology War.* Special Report. Waterloo, ON: CIGI. www.cigionline.org/publications/competing-artificial-intelligence-chips-chinas-challenge-amid-technology-war/.

Ernst, Dieter and Barry Naughton. 2012. "Global Technology Sourcing in China's Integrated Circuit Design Industry: A Conceptual Framework and Preliminary Findings." East-West Center Working Paper No. 131. August. https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2390980.

Ewing, Jack and Don Clark. 2021. "Lack of Tiny Parts Disrupts Auto Factories Worldwide." *The New York Times*, January 13. www.nytimes.com/2021/01/13/business/auto-factories-semiconductor-chips.html.

Farrell, Henry and Abraham L. Newman. 2019. "Weaponized Interdependence: How Global Economic Networks Shape State Coercion." *International Security* 44 (1): 42–79.

FP Analytics. 2021. "Semiconductors and the U.S.-China Innovation Race." *Foreign Policy*, February 16. https://foreignpolicy.com/2021/02/16/semiconductors-us-china-taiwan-technology-innovation-competition/.

GAO. 2021. "U.S.-China Trade: USTR Should Fully Document Internal Procedures for Making Tariff Exclusion and Extension Decisions." July 28. www.gao.gov/products/gao-21-506.

Garamone, Jim. 2021. "China Task Force Begins Work; DOD Makes Progress on COVID-19." U.S. Department of Defense, March 1. www.defense.gov/Explore/News/Article/Article/2519254/china-task-force-begins-work-dod-makes-progress-on-covid-19/.

Gartner. 2021. "Gartner Says Global Chip Shortage Expected to Persist Until Second Quarter of 2022." Press Release, May 12. www.gartner.com/en/newsroom/press-releases/2021-05-12-gartner-says-global-chip-shortage-expected-to-persist-until-second-quarter-of-2022.

Goodrich, Jimmy and Zhi Su. 2020. "The U.S. Should be Concerned with its Declining Share of Chip Manufacturing, Not the Tiny Fraction of U.S. Chips Made in China." *SIA blog*, July 10. www.semiconductors.org/the-largest-share-of-u-s-industry-fab-capacity-is-in-the-united-states-not-china-lets-keep-it-that-way/.

Gros, Daniel. 2020. "The US Must Accept China's Rise." Project Syndicate, November 5. www.project-syndicate.org/commentary/us-china-competition-high-tech-sectors-by-daniel-gros-2020-11.

He, Alex. 2021. *China's Techno-Industrial Development: A Case Study of the Semiconductor Industry*. CIGI Paper No. 252. Waterloo, ON: CIGI. www.cigionline.org/publications/chinas-techno-industrial-development-case-study-semiconductor-industry/.

Hille, Kathrin. 2021. "TSMC: how a Taiwanese chipmaker became a linchpin of the global economy." *Financial Times*, March 23.

Hille, Kathrin and Yuan Yang. 2021. "Boardroom drama shakes China's biggest chipmaker SMIC." *Financial Times*, January 19.

Hirschman, Albert O. 1945. *National Power and the Structure of Foreign Trade.* Berkeley, CA: University of California Press.

Howard, Michael. 2006. *Captain Professor: A Life in War and Peace*. New York, NY: Bloomsbury.

Hunt, Will, Saif M. Khan and Dahlia Peterson. 2021. "China's Progress in Semiconductor Manufacturing Equipment: Accelerants and Policy Implications." CSET Policy Brief. March. https://cset.georgetown.edu/wp-content/uploads/CSET-Chinas-Progress-in-Semiconductor-Manufacturing-Equipment.pdf.

Inside U.S. Trade's World Trade Online. 2020. "Biden faces challenges in cooperating with China — and, with allies, against it." December 31. https://insidetrade.com/daily-news/biden-faces-challenges-cooperating-china-and-allies-against-it.

———. 2021a. "Senators introduce bill to create Commerce 'supply chain preparedness' office." March 19. https://insidetrade.com/trade/senators-introduce-bill-create-commerce-%E2%80%98supply-chain-preparedness%E2%80%99-office.

———. 2021b. "Final ICTS rule offers some clarity, still gives Commerce broad authority." January 15. https://insidetrade.com/daily-news/final-icts-rule-offers-some-clarity-still-gives-commerce-broad-authority.

———. 2021c. "Top Chinese official calls for high-tech cooperation, others push self-reliance." January 29. https://insidetrade.com/daily-news/top-chinese-official-calls-high-tech-cooperation-others-push-self-reliance.

———. 2021d. "China moves to attract foreign investment to bolster high-tech sectors." March 4. https://insidetrade.com/daily-news/china-moves-attract-foreign-investment-bolster-high-tech-sectors.

———. 2021e. "China launches semiconductor standards group seen as part of decoupling effort." February 5. https://insidetrade.com/daily-news/china-launches-semiconductor-standards-group-seen-part-decoupling-effort.

———. 2021f. "Sen. Cotton: U.S. must expand restrictions on inbound, outbound Chinese investment." February 19. https://insidetrade.com/trade/sen-cotton-us-must-expand-restrictions-inbound-outbound-chinese-investment.

———. 2021g. "China check-in: China bill opposition from the far left and the far right." https://insidetrade.com/trade/china-check-china-bill-opposition-far-left-and-far-right.

———. 2021h. *China Trade & Tech*, May 14. https://insidetrade.com/china-trade-tech-alert.

———. 2021i. "Senate panel overhauls Endless Frontier Act, cuts funds for new NSF tech arm." *China Trade & Tech*, May 13. https://insidetrade.com/daily-news/senate-panel-overhauls-endless-frontier-act-cuts-funds-new-nsf-tech-arm.

———. 2021j. "Senate passes the American Innovation and Competition Act." June 8. https://insidetrade.com/daily-news/senate-passes-american-innovation-and-competition-act.

———. 2021k. "Senate Foreign Relations panel: Use trade negotiations to counter China." April 8. https://insidetrade.com/daily-news/senate-foreign-relations-panel-use-trade-negotiations-counter-china.

———. 2021l. *China Trade & Tech*, July 2. https://insidetrade.com/china-trade-tech-alert.

———. 2021m. *China Trade & Tech*, June 11. https://insidetrade.com/china-trade-tech-alert.

———. 2021n. "Barshefsky: EU may 'fall short' in cooperating with U.S. to counter China." May 20. https://insidetrade.com/trade/barshefsky-eu-may-%E2%80%98fall-short%E2%80%99-cooperating-us-counter-china.

———. 2021o. "Semiconductor supply review welcomed by industry, but won't be a quick fix." *China Trade & Tech*, February 19. https://insidetrade.com/daily-news/semiconductor-supply-review-welcomed-industry-won%E2%80%99t-be-quick-fix.

———. 2021p. "Commerce outlines business costs for compliance with ICT supply chain rule." February 18. https://insidetrade.com/daily-news/commerce-outlines-business-costs-compliance-ict-supply-chain-rule.

———. 2021q. "Biden announces picks for BIS, senior Commerce enforcement slot." July 13. https://insidetrade.com/trade/biden-announces-picks-bis-senior-commerce-enforcement-slot.

———. 2021r. "HASC chairman: U.S. must accept competition with China, not aim for dominance." *China Trade & Tech*, March 23. https://insidetrade.com/daily-news/hasc-chairman-us-must-accept-competition-china-not-aim-dominance.

Kennan, George F. 2020. *Memoirs 1950–1963*. Lexington, MA: Plunkett Lake Press. Originally published in 1972 by Atlantic-Little, Brown.

Khan, Saif M. 2021. *Securing Semiconductor Supply Chains*. CSET Policy Brief. January. https://cset.georgetown.edu/wp-content/uploads/Securing-Semiconductor-Supply-Chains-Policy-Brief.pdf.

Khan, Saif M., Alexander Mann and Dahlia Peterson. 2021. "The Semiconductor Supply Chain: Assessing National Competitiveness." CSET Issue Brief. January. https://cset.georgetown.edu/publication/the-semiconductor-supply-chain/

Lee, Yen Nee. 2021. "EU-China investment deal is still possible — but not before 2023, analyst says." CNBC, June 15. www.cnbc.com/2021/06/15/eu-china-investment-deal-still-possible-but-not-before-2023-analyst.html.

Lovely, Mary E. and Jeffrey J. Schott. 2021. "Can China Blunt the Impact of New US Economic Sanctions?" Peterson Institute for International Economics Policy Brief. June. www.piie.com/sites/default/files/documents/pb21-13.pdf.

Maroney, Patrick and Jeff Howell. 2021. "Reimagining the Semiconductor Supply Chain to Prevent the Next Chip Shortage." EET Asia, May 14. www.eetasia.com/reimagining-the-semiconductor-supply-chain-to-prevent-the-next-chip-shortage/.

McGrath, Dylan and Barb Jorgenson. 2019. "Huawei Ban May Prove to Haunt US." EET India, June 11.

Moore, Samuel K. 2021. "U.S. Takes Strategic Step to Onshore Electronics Manufacturing." IEEE Spectrum, January 6. https://spectrum.ieee.org/tech-talk/semiconductors/processors/us-takes-strategic-step-to-onshore-electronics-manufacturing.

Nippon.com. 2021. "Japanese Ministry Proposes Boosting Chip Production." March 24. www.nippon.com/en/news/yjj2021032401098/.

Nooteboom, Bart. 2013 "Trust and Innovation." In *Handbook of Advances in Trust Research*, edited by Reinhard Bachmann and Akbar Zaheer. Northampton, MA: Edward Elgar Publishing.

NSCAI. 2021. *Final Report*. www.nscai.gov/wp-content/uploads/2021/03/Full-Report-Digital-1.pdf.

Obama, Barack. 2016. "Remarks of President Barack Obama — State of the Union Address As Delivered." The White House. January 13. https://obamawhitehouse.archives.gov/the-press-office/2016/01/12/remarks-president-barack-obama-%E2%80%93-prepared-delivery-state-union-address.

O'Hanlon, Michael. 2021. *The Art of War in an Age of Peace: U.S. Grand Strategy and Resolute Restraint.* New Haven, CT: Yale University Press.

Pan, Che. 2021. "US-China tech war: Beijing's top policy official lays out strategy to address Washington's 'stranglehold' over China." *South China Morning Post*, January 26. www.scmp.com/tech/policy/article/3119294/us-china-tech-war-beijings-top-policy-official-lays-out-strategy.

Petri, Peter A. 1984. *Modeling Japanese-American Trade: A Study of Asymmetric Interdependence.* Cambridge, MA: Harvard University Press.

Pettit, Timothy J., Joseph Fiksel and Keely L. Croxton. 2010. "Ensuring Supply chain resilience: Development of a Conceptual Framework." *Journal of Business Logistics* 31 (1). doi:10.1002/j.2158-1592.2010.tb00125.x.

Ramaswamy, Sree. 2021. "Biden Officials Discuss White House Supply Chain Report." Virtual Webinar, June 16. Information Technology & Innovation Foundation. https://itif.org/events/2021/06/16/biden-officials-discuss-white-house-supply-chain-report.

Randall, Stewart. 2019. "Why Chinese EDA tools lag behind." TechNode, November 13. https://technode.com/2019/11/13/silicon-why-chinese-eda-tools-lag-behind/.

Rasser, Martijn. 2020. "Rethinking Export Controls: Unintended Consequences and the New Technological Landscape." CNAS, December 8. www.cnas.org/publications/reports/rethinking-export-controls-unintended-consequences-and-the-new-technological-landscape.

Reuters. 2020. "Edited Transcript of ASML.AS earnings conference call or presentation 14-Oct-20 1:00pm GMT." October 14. www.yahoo.com/amphtml/now/edited-transcript-asml-earnings-conference-130000661.html.

Scheiber, Noam. 2021. "The Biden Team Wants to Transform the Economy. Really." *The New York Times Magazine*, February 11.

Schulman, Loren DeJonge and Ainikki Riikonen. 2021. *Trust the Process: National Technology Strategy Development, Implementation, and Monitoring and Evaluation.* Washington, DC: CNAS. www.cnas.org/publications/reports/trust-the-process.

Segal, Adam. 2019. *Innovation and National Security: Keeping Our Edge.* Independent Task Force Report No. 77. September. New York, NY: Council on Foreign Relations.

Sevastopulo, Demetri, Sam Fleming and Michael Peel. 2021. "Will Europe sign up to Joe Biden's plan to counter China?" *Financial Times*, June 6.

Shen, Jessie. 2021. "Global chip shortage to persist until 2Q22, says Gartner." DIGITIMES, May 13.

Sherman, Justin. 2021. "The U.S. Is Continuing Its Campaign Against Huawei." *Lawfare* (blog), July 20. www.lawfareblog.com/us-continuing-its-campaign-against-huawei.

SIA. 2020. **2020** *State of the U.S. Semiconductor Industry.* www.semiconductors.org/wp-content/uploads/2020/06/2020-SIA-State-of-the-Industry-Report.pdf.

———. 2021a. "Semiconductor Industry Leaders Urge President Biden to Prioritize Funding for Semiconductor Manufacturing, Research." February 11. www.semiconductors.org/semiconductor-industry-leaders-urge-president-biden-to-prioritize-funding-for-semiconductor-manufacturing-research/.

———. 2021b. "SIA Whitepaper: Taking Stock of China's Semiconductor Industry." www.semiconductors.org/wp-content/uploads/2021/07/Taking-Stock-of-China%E2%80%99s-Semiconductor-Industry_final.pdf.

Tang, Frank. 2020. "US technology embargo list gives China a blueprint for home-grown innovation over the next decade, top science official says." *South China Morning Post*, September 17. www.scmp.com/economy/china-economy/article/3101948/us-technology-embargo-list-gives-china-blueprint-home-grown?mc_cid=e4d53b3d67&mc_eid=c1f9a346a7.

Terblanche, Ian. 2021. "Building resilience into a Supply Chain 4.0 strategy." Supply Chain, May 30. https://supplychaindigital.com/digital-supply-chain/building-resilience-supply-chain-40-strategy.

The White House. 2021a. *Building Resilient Supply Chains, Revitalizing American Manufacturing, and Fostering Broad-Based Growth*. 100-Day Reviews under Executive Order 14017. June. www.whitehouse.gov/wp-content/uploads/2021/06/100-day-supply-chain-review-report.pdf.

———. 2021b. *Renewing America's Advantages: Interim National Security Strategic Guidance*. March. www.whitehouse.gov/wp-content/uploads/2021/03/NSC-1v2.pdf.

———. 2021c. "Readout of White House CEO Summit on Semiconductor and Supply Chain Resilience." April 12. www.whitehouse.gov/briefing-room/statements-releases/2021/04/12/readout-of-white-house-ceo-summit-on-semiconductor-and-supply-chain-resilience/.

Thomas, Christopher A. and Xander Wu. 2021. "How global tech executives view U.S.-China tech competition." TechStream, February 25. www.brookings.edu/techstream/how-global-tech-executives-view-u-s-china-tech-competition/.

Ting-Fang, Cheng and Lauly Li. 2020. "China chipmakers speed up effort to cut reliance on US supplies." *Nikkei Asia*, September 9. https://asia.nikkei.com/Politics/International-relations/US-China-tensions/China-chipmakers-speed-up-effort-to-cut-reliance-on-US-supplies.

———. 2021a. "China ousts Taiwan as Apple's biggest source of suppliers." *Nikkei Asia*, June 2. https://asia.nikkei.com/Business/China-tech/China-ousts-Taiwan-as-Apple-s-biggest-source-of-suppliers.

———. 2021b. "China's top chipmaker SMIC says US restrictions hampering growth." *Nikkei Asia*, February 5. https://asia.nikkei.com/Business/Tech/Semiconductors/China-s-top-chipmaker-SMIC-says-US-restrictions-hampering-growth.

Tyborski, Roman. 2021. "Conti kooperiert mit Chip-Start-up Recogni." *Handelsblatt*, February 19.

US Chamber of Commerce. 2021. "Global Forum on Economic Recovery." May 19. Video. www.uschamber.com/on-demand/international/global-forum-on-economic-recovery-day-2?autoplay=1.

Varas, Antonio, Raj Varadarajan, Jimmy Goodrich and Falan Yinug. 2020. *Government Incentives and US Competitiveness in Semiconductor Manufacturing*. BCG and SIA. September. www.semiconductors.org/wp-content/uploads/2020/09/Government-Incentives-and-US-Competitiveness-in-Semiconductor-Manufacturing-Sep-2020.pdf.

———. 2021. *Strengthening the Global Semiconductor Supply Chain in an Uncertain Era*. BCG and SIA. April. www.semiconductors.org/wp-content/uploads/2021/04/SIA-BCG-Report_Strengthening-the-Global-Semiconductor-Supply-Chain_April-2021.pdf.

Wang, Dan. 2021. "The future of semiconductors is overcapacity." Gavekal, May 13. https://research.gavekal.com/system/files/The%20Future%20Of%20Chips%20Is%20Overcapacity.pdf.

WilmerHale. 2021. "New Commerce Rule Covering ICTS Transactions Involving Foreign Parties." JD Supra, March 23. www.jdsupra.com/legalnews/new-commerce-rule-covering-icts-9248149/.

Wolf, Martin. 2021. "Containing China is not a feasible option." *Financial Times*, February 2.

Centre for International
Governance Innovation

67 Erb Street West
Waterloo, ON, Canada N2L 6C2
www.cigionline.org

@cigionline