The Battle for Chips

Semiconductors Crucial Role in AI Development and its Implications for U.S.-China Strategic Competition

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I. ABSTRACT

This thesis focuses on the role of U.S. semiconductor companies in developing U.S. and Chinese AI capabilities. I utilized original research including interviews with experts and quantitative financial data as well as government regulatory policies and speeches. I developed two hypotheses focused on a strategic partial decoupling of the U.S-China semiconductor supply chain and U.S.-China strategic competition hampering the state of global semiconductor innovation. The evidence from the data and interview testimony illustrates that the partial decoupling is a necessary step to protect U.S. national security interests due to China's end usage of these chips for AI systems that suppress democracy and threaten U.S. interests. However, the evidence also points to a hampered pace of innovation for the global semiconductor industry that will affect the U.S.'s AI development efforts. These two hypotheses are interrelated, and I explore the effect each one has on the other to illustrate the complex landscape facing U.S. national security policymakers. U.S. semiconductor companies serve as the focal point of these themes and are the primary targets of my data analysis. The thesis also proposes a policy recommendation that threads the needle and balances the importance of innovation with restricting China's access to advanced semiconductor technology. Finally, the thesis concludes by addressing the geopolitical and economic importance of Taiwan and paths forward for future research.

II. INTRODUCTION

Introduction:

IBM defines artificial intelligence as a system that "leverages computers and machines to mimic the problem-solving and decision-making capabilities of the human mind". At its core the field of artificial intelligence is the art of combining computer science and robust data sets to solve problems (IBM, 2004). Advanced AI systems can be applied to a multitude of problems and AI is woven into every aspect of our daily lives and nearly every facet of the global economy. Although AI has nearly unlimited uses and applications, it is becoming increasingly relevant within the national security sphere. Underscoring its importance in 2017, Vladimir Putin famously stated that "Artificial intelligence is the future… whoever becomes the leader in this sphere will become the ruler of the world" (Vincent, 2017). Recent developments in AI are proving one of the most cunning and vicious leaders of the 21st century correct and illustrate the need for the U.S. to address AI's role as it engages in strategic competition with China (NSCAI, 2021).

Semiconductors are not only the lifeblood of the modern economy and digital world but the crucial hardware that AI systems develop and run on (Williams, 2021). The two leading state actors in this field, China, and the United States, are racing to out develop each other while begrudgingly recognizing the interdependent relationship they have in the development of semiconductor chips, the crucial hardware necessary for AI development and the basis of innovation and modern-day computing power (Miller, 2022).

This thesis explores the intersection of semiconductors and AI through a geopolitical lens and identifies the crucial player as U.S. semiconductor companies. Their dominant market share, enormous R&D budgets and global network of suppliers places them in the middle of the U.S.-

China strategic competition and the ongoing global race towards rapid AI development and implementation.

Research Question:

The thesis looks at the role U.S. semiconductor companies are playing in developing both U.S. and Chinese AI capabilities. As U.S. companies have offshored their manufacturing to Asia, many are asking what the implications are for the U.S.'s ability to access a secure supply of chips and whether companies are exporting talent and expertise in their drive to lower costs. These companies face a legal and moral reckoning as reports have emerged of their technology being used by the Chinese government for military applications or to commit human rights abuses. Moreover, for the first time since the end of the Cold War, many are questioning the U.S.'s technological primacy and whether China is closing the gap. Nowhere is that fear more evident than AI because of its numerous applications and revolutionary nature. Policymakers and academics alike worry that a decisive lead in AI development could alter the global balance of power for whoever achieves it first. My question seeks to explore these themes through a central research question:

What role do U.S. semiconductor companies play in developing U.S. and Chinese AI capabilities and what are the implications for U.S. national security?

III. BACKGROUND

AI for National Security:

AI's increasingly important role in U.S. national security is particularly evident in two areas, military modernization, and mass surveillance. Hindering China's development of AI and accelerating U.S. innovation in those two areas will be crucial if the U.S. wants to prevail in its strategic competition with China.

Military Modernization

China views AI as the cornerstone of its military modernization efforts. Many Chinese military leaders are strong proponents of “military intelligentization” or the theory of incorporating AI into every combat system and networking them to work in harmony to maximize for efficiencies and overpower adversaries. They believe this is the future of modern warfare that will relegate human controlled systems to relics of the past (Kania, 2017).

China’s military, the People’s Liberation Army (PLA), sees advancing its AI capabilities as the way to achieve its goal of reaching “strategic party” with the U.S. military (Xuetong, 2021). In 2017, President Xi Jinping established the Military-Civil Fusion Development Commission to coordinate the resources of the government, Chinese universities, and the private sector towards developing innovative AI systems that can be leveraged for military applications. The darker side of this policy is that no commercial technology can be withheld from the military for potential use in combat. The commission’s broad mandates give it wide latitude in directing research investments and repurposing civilian technologies towards the goal of accelerating the PLA’s military capabilities and use of advanced technologies. One of the core tenets of the commission is “leapfrog development”, or the idea that blurring the lines between military and civilian sectors and applying new technologies for military applications will allow China to surpass U.S. military capabilities in certain areas.

Senior leadership within the Communist party believe this commission will give the PLA the necessary tools to allow China to achieve its regional ambitions including the “reunification” of Taiwan and forcibly asserting its claims in the South China Sea. President Xi Jinping rhetoric reflects this sentiment as he has pushed the PLA to “vigorously advance military innovation” and “seize the high ground” (Kania, 2017).

Technologies ranging from autonomous drones that can track and eliminate targets with “minimal human intervention” to augmented reality for combat soldiers, AI is changing every aspect of modern warfare. One of the deadliest applications theorized by military experts is the concept of swarm intelligence which distributes the offensive capabilities of a military force among hundreds of drones, a technique that makes it virtually impossible for current air defense systems to defend against. A swarm intelligence assault by hundreds of drones is considered by both PLA and U.S. military experts to be the best way to overwhelm the defenses of a U.S. aircraft carrier and fifth generation fighter jets. Beijing has also invested in intelligent unmanned surface vehicles (USV), deploying its first USV in 2017. These moves are seen by many as threatening U.S. naval assets operating in the South China Sea and the Taiwan Strait, undermining U.S. power projection in the Indo-Pacific (Kania, 2017).

Mass Surveillance:

China has laid the groundwork for an AI powered mass surveillance system, concentrating all their societies data under the government’s control, introducing more ways to collect data on its citizens, and limiting the power of Chinese and foreign tech companies.

In 2016, President Xi consolidated the numerous internet regulators under the Cyberspace Administration of China (CAC) to crack down on any dissent and improve China’s censorship efforts. Xi installed a new head of the agency, Xu Lin, who publicly stated after his confirmation to the role that his goal was to ensure the Communist Party retains complete control over the internet (Parasol, 2018).

China not only wants tight control of the internet but also unrestricted access to its citizens data as it seeks to integrate devices and entire cities into a connected network that will allow the government to drastically increase their surveillance capabilities as well as improved government services. In the most recent five-year plan, President Xi announced the concept of 'Smart Cities' which utilizes the internet of things (IoT), or millions of devices all connected to the internet, as well metadata, and cloud computing to improve municipal governance such as urban planning, traffic congestion, and the efficiency of city services. AI will power these 'Smart Cities' but more importantly, it will give the Chinese government an unprecedented ability to track and monitor all its citizens. These plans will generate huge amounts of personal information on Chinese citizens and raises the question of which entities have access to this data. China is following a doctrine of "informatization", or the concept of harnessing AI technology to help Chinese leaders determine economic policy and efficiently allocate resources by harnessing the vast amounts of data that an interconnected economy and 'Smart Cities' produce (Parasol, 2018). However, these 'smart cities' have alternative applications that can suppress dissent and infringe on civil liberties. Informatization can just as easily be used to predict political protest and and help authorities track down dissenters with brutal efficiency, exerting a previously unseen level of social control over 1.4 billion Chinese citizens (Lin & Chin, 2022).

China passed a National Intelligence law in 2017 shortly after its cybersecurity law that mandates Chinese and foreign companies work with the Chinese government in the name of national security. The vague language within the law itself gives the government broad leeway to take companies data on its for its own purposes. The law is inherently aggressive, forcing the compliance of Chinese and foreign companies to allow police services to commander equipment and gain access to any private building. This legislation, coupled with the 2016 cybersecurity law, eliminates companies' power to stand up to the party and accelerates the adoption of the informatization theory that party leaders are eagerly seeking to implement as a form of digital social control (Tanner, 2017).

AI Technology Stack:

The AI Technology stack is crucial for understanding semiconductors importance to AI and provides a holistic view of the necessary inputs for a nation seeking to build a robust AI development program. Kevin McGinnis, former Director of Research and Analysis for the National Security Commission on Artificial Intelligence defined the "AI technology stack" as the best way to measure a country's AI development progress and identify points of comparative advantage and disadvantage. The 4 parts of the AI technology stack are *hardware, software, data, and talent*. McGinnis, during our interview, walked me through all four parts to see how China and the U.S. compared in each segment (McGinnis, 2022).

Hardware: McGinnis identified hardware, which encompasses semiconductors, as a place where the U.S. is leading. However, the offshoring of manufacturing makes this advantage precarious. All major chip companies and the manufacturing equipment suppliers are in the U.S. or in U.S. allied countries, giving the U.S. enormous influence over the supply chain. China, on the other hand, is a large market for semiconductors but lacks the manufacturing capacity to meet its own demand

Software: On software, U.S. companies are industry leaders but the open-source nature of many of AI algorithms and China's ability to quickly implement them negates the U.S. advantage on this aspect of the stack. China has been able to use American algorithms effectively within their own systems and it is hard to restrict China's access.

Data: China has a huge advantage with data because it's able to collect vast amounts of data without a concern for privacy concerns or ethical issues unlike the U.S. Xi Jinping has centralized control of China's internet and cybersecurity infrastructure under the CAC and mandating companies share user data with the government, giving the Chinese government the ability to surveil and censor its 731 million internet users. These policies have eliminated the "data siloes" that persist in the U.S., where different entities including the government and companies have access to different data sets but no entity has access to all of them.

Talent: Finally, on talent the U.S. has a big advantage in terms of quality of researchers and programmers considering the best research institutions in the world reside within the U.S. However, China has invested billions training a new generation of STEM engineers that has given them access to a huge quantity of researchers to tap into (McGinnis, 2022).

As a result, the U.S.'s only concrete advantage over China resides within the hardware part of the stack. This places semiconductors at the center of U.S. foreign policy and national security as the U.S. engages in a fierce strategic competition with China.

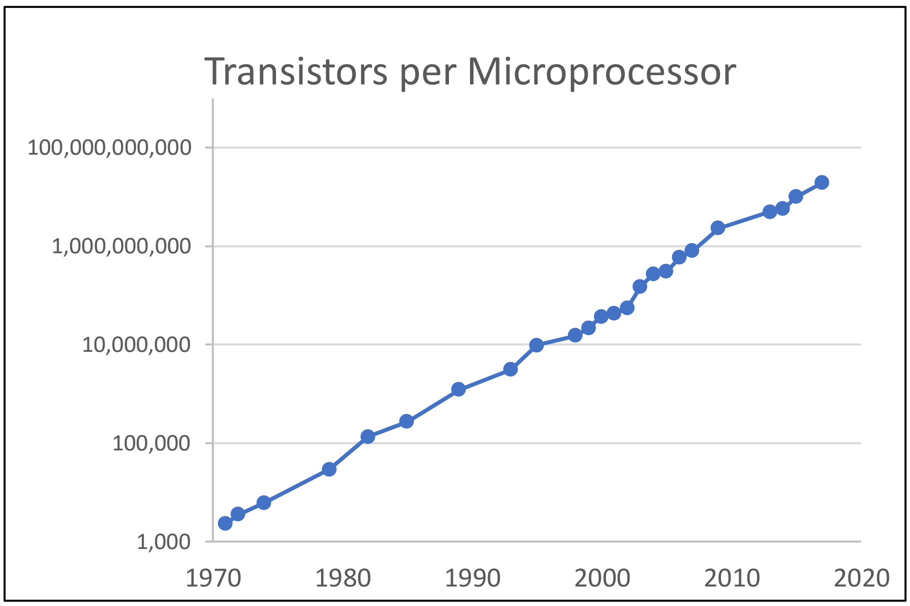
China use of these chips to develop and apply its AI algorithms towards surveilling and repressing their population and advancing their military capabilities is causing many to question the globalized supply chain and the U.S.'s status as global leader in technology and innovation (Parasol, 2018).

Moore's Law:

Moore's Law has been the guiding theory for semiconductor innovation and development for the past sixty years. In 1965, Gordon Moore hypothesized that the number of transistors on microchips will double every two years. The implication was that progress in computing will become exponentially more efficient, faster, and smaller over time. This hypothesis, based on empirical evidence and not any theory of physics has held strong. Although some are beginning to question whether it even still applies, many questioned the continuing relevance of the law in the both the 1980s and early 2000s but were ultimately proven wrong (Miller “Chip War”, 2022).

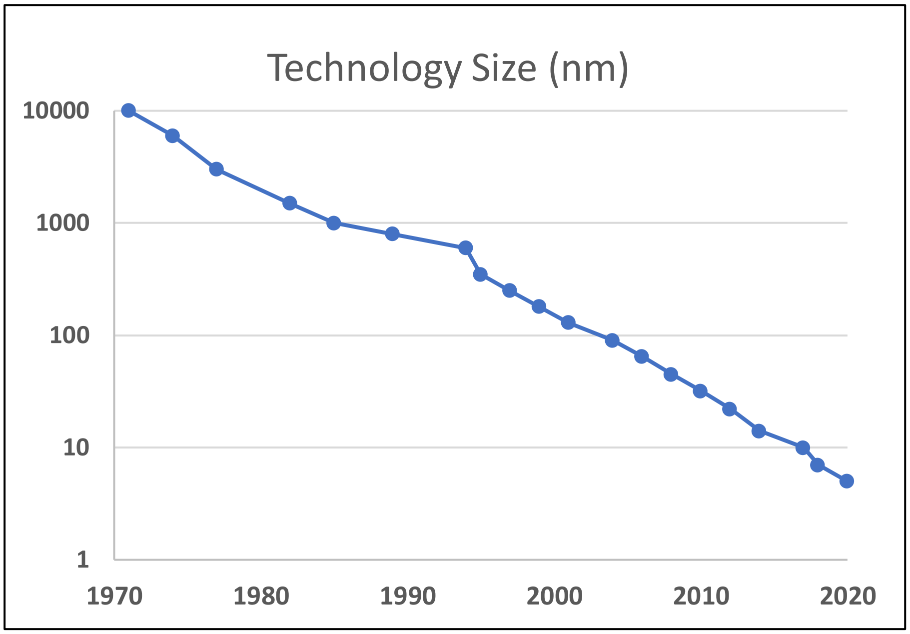
To provide some additional context, a transistor is the tiny node on a chip that relays either a 1 or a 0, the binary language of all digital machines. As the number of transistors number on a chip increases, the applications and computing power increased dramatically (Miller “Chip War”, 2022). Figures 1 & 2 illustrate the exponential progress semiconductors have made since 1960 and the prevalence of Moore’s Law.

Figure 1



Our World in Data: Technological Change, 2022

Figure 2



Our World in Data: Technological Change, 2022

Semiconductor innovation on the number of transistors per chip has heralded fantastic innovations that have transformed our society, from precision guided bombs to the iPhone. Advances in semiconductors and the number of transistors per chip have served as the basis of innovation for computing advances that have radically transformed our society. Artificial Intelligence rests at the same point. As AI algorithms continue to develop, the speed at which they operate and process data as well as their ability to integrate into systems ranging from autonomous vehicles to missiles depends on the advancement of semiconductors (Miller “Chip War”, 2022).

As Chris Miller stated in our interview, software engineers have not gotten ten times smarter in the past twenty years, but chips have increased the modern-day computing power by at least that amount. Advancements in semiconductors have allowed AI systems to collect, store and process more data in an increasingly efficient manner, moving AI systems from huge research laboratories to the pockets of everyday Americans. AI's rising prominence in society is a direct result of the prevalence of Moore's Law within semiconductor innovation (Miller, 2022).

Origins of the Globalized Supply Chain:

U.S. semiconductor companies have long been the source of innovation in designing and manufacturing these chips efficiently and at scale. However, the capital-intensive process of manufacturing these chips has led to long trend of offshoring manufacturing to countries where the cost of labor is far lower. However, along with the offshoring of manufacturing, over time the expertise and innovation behind manufacturing ever more complex chips efficiently and at scale moved offshore as well (Grimes, 2022).

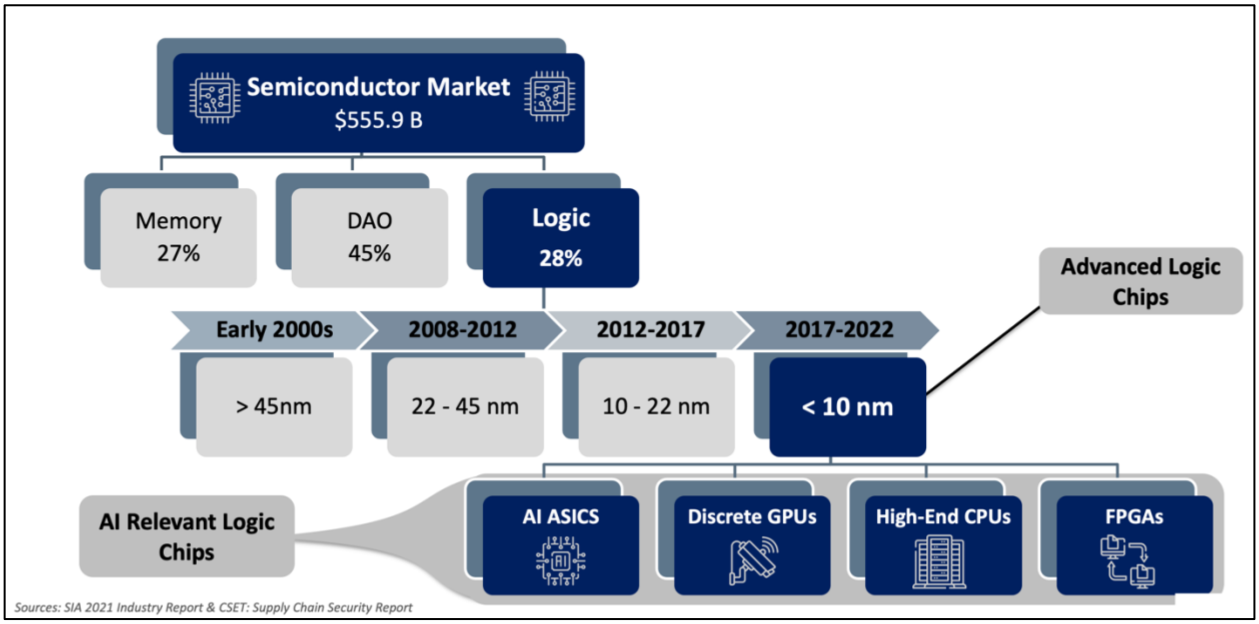
As the U.S. grapples with this pressing issue, it is important to understand the history that has led tup to this moment. Semiconductors were invented in the 1960s, as part of an effort funded by the Department of Defense to replace vacuum tubes, the highly inefficient system preceded semiconductors as the system that computers first ran on. As more companies saw the potential of this technology, they invested in semiconductor manufacturing, and the number of transistors per chip took off from 10 to over 100,000 within a couple years. However, many companies were bogged down by the manufacturing costs associated with engineers' hand carving the designs into the chips and then applying light to photo resistant chemicals on the silicon wafer to etch out their designs. Many early semiconductor companies went under because of the enormous upfront costs and the fact that many chips, once tested, were thrown out for minute deficiencies (Miller "Chip War", 2022).

As a result, many companies recognized that lowering labor costs was essential for achieving profitability. Around the early 1970s, many semiconductor industry executives recognized that they could offshore manufacturing to Asia, where factory jobs were far more lucrative for rural villagers in Asia living on subsistence farming. As a result, companies such as Intel moved their factories to Asian countries, including China. Moreover, Japan and South Korea, both devastated after WWII and the Korean War, saw semiconductor manufacturing as a way to boost their war-ravaged economies and lift the incomes of their citizens. These historical trends helped create companies such as TSMC, Samsung, Sony, and Nikon as well as historic investments in the region by U.S. companies like Intel. These economic trends coupled with an ascendant and aggressive China have created the contentious and vulnerable semiconductor supply chain that has many U.S. policymakers concerned and eager to institute changes (Miller, “Chip War”, 2022).

Logic Chips:

There are three main types of semiconductors, logic chips, memory chips and discrete, analog & optics (DAO) chips. All three are crucial for advanced systems but differ in their manufacturing complexity and accessibility. Memory chips are responsible for storing the huge amounts of data produced by our data driven modern world. DAO chips are responsible for collecting the array of sensory data for computers to store and process. While artificial intelligence needs all three types to effectively operate, logic chips are the most important as they act as the AI’s “brain”. Logic chips process enormous amounts of data in real time and allow AI systems to execute their assigned functions. In other words, the semiconductor chips that run the AI algorithms themselves are logic chips. These chips determine the speed at which AI operates, its power efficiency and its ability to integrate into a range of different systems. There four relevant logic chips for this thesis, CPUs, GPUs, FPGAs, and AI ASIC as they are all are essential for AI development and the "most relevant to national and international security" (Khan, Mann, and Peterson, 2021 p. 19-20). Figure 3 illustrates the size of the 2021 semiconductor market and its breakdown by chip type.

Figure 3



High-End Central Processing Units: These are the most common types of logic chips that are found in most PCs and large data centers, serving as the workhorse of traditional computing processing power. The CPU market remains dominated by two U.S. firms, Intel & AMD, with little competition from China. As a result, China imports 95% of their CPUs. These chips are an essential component for supercomputers and running their core functions (Khan, Mann, and Peterson, 2021). Although CPUs account for 75% of the market, a study by McKinsey estimates that it will decline to 50% by 2025 as ASIC AI become more popular, especially for deep learning algorithms (Batra, Gaurav, 2019).

Discrete Graphics Processing Units: These chips are responsible for traditional graphic processing but recently they have been used to run AI algorithms. Although Nvidia and AMD dominate the design market, most GPUs are produced in Taiwan (Khan, Mann, and Peterson, 2021).

Field Programmable Gate Arrays: These chips are unique because they are general purpose chips that can be used for a range of purposes, including AI algorithms. Chinese firms are not competitive with the U.S. on FPGAs and lag technologically. However, due to their ability to be used for multiple purposes, it is hard to determine how U.S. designed FPGAs chips are used by Chinese customers (Khan, Mann, and Peterson, 2021).

Application-Specific Integrated Circuits for Artificial Intelligence: These logic chips are optimized for AI processing, resulting in better efficiency and speed than GPUs and FPGAs. AI start-ups researching the design of these chips received most of the VC investment in fabless firms between 2017 and 2019. China competes with the U.S. in design of these chips and Huawei has developed and designed the Ascend 910, a 7-nanometer chip manufactured by Taiwan's TSMC (Khan, Mann, and Peterson, 2021). Furthermore, AI specific semiconductor chips accounted for 11% of the global semiconductor market in 2020 but they are projected to grow to 19% of the market by 2025 (Batra, Gaurav, 2019).

Researchers are also looking at nonvolatile memory or chips that can store data without using power to meet the demands of AI algorithms. Memory chips designed for AI are far larger than their traditional counterparts due to the memory storage required for a functioning AI system. As a result, AI memory chips are not economically viable for manufacturers to make at a large scale nor is demand for AI systems high enough for manufacturers to pivot towards them, making it an issue of economies of scale (IEEE, 2021). Memory chips, specifically nonvolatile memory or NAND flash chips are easier to produce than logic chips, which means they play less of a central role in the AI innovation race between the U.S. and China. Chinese firms are far better at the latter and designing and manufacturing advanced logic chips remains a strategic weakness for them (Khan, Mann, and Peterson, 2021). As a result, this paper will focus on logic chips.

Overview of the Semiconductor Manufacturing Process:

There are two crucial sides of the manufacturing process when it comes to semiconductors. The first side are the chip companies themselves that design, manufacture and integrate the chips into devices. However, equally as important are the inputs or the companies that make the tools and software that the chip companies need to design and manufacture their chips. Semiconductor manufacturing is the most complex manufacturing process in the world and has a couple of key choke points that have huge national security implications. For this thesis, the logic chip supply chain has been split into two parts (see Figure 4), logic chip production and inputs to logic chip production (Khan, Mann, and Peterson, 2021).[1]

There are three relevant types of companies within logic chip production. Fabless firms, foundries, and integrated device manufacturers. Fabless firms, the majority of which are in the U.S., make the complex chip design that fits billions of transistors within it and optimize them for the system they are integrated into. The second type of firm is foundries, which take the chip

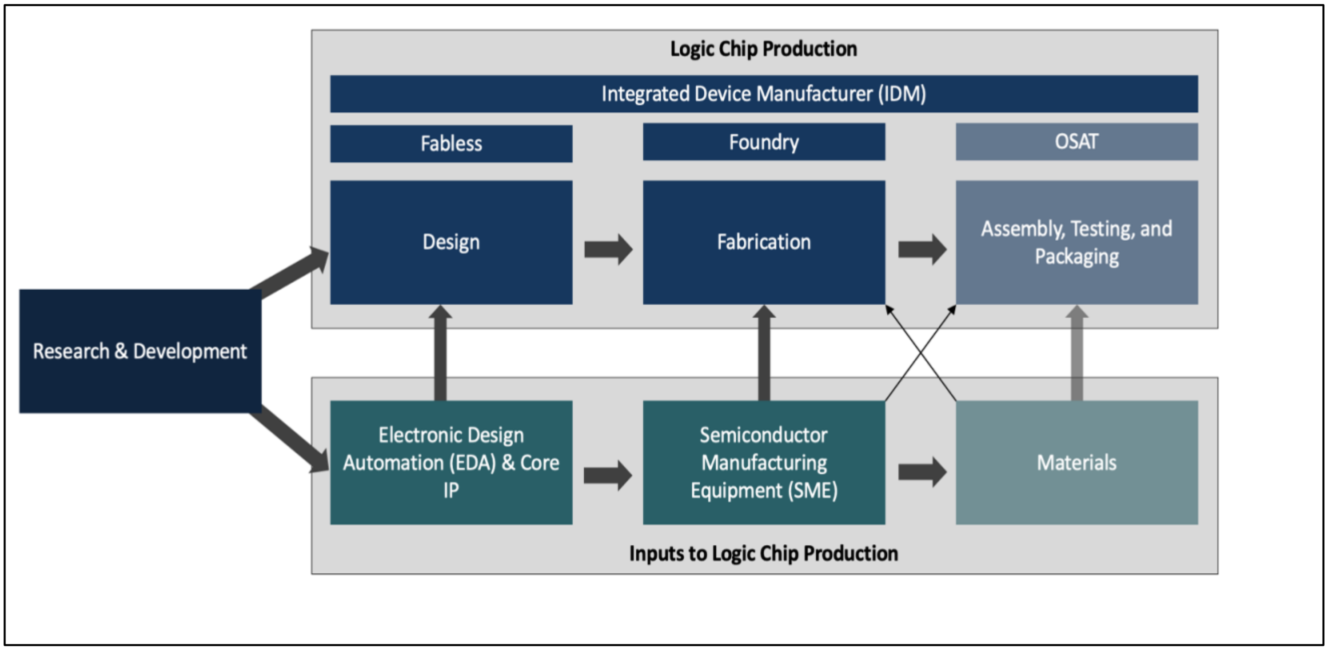
[1] Assembly, testing & packaging as well as the materials are the less complex and capital-intensive parts of the manufacturing process. Moreover, the outsourced semiconductor assembly and test (OSAT) companies that conduct these services are less important within the supply chains as a result. Therefore, for the scope of this thesis, I will focus on the other aspects of the manufacturing process.

designs from fabless companies and manufacture the chips. Foundries have become increasingly powerful within the manufacturing process because foundries cost nearly 13 billion dollars to construct and require talented experts to maintain and operate. Foundries overcome these high barriers to entry for such a capital-intensive process by manufacturing chips for numerous companies and developing internal R&D and expertise to streamline and innovate the process, eliminating inefficiencies and increasing production output. The third type of company are integrated device manufacturers that both design and manufacture the chips. These companies are rare because of the capital-intensive manufacturing process and many struggle to compete with foundries which are only focused on the manufacturing of the chip (SIA, 2021).

The inputs to logic chip production serve as the second part of the logic chip supply chain. Electronic design automation (EDA) software and core intellectual property (IP) serve as the key inputs for designing a chip. An apt metaphor for this stage is the blank canvas and brushes upon which chip designers paint or design their specific chip. The software communicates with the machines that build the chip, ensuring the foundries can 'read' the instructions and translate a design into a chip.

The other key part of logic chip production is the semiconductor manufacturing equipment (SME). This is the complex equipment that makes up the manufacturing assembly line at foundries across the world. While there are thousands of machines and chemicals necessary to effectively manufacture a semiconductor, my thesis focuses on two specific machines that are highly complex and made by only a handful of companies. The first are lithography machines which are massive lasers that produce light in nanometer wide wavelengths, etching the nodes onto semiconductors with incredible precision. These machines have over 47,000 components sourced from across the globe. The other is the Kr Afi gas, a highly concentrated gas necessary for advanced logic chip production (Miller, 2022).

Figure 4



CSET Issue Brief, 'The Semiconductor Supply Chain: Assessing National Competitiveness', page 5

IV. HYPOTHESIS

Cascading Hypotheses:

The two theses are interrelated and directly affect each other. As the U.S. implements a strategic partial decoupling to limit China's AI development, the U.S. will also adversely impact its own AI development. The same U.S. semiconductor companies that have made billions selling their products to China are also at the cutting edge of innovation and designing the next generation of chips that power AI systems. Decoupling underlies the free trade and division of labor economic theories that have characterized the highly globalized semiconductor supply chain to date. The first hypothesis explores the extent of a decoupling and limiting China's access to chips for AI through a national security lens. The second hypothesis explores the impact on innovation and for the world as the decoupling measures ripple across the supply chain. I believe these hypotheses will illustrate that decoupling, from a national security perspective, is highly necessary but also a double-edged sword due its negative impact on innovation.

Decoupling Hypothesis

- *Strategic Partial Decoupling:* I predict the U.S. will move to restrict China's access to advanced logic chips and its production inputs to hamper any Chinese efforts to domesticate semiconductor manufacturing and the role of U.S. semiconductor companies in developing China's AI capabilities to date. The U.S. government will not discriminate based on end-usage but instead restrict China's access to advanced chips to hobble their AI development. However, the U.S. has no desire to decouple its economy with China and will maintain a strategic rationale using AI to guide the implementation of its restrictions to mitigate any economic fallout.

State of Innovation Hypothesis

- *Hampering Semiconductor Innovation*: A partially decoupled supply chain with restrictions on the transfer of certain technologies will reduce revenues and profit margins for U.S. semiconductor companies at the cutting edge of innovation. Moreover, this decoupling will inject a level of unpredictability into the global semiconductor market and adversely impact private sector R&D funding on semiconductors.

V. METHODOLOGY

I employed a qualitative and quantitative approach to understand the complex political dynamics at play and the hard data behind logic chip development and manufacturing to determine the role of U.S. semiconductor companies in advancing U.S. and Chinese AI capabilities. My qualitative approach included nine interviews that provided a multitude of different perspectives on the issue. The quantitative data provided numbers to help ground the testimony I collected and provide a more comprehensive picture. The quantitative data gave me a complete picture of the current state semiconductor companies' revenue exposure to China and their R&D investment levels. Interview testimony and qualitative analysis of government policy allowed me to hypothesize on the scope of the decoupling and the impact on semiconductor innovation.

Interview Methodology

I classified my interviewees into three different groups, industry, government, and academia. All three of these groups have their own perspectives and biases that I sought to understand and account for.

The *Industry Sources* offered an inside look on how companies view their role as it relates to the strategic competition between the U.S. and China. Their testimony offered insight into how companies are preparing for a potential decoupling and how they weigh revenues and profits against regulatory and ethical considerations. I specifically targeted senior policymakers and executives from within large U.S. semiconductor companies. Of the three groups, this had by far the lowest response rate. Out of nearly thirty interview requests, I received only two. One of those interviews was with an executive from a U.S. tech company but not a U.S. semiconductor company so their testimony did not prove relevant enough for this thesis. Moreover, a couple potential interviewees responded and explicitly told me it was not worth my time because they could not answer the questions since any meaningful answers contained "confidential company information".[2]

The *Academic and Journalist sources* offered a holistic and broad view of the issue. These sources were experts on the intersection between technology (semiconductors and/or AI) and foreign affairs. Their insights, developed through years of research, helped make me make long term predictions for my two hypotheses. I interviewed across a range of think tanks and one industry association. Many of the sources had experience in industry or government, but their current position often allowed them more leeway to speak freely about these issues. These sources also helped strike a balance between the more pro-business industry sources and the more hawkish government sources.

Government sources offered insight into the government's current approach and its priorities going forward regarding this issue. These sources knew U.S. vulnerabilities around AI and semiconductors and helped me understand the potential extent and scope of a decoupling based on the internal policy discussions occurring within government.

I used my interviews to not only ask a range of targeted questions about my two hypotheses based on the interviewees background, but also to corroborate the frameworks I built and assumptions I make throughout this thesis. My decision to narrow down on logic chips was based off a couple of scholarly sources, particularly a paper from Georgetown's Center for Security and Emerging Technologies. However, in my interviews I asked about my decision to focus in on logic chips and particularly CPUs, GPUs, FPGAs, and AI ASICs. All the sources I

[2] All interviewees were emailed the questions before the interview

asked verified this approach since I was focusing on AI development and its connection to semiconductors.

I also used my interviews to help narrow down the companies I analyzed, focusing on companies that would best address my two hypotheses. I sourced my framework for the relevant U.S. logic chip companies (see figure 5) from Georgetown's Center for Security and Emerging Technology (CSET), and specifically a paper on the state of the semiconductor supply chain. However, I also showed it to my interviewees to confirm those choices. None thought I was missing any, but one of my industry sources suggested I include Amazon and Apple in the framework.[3] I used the same source from CSET for my framework on logic chip input companies (see Figure 11) and corroborated the framework with the same set of interviewees who agreed with the companies I selected. However, I did not have financial data on certain companies while others had too diversified of product offerings to provide a focused analysis on just semiconductors. As a result, not every company within the framework was individually analyzed.

I based the global companies I analyzed off my interview with my SIA source and scholarly sources that identified those companies as dominant in their part of the supply chain (see Figure 15).

For my interview with Chris Miller, I both interviewed him and read his book *Chip War: The Fight for the World's Most Critical Technology* that recently came out. When citing his book, I used the in-text citation "(Miller "Chip War", 2022) while the in-text citation for our interview is just (Miller, 2022).

[3] Apple and Amazon had too diversified of a business model and product offerings to adequately focus on their semiconductor business so they were not included in the overall framework

Interview Sources:

Industry Sources:

Intel Corporation: The leading U.S. semiconductor chip manufacturer and a huge source of innovation for numerous types of chips. As the largest semiconductor company in the world, it has factories across the globe. As an integrated device manufacturer, Intel has expertise in every aspect of the semiconductor supply chain.

Academic Sources

- *Semiconductor Industry Association (SIA)*: The Semiconductor Industry Association (SIA) represents the American semiconductor industry and maintains data on industry trends and hires experts in this field. SIA provided me with non-publicly available data sources based on internal estimates and databases.
- *Wall Street Journal:* Leading U.S. investigative newspaper with journalists around the world, reporting on foreign policy events.
- *Center for New American Security (CNAS):* CNAS is a renowned bipartisan think tank that focuses on U.S. security and foreign policy. Comprised of academics, former government officials, and leaders within the private sector producing groundbreaking research and analysis around U.S. national security. I interviewed experts from the Technology and National Security Program.
- *Council on Foreign Relations:* Leading bipartisan foreign policy think tank that looks at the most complex security issues facing the U.S., drawing on experts from across the world. I focused specifically on the organizations national security and defense program as well as the digital and cyberspace policy program.

- *RAND Corporation:* Global policy think tank offering research and analysis to the United States Armed Forces. Funded by the U.S. government, universities, corporations, and private endowments.

Government Sources:

- *National Security Council on Artificial Intelligence (NSCAI)*: This was a commission put together by the national security council to look at the U.S.'s progress in AI development and the role it will play in national security.
- *DARPA – Microsystems Technology Office:* DARPA is the Pentagon's advanced research arm that invests in nascent technologies for the U.S. military. The Microsystems Technology Office, an office of DARPA, specializes in developing high-performance intelligent microsystems and next-generation microelectronics for the U.S military.

Quantitative Data Methodology:

My quantitative sources served to determine the extent of interdependence within the semiconductor supply chain between the U.S. and China. This data provided the basis upon which I was able to make estimates on the ramifications of a potential decoupling.

I first used SIA industry report data to understand the full extent of the interdependency and the volumes of semiconductors being sold to China. This data had breakdowns on the types of semiconductors as well as industry wide profit margins, R&D expenditures, and capital expenditures. These provided an industry standard before looking at the individual companies' financials and offered a twenty-year perspective on the industry overall. The data provided an overlook on the manufacturing capacity of the U.S., China, and other relevant third-party countries. Moreover, it offered insight into the U.S. and China's strengths and weaknesses within the semiconductor supply chain.

I used supply chain data from Bloomberg and company financial data from Wind to better determine the amount and types of chips being sent to China and to which companies. Although SIA had some breakdown on the types of chips, knowing the volume from specific companies provided a way to narrow down further to advanced logic chips. Since I did not have the breakdown on the level of advanced chips being sold to China, I used the amount each U.S. company and combined that information with the company's SEC 10-k annual filings to estimate the how many advanced chips China received and what they stand to lose in the face of potential restrictions. I applied this same data method to the companies on the input side of the logic chip supply chain**.**

The Wind company financial data allowed me to examine a company's revenue exposure to China over time and account for any market fluctuations. This data and data from the SEC 10-ks also allowed me to estimate the impacts on the state of innovation based on profit margins and adverse effects on a company's R&D budget. Many of the estimates I made were also supplemented by insights from my interviewees that had familiarity on the industry and regulatory policy including export bans.[4]

Quantitative Data Sources:

Financial Analysis

- *Bloomberg – Global Supply Chain Data*: Provides customer and supplier relationships across more than 23,000 public and 100,000 private companies. Bloomberg uses financial

[4] All figures in this paper were originally produced or reproduced, even if based off an existing graph from a source using Excel or PowerPoint.

report, investor presentations, internal data, trade journals and company websites to compile the data. When pulling the data over the course of the semester, I always used the date of 9/30/22 to remain consistent in the face of a constantly changing regulatory environment. As a result, none of the Bloomberg data shows any impact of the export bans.

- *Wind Database*: Wind is a financial services tool, like Bloomberg, but based out of Shanghai for Chinese investors. I gained access with the help of Luo Zhou, the Chinese librarian at Duke. Luo helped me translate the data to English and convert the numbers to U.S. dollars.
- *Pitchbook:* This tool allows me to look at the number of start-ups in semiconductor chip design and manufacturing processes along with their country of origin.

Semiconductor Industry Sources

- *SIA Reports:* These reports allowed me to look at the financial health of the industry, revenue and profitability margins, and volumes of each type of chip sold. Moreover, they also offered insight into the different stages of the manufacturing process. Boston Consulting Group, a management consulting firm, also assisted SIA on some of the reports.
- *SEC 10-k Filings:* The SEC mandates that all publicly traded companies (which all large U.S. semiconductor companies are) produce detailed annual reports about their revenues and overall product offerings for investors. Although these reports are not uniform across, many had revenue breakdowns by region and product offerings which proved helpful for analyzing and tracking types of chips and semiconductor manufacturing equipment.

Policy Analysis Methodology

Since most of interviews occurred before the Biden administration announced its export bans on October 7th, I relied on speeches from government officials and the text from the executive order itself to provide original analysis and context for the reader. Although these bans have not been fully implemented it and a lot remains to be seen, they have already had an enormous impact on the industry and partially reaffirmed my hypothesis on the strategic partial decoupling.

IV. RESULTS

The results of my thesis illuminate key themes behind my core research question. U.S. semiconductor companies played a crucial and extensive role in developing Chinese AI capabilities, bringing about a strategic partial decoupling and introducing comprehensive technology bans to U.S. foreign policy regarding China. However, U.S. semiconductor's crucial role in developing U.S. capabilities proves that even from a national security perspective, restrictions are a double-edged sword as the partial decoupling will hamper the state of innovation and erode at long term U.S. technological advantages.

Strategic Partial Decoupling Hypothesis:

A partial strategic decoupling will occur because of the role of U.S. semiconductor companies in developing China's AI capabilities and China's end use of their products. The data shows the complicit nature of U.S. companies in developing these capabilities and China's use of AI for military modernization and mass surveillance serves as the justification used by the Biden administration to implement these bans. However, the role of U.S. allies and the semiconductor companies located in those countries will determine the true extent and effect of any export bans and illustrate the limitations of U.S. power if it acts unilaterally or its global influence should U.S. allies act in concert with America on the bans. Moreover, China's dependency on U.S. semiconductors for its AI development indicates the bans will only go one way as China will continue purchasing any semiconductors that the ban does not apply to.

Rationale Behind Strategic Partial Decoupling:

The Biden administration instituted the export bans because they fear U.S. technology could undermine the U.S. as it engages in a fierce ideological competition with China around the viability of their governance models, pitting democracy against autocracy. Hal Brands and Peter Feaver effectively illustrate the Biden administration's rationale through their historical analysis of American Grand Strategy. Brands and Feaver identified seven core assumptions that America's foreign policy since the Cold War's end has rested upon. America's support for globalization and defense of the liberal international order can be tied to these underlying assumptions that have guided successive presidential administrations for the past thirty years. China's fast rise over the past two decades have called into question those underlying assumptions and Biden's export bans on semiconductors illustrate the open questioning of one of those core assumptions. That assumption is that "technological innovation will lead to greater human flourishing and freedom and will disproportionately favor the United States" (Feaver and Brands, 2016, p. 20).

Widespread bans that limit China's access to a whole level of technology shows the Biden administration is no longer basing its foreign policy on that assumption. Jake Sullivan, Biden's National Security Advisor, laid out the four strategic pillars guiding U.S. foreign and domestic policy around advanced technologies. Those four pillars are investing in our science and technology ecosystem, nurturing STEM talent, protecting U.S. technology advantages, and deepening partnerships with allies. Sullivan started the speech with the line, "there is nothing inevitable about maintaining our core strength and comparative advantage in the world", a direct allusion to the failing assumptions that Brands and Feaver discussed. Sullivan went on to state that protecting U.S. technologies and intellectual property is crucial to ensure countries do not use "our technologies against us or their own people". The Biden administration is highlighting AI and China use of it to advance its military, an implicit nod to AI being used "against us" and the oppressive AI mass surveillance model it built using U.S. semiconductors for use against its "own people". Sullivan called for revisiting previous export controls because the approach of staying a few generations of technology ahead was no longer enough. Sullivan stated that "the foundational nature of certain technologies, such as advanced logic and memory chips" called for maintaining as large a lead a possible (Sullivan, 2022).

The same country that opened China to the global economy and built out a liberal rules based international order based on multilateral trade is forging ahead, determined to build barriers around its rival. The financial pain these bans will cause, as I'll explore later in my thesis, illustrate the Biden administration's commitment to maintaining that "as large a lead as possible" despite the high cost (Sullivan, 2022).

Analysis of the language of Biden's export ban, published by the Bureau of Industry and Security, the agency in charge of its implementation, explicitly states the fears Sullivan alluded to in his speech. Under the background section of the order, it states "These [AI} systems are being used by the PRC for its military modernization efforts" before listing a range of military capabilities and technologies that AI enhances and the threat it poses to U.S. military assets. It also implicates China for its use of AI on its own people, reading “advanced AI surveillance tools, enabled by efficient processing of huge amounts of data, are being used by the PRC without regard for basic human rights to monitor, track, and surveil citizens”. The order cites China’s military civil-fusion effort to illustrate why it cannot apply bans to the end use of these chips because a chip bound for a commercial application can easily be taken and transferred for another use once in China, in line with military civil fusion policy (DOC – Bureau of Industry & Security, 2022 p. 5-8). The Biden administration is officially acknowledging that China is manipulating its access to the global economy, access initially granted by the U.S., to bolster its military capabilities. The implicit implication is that technological exchanges with China will undermine U.S. military advantages if that technology has any military application.

The order illustrates the dangerous applications of advanced logic chips specifically and uses that same logic to apply the ban to all supporting software and technology that goes into manufacturing them. Moreover, the order explicit names FPGAs, GPUs, and AI ASICs with certain performance metrics for their integral role in AI development and usage (DOC – Bureau of Industry & Security, 2022, p. 102).

Digital Authoritarianism:

China’s effective use of AI to perfect a mass surveillance model has been dubbed by experts as “Digital Authoritarianism”. The complicit role U.S. semiconductors have played in developing it explains the recent bans and indicates ominous headwinds for the semiconductor industry going forward. China’s AI programs have built up a robust firewall that censors any anti-government content before it can spread while also allowing the Chinese people to use many of the same features and conveniences of the internet that Americans enjoy, such as social media, online shopping, and internet-based payments. China's AI powered surveillance processes data generated by over a billion people and identify and track dissidents or anyone else deemed a threat to the Communist Party. Whereas China's military modernization effort requires an enormous amount of advanced chips, China's domestic surveillance operations requires an order of magnitude higher in terms of the volume of chips needed to successfully operate. Moreover, the more advanced chips China has, the more invasive and effective its domestic surveillance AI becomes (Lin, 2022).

A changing consensus has built up on the hill that AI is helping the U.S.'s strategic competitor in the ideological battle between democracy and authoritarianism and U.S. semiconductor companies are complicit in China's newfound advanced capabilities. Analysis from Bloomberg supply chain data supports this consensus, as companies such as Alibaba, Tencent, Huawei, and ZTE have received billions of dollars from U.S. firms that manufacture advanced logic chips. China's surveillance industry is using U.S. chips to perfect AI systems tailored for authoritarian regimes and are selling them across the world. According to my interview with Chris Miller, 95% of AI enabled surveillance cameras in China are using Nvidia's GPUs (Miller, 2022).

Liza Lin, in a group interview, pointed out that China has used the AI powered "smart cities" program built by companies like Alibaba, ZTE, and Huawei to build out a police state in the Xinjiang province to monitor and oppress the Uyghur Muslims living in the region. China has collected an enormous amount of personal information on the Uyghur Muslim population there including blood and hair samples, detailed facial scans and detailed family and religious history. This data has helped perfect an AI system that monitors and classifies the entire population. The Chinese government has forced millions of Uyghurs into “re-education” camps, closing mosques and imprinting Chinese state propaganda onto the population. The AI surveillance system meanwhile has eliminated the dissent that shook the region in previous decades as it has given police the ability to stop protests and organizations before they gain speed. However, this system is the same being used in “smart cities” around the rest of the country, improving the daily lives of millions of Chinese citizens. It is a perfect illustration of the “dual-use” applications of AI, for the same system used to identify and predict traffic jams and accidents can also help police clamp down on protestors and identify political dissidents. It is also important to note that while many Chinese currently report high satisfaction with “smart cities”, as the government adopts unpopular policies producing widespread dissent, that same system can easily be applied in the same way it is used in Xinjiang (Lin).

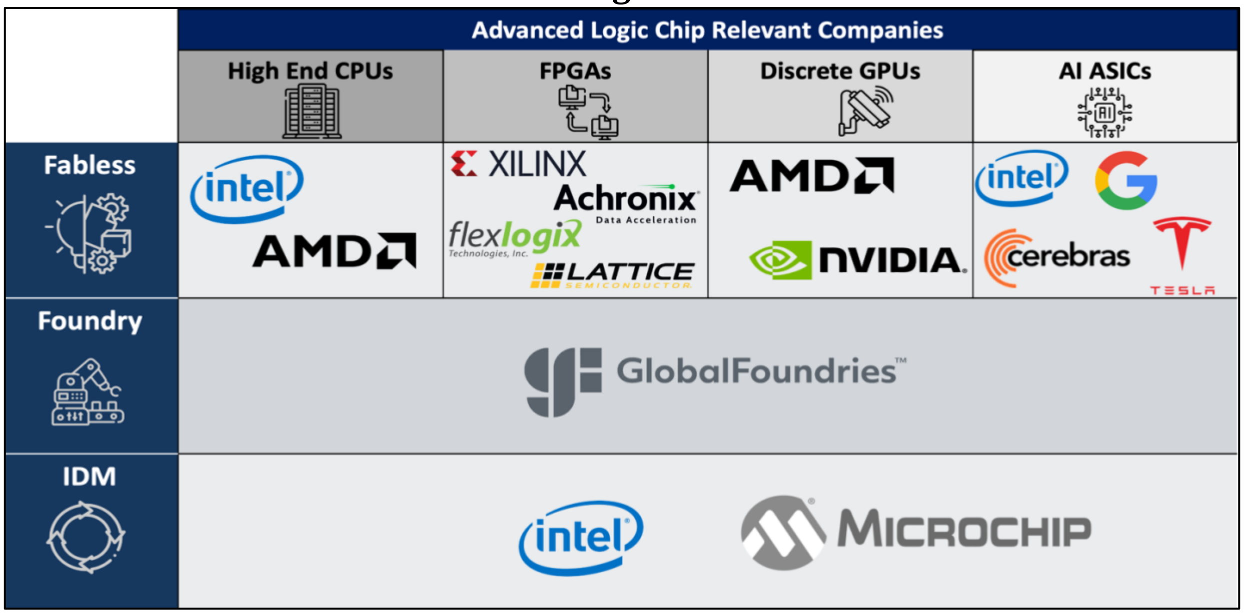
Companies like Huawei and ZTE have not only built out these systems for China domestically but exported them abroad as part of China’s Belt and Road Initiative. Specifically, a subset of that policy called the “Digital Silk Road”. Although a lot of it has gone to telecommunications and 4G infrastructure, surveillance continues to take a sizeable and growing portion of those investments. As the world today faces a democratic backsliding and a resurgence of illiberal autocracies, the role AI can play in empowering authoritarian regimes is an alarming trend. Lin points out the example of Uganda as a troubling example of the power of these AI systems for nascent autocratic regimes. Uganda’s current president, Yoweri Museveni came to power in 1986 and helped quell rampant violence and unrest throughout the country. In 1996, he easily won re-election that international observers noted as fair, and President Clinton later congratulated him on his win and expressed hope for Uganda’s future (Lin, 2022).

However, today Uganda is no longer considered a democracy is ranked 34/100 on personal liberties and freedom according to Freedom House, a non-profit (Freedom House, 2021). So, what happened to this thriving democracy. Huawei invested heavily in the country throughout the early 2000s and worked with the Ugandan police to install spyware on journalists and opposition politicians. Museveni used the technology and access provided by Huawei to track down and arrest anti-government activists and journalists. In November of 2019, Museveni announced the first phase of the Huawei surveillance project or the National CCTV system. In the wake of the pandemic, China views this low cost and highly efficient AI surveillance system as further evidence of the success of their governance model and existence of a robust alternative to the U.S. model of democracy. Although some are western democracies, ZTE and Huawei have sold their systems in 60 and 100 countries respectively, for a total of 860 cities across the globe (Lin, 2022). Digital authoritarianism is not just a tool for the Chinese domestic surveillance, but a powerful instrument of China's foreign policy and its efforts to expand its global influence.

Implications of Biden's Export Bans for U.S. Companies:

When examining the implications of a partial decoupling effect on China, I established a framework of companies along the value chain that design and manufacture these advanced chips to understand their exposure to the Chinese market and the national security implications of decoupling. These companies will be targeted extensively by the Biden administration for their role in advanced AI logic chips and this framework provides a structure to narrow down on specific companies. The logic chip companies within the framework (see Figure 5) were the focus of my analysis[5].

Figure 5

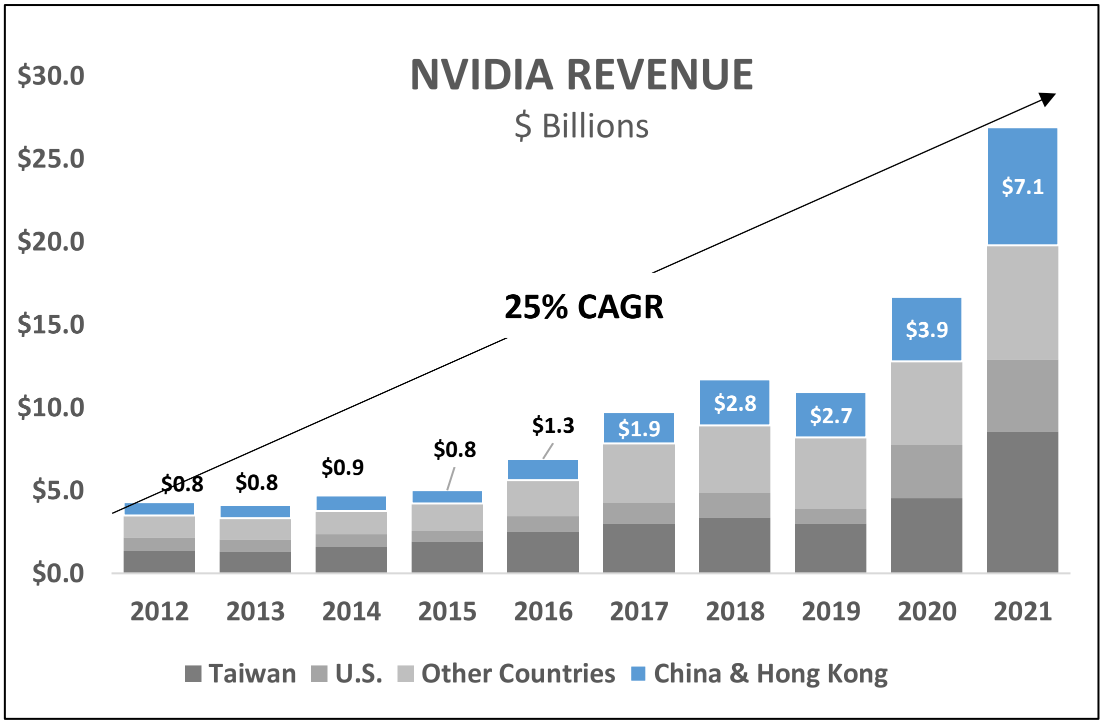


Center for Security and Emerging Technology & Expert Interviews

Many of the U.S. companies within the framework had significant revenue exposure to China and relied upon the country's enormous demand to fuel profits and long-term growth projections. For example, Nvidia, which has played a crucial role in China's AI development to date, has a 21% average revenue exposure to China over the past 10 years and a 25% CAGR over that same time-period in just the Chinese market (see Figure 6). Nvidia not only relies upon China as a huge revenue source but also had a 25% compound annual growth rate. Prior to the bans, Nvidia was relying on China for future growth to fund new projects and next generation chips (see Figure 6).

[5] Due to TSMC and Samsung's dominance of advanced manufacturing, Global Foundries and Microchip do not have the capabilities to manufacture the most advanced logic chip and therefore are not as relevant for the scope of this thesis as they are only considered advanced by U.S. standards, not global standards.

Figure 6



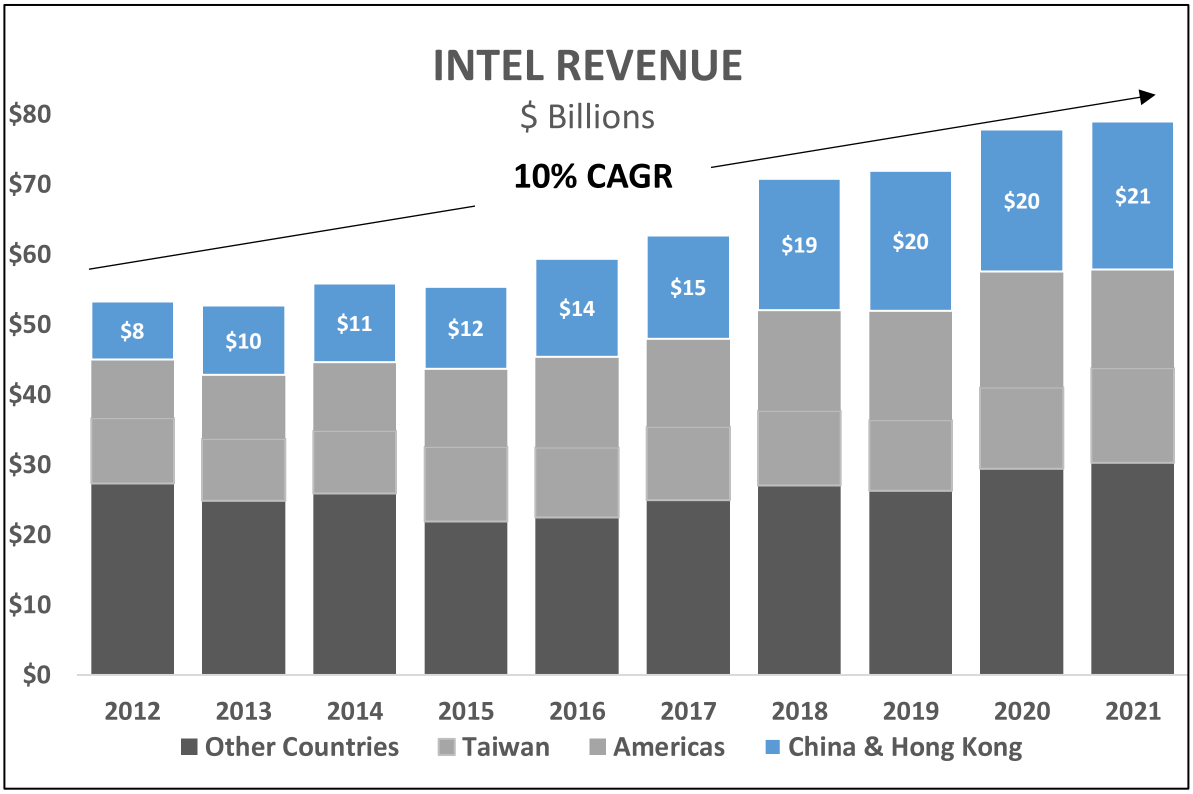
Wind Financial Database

Meanwhile Intel, another leading chip designer and IDM, has a similarly high level of exposure to the Chinese market. Intel has had an average revenue exposure of 23% over the past 10 years to China, earning 21 billion dollars in 2021 from China alone (see Figure 7).

Based on analysis of a data from Wind, a Chinese financial database, AMD delivered 6.19 billion dollars to Greater China last year, making up 38% of its revenue.[6] Meanwhile, Xilinx delivered 24 million dollars' worth of chips to China, making up 4% of its revenue (Wind, 2022).

[6] Important to note included in 'Greater China' for AMD's revenue sources is Taiwan. Wind delineated the data only for AMD so the 38% is artificially high since Taiwan is a large consumer as well.

Figure 7



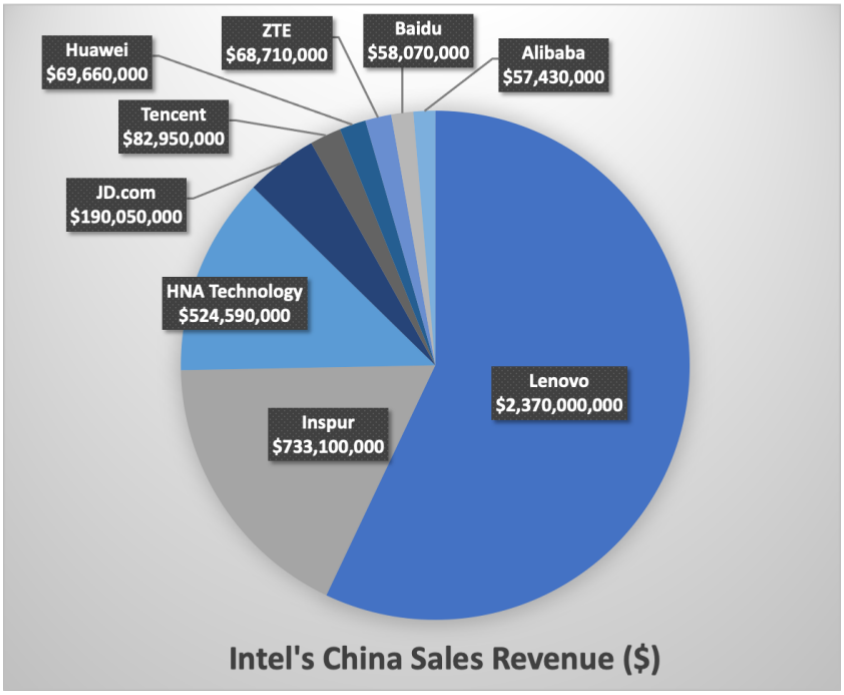
Wind Financial Database

For Intel, Nvidia and AMD, these companies have enormous revenue exposures to China and their advanced products, which have the highest margins, are being directly targeted. Their revenue streams from China illustrate both their dependence on China to fuel long term growth and their complicity in developing China's AI capabilities. For example, Nvidia and AMD both experienced a 10.6% and 5.8% drop in their stock prices respectively in immediately following the announcement of the export bans on October 7th, 2022 (Noonan, 2022).

Chinese Customers

Bloomberg supply chain data illustrates the extensive relationship these U.S. companies have with large Chinese companies and the sheer amount of chips being transferred between companies. Figure 8 illustrates Intel's customers in China as of September of this year. Two of them, ZTE and Huawei, were placed on the entity list by the Trump administration for their close relationships with the Chinese government but they still are receiving Intel products (Wolf and Brown, 2022).

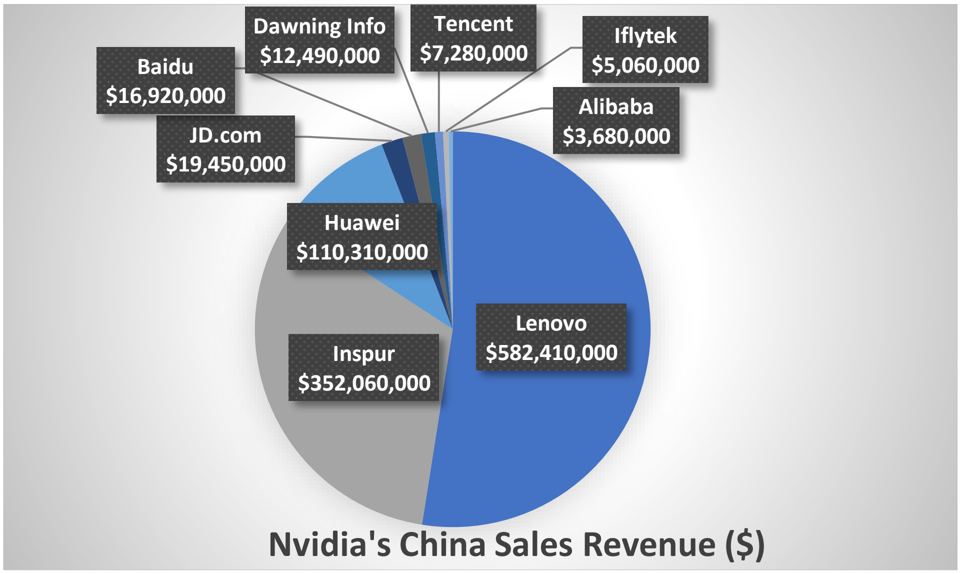
Figure 8



Supply Chain Data Bloomberg

Nvidia, another large, advanced logic chip supplier for China, illustrates the same trend. Many of the same Chinese companies are purchasing large volumes of their chips, combining the cutting-edge CPUs and AI ASICs from Intel with Nvidia's advanced GPUs (see Figure 9).

Figure 9



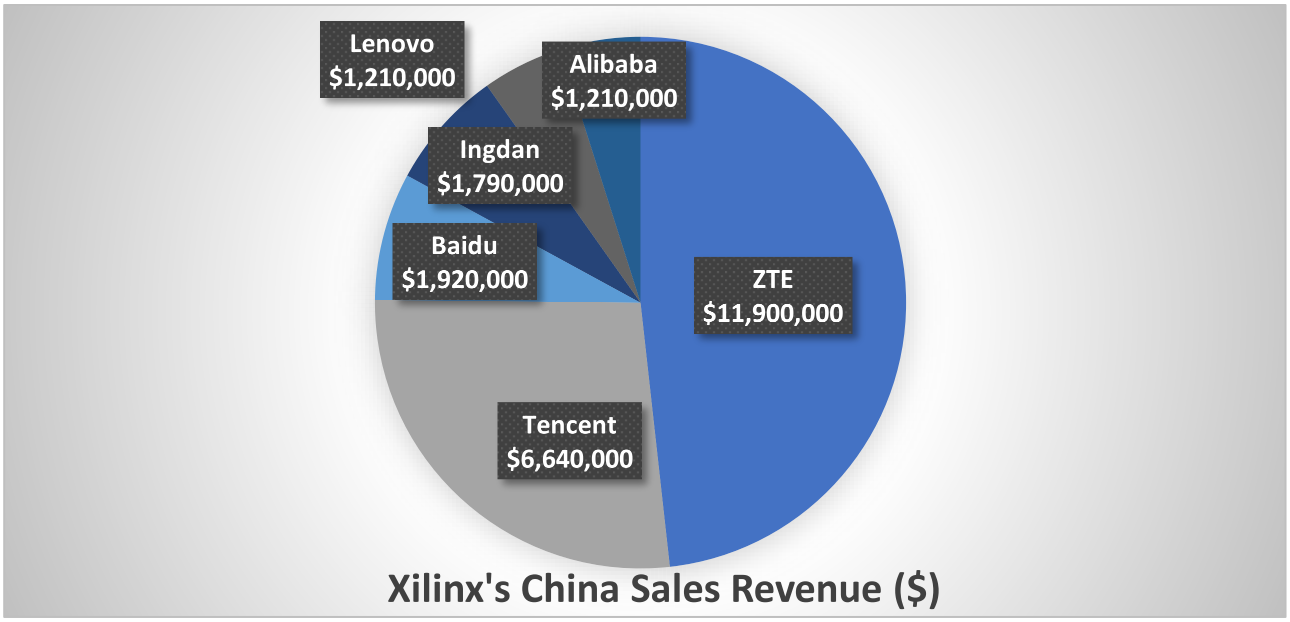
Supply Chain Data Bloomberg

Moreover, Iflytek was specifically named in Biden's export ban as a company subject to increased scrutiny and placed on an additional entity list due to its work with the Chinese government on AI development (DOC – Bureau of Industry & Security, 2022, p. 22)

The data is also not able to capture the type of chips being sold to these companies. The millions of dollars going towards companies with a history of working with the Chinese government coupled with new regulations mandating companies turn over any necessary data to the government is the reasoning behind the bans being applied to the level of advancement not the end customer (Parasol, 2018). This has enormous implications for the decoupling because all the companies below will see their access restricted no matter their history or industry, leading to an industry wide decoupling of the advanced logic chip supply chain.

Finally, Xilinx also has significant revenue exposure to China, which indicates China has access to all four types of advanced logic chips, Intel's CPUs and AI ASICs, Nvidia's GPUs, and Xilinx's FPGAs. Figure 10 illustrates Xilinx's revenue exposure to its top Chinese customers (Bloomberg 2022).

Figure 10



Supply Chain Data Bloomberg

Moreover, one particularly concerning thing about FPGAs, Xilinx's main product, is their ability to be interchangeable with numerous systems. Once in China, their products can go towards any number of applications and its nearly impossible to trace once it's in China (Khan, Mann, and Peterson, 2021).

The data combined with my expert interviews illustrates why a strategic but partial decoupling will occur. A senior executive from Intel confirmed that Tencent and Alibaba are two of Intel's biggest customers and not because of volume of chips but because they are buying the advanced chips that have margins in the hundreds of dollars compared to the five-to-ten-dollar margin on the lower end processors.

However, according to the same source, Lenovo is one of the biggest purchasers of lower end processors, which are not subject to any of the export bans. These processors are used in Internet of Things devices and not advanced data centers. If we use Intel as the standard and apply it to Xilinx and Nvidia, that's a total of nearly 2.9 billion dollars' worth of chips sent to

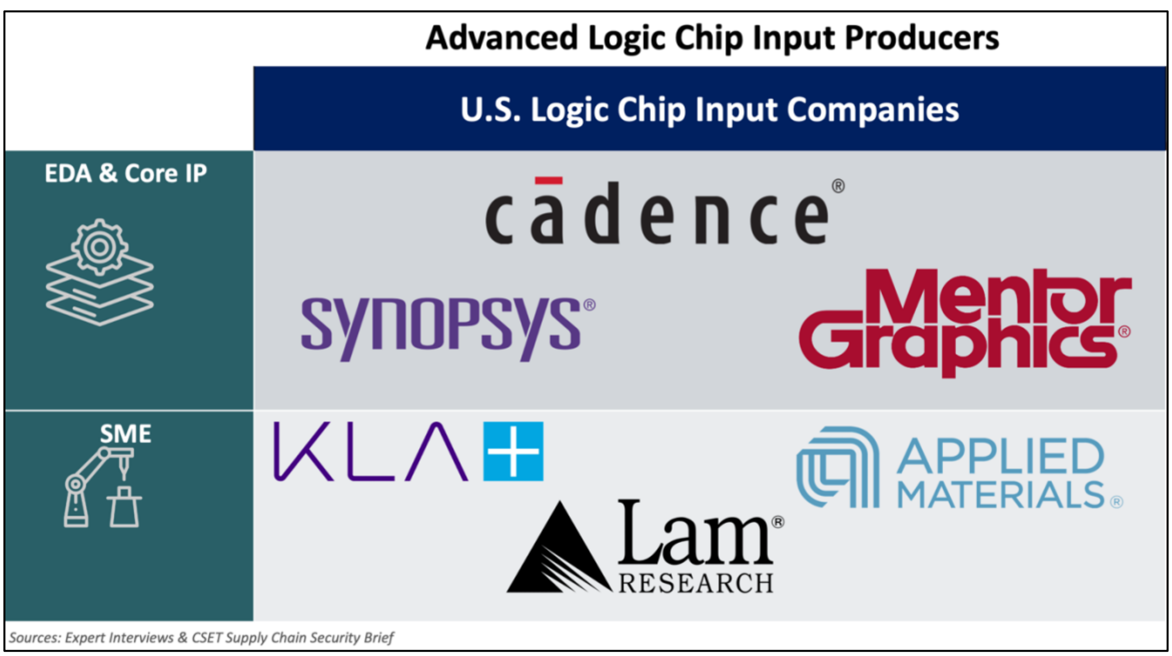
Lenovo last year (Bloomberg, 2022). Although its likely some of the chips are advanced, many of the consumer electronics that Lenovo manufactures do not contain the advanced chips that the bans target, highlighting the partial decoupling that will occur.

Moreover, there is no reason for the U.S. to target these chips as they do not have an impact on improving China's AI capabilities and they fund the U.S. companies that are investing in crucial technologies and supplying the everyday chips Americans rely on for their daily lives.

Impact on Logic Chip Input Companies:

The U.S. exerts a lot of control over the companies that manufacture the equipment and necessary input components to manufacture a chip, despite its low overall manufacturing capacity (Khan, Mann, and Peterson, 2021). Although operating foundries is incredibly capital and labor intensive with high associated costs, many of the machines themselves have better margins, lower barriers to entry and allows the U.S. to leverage its large pool of intellectual talent (SIA, 2021). From the design software to the machines that clean and etch the semiconductors, U.S. companies play a crucial role in this aspect of the supply chain.

Figure 11



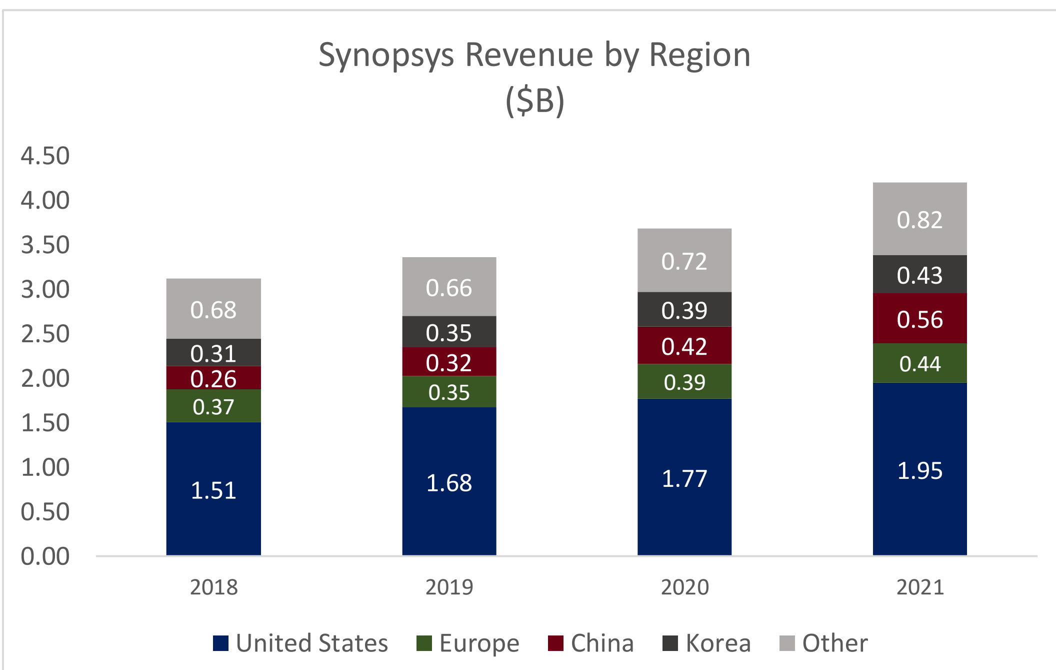
EDA & Core IP Companies:

The electronic design automation (EDA) and core intellectual property (IP) stage (see Figure 4) is a crucial aspect of the input side of the logic chip supply chain and a source of comparative advantage for the U.S. According to a study by the Center for Security and Emerging Technology (CSET), the U.S. has a 95.5% market share in the EDA global market and a 52% market in the Core IP segment, with the United Kingdom at a close second with 43.4% market share (Khan, Mann, and Peterson, 2021, p. 49). As mentioned earlier in the introduction, without the software from these companies, it is virtually impossible to design a cutting-edge chip that can integrate into a larger system and manufactured by an advanced foundry. These tools or set of instructions provided by these companies are universal in the industry and a key chokepoint that the U.S. can leverage over China. Figure 11 is a framework built off the same paper from CSET and narrowed down during my expert interview with Chris Miller.

Cadence, Synopsys, and Mentor Graphics are the dominant players within the EDA & Core IP market segment (Miller, 2022). According to the Bloomberg data, Cadence had four Chinese customers, Huawei, Cambricon Technologies, HiSilicon Technologies and the Semiconductor Manufacturing International Group (SMIC), a state backed entity. Bloomberg did not list a transaction value for SMIC, but Huawei purchased 87 million dollars of Cadence software (Bloomberg, 2022). Cadence operates using a licensing model which means Huawei paid a significant amount of money to design their own chip internally (Miller, 2022). There’s no other reason to purchase Cadence software and Huawei has expressed an ambition to develop their own chips since being placed on the entity list by the Trump Administration (Wolf and Brown, 2022). Further illustrating this point, HiSilicon is a subsidiary of Huawei and a fabless semiconductor company. Moreover, Cambricon technologies builds core logic chips for AI systems and has helped build out China's AI surveillance system (Lin, 2022). Cadence also resides at the top of the value chain, so their software is only purchased by a few companies but could be used to make products that end up in the hands of Chinese companies.

The data for Synopsys illustrates the same trends. It has three Chinese customers, Shanghai Fullhan Microelectronics, Infotmic, and Cambricon Technologies. Cambricon Technologies' role in China's AI development has been proven. Meanwhile. Shanghai Fullhan Microelectronics and Infotmic are two of China's leading fabless companies. However, Bloomberg does not give a transaction value for any deals between these companies, so it is impossible to determine how much these companies received from Synopsys (Bloomberg, 2022). However, analysis of Synopsys's annual 10-k filing illustrates their significant revenue exposure to China.

Figure 12



Synopsys 10-k 2021 Annual Filing, p. 90

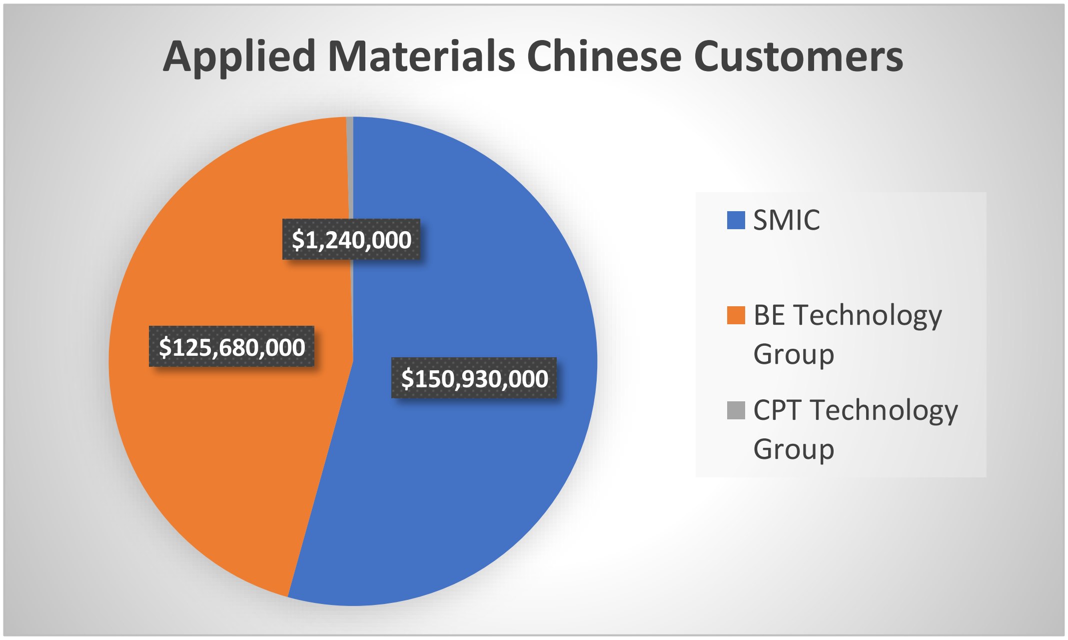
In 2021, Synopsys made 560 million dollars from the Chinese market. Software is much cheaper than hardware and Synopsys operates on a similar licensing model to Cadence which means China either purchased numerous design instructions for a range of chips or purchased a highly specialized proprietary chip design to advance their domestic semiconductor manufacturing capabilities and reduce their reliance on foreign suppliers. Furthermore, Synopsys has had a compound annual growth rate of 21.4% over the past four years, indicating a growing customer base within China. It is also important to note that other key customers listed for Synopsys on Bloomberg were the Department of Defense and DARPA, underscoring the national security relevance of its software (Synopsys, 2022).

Impact on SME Companies:

KLA, LAM Research and Applied Materials are all crucial players within the semiconductor manufacturing equipment supply chain that dominant a different aspect of the complex process. Applied Materials is one of the largest semiconductor toolmaking companies in the world, building the equipment that deposits thin layers of chemicals on top of the silicon wafer in a process called deposition, a 13.2-billion-dollar market in 2019 and the third largest segment within semiconductor equipment manufacturing. LAM Research builds out the machines that etch the circuits onto the silicon wafer while KLA constructs the tools that test and clean the completed chip, scanning for nano-meter sized errors (Miller, 2022). Moreover, the etch and clean segment of the SME market is the largest segment at 14.7 billion dollars (Khan, Mann, and Peterson, 2021, page 25).

Bloomberg data illustrates the relatively low revenue exposure these three companies have to China and their top customers. Figure 10 shows that Applied Materials biggest customer is the Semiconductor Manufacturing International Corporation (SMIC), China's largest domestic semiconductor manufacturer and with significant state funding (Bloomberg, 2022).

Figure 13

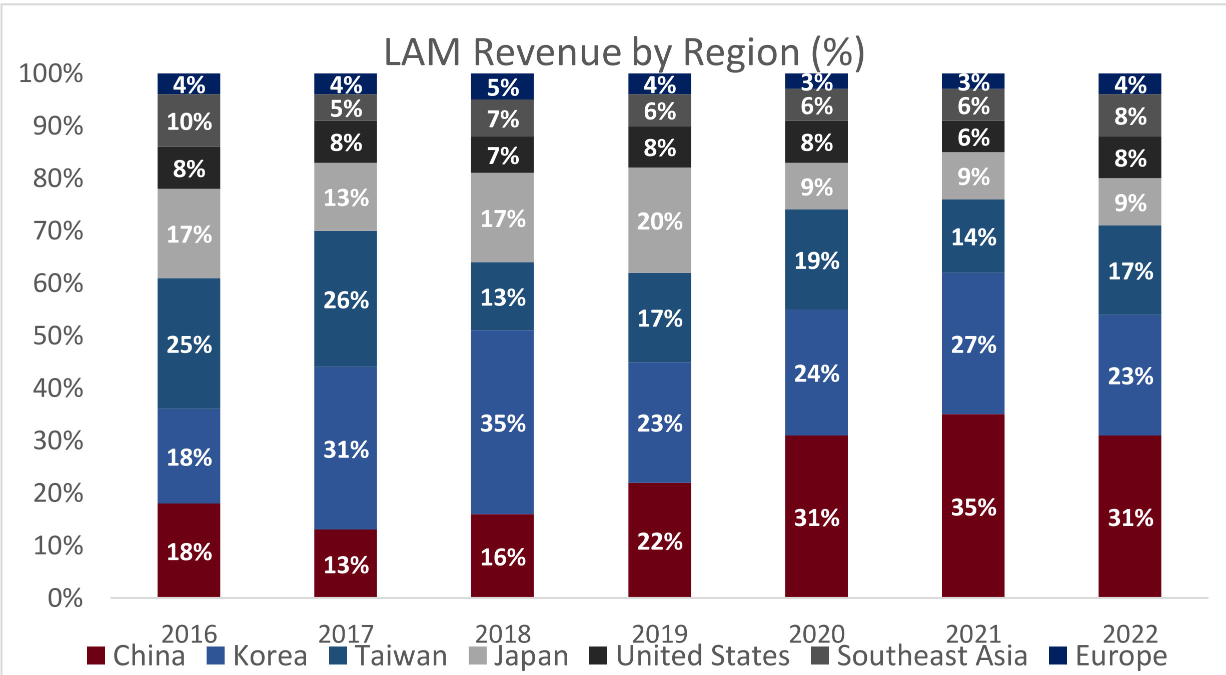


Supply Chain Data Bloomberg - 2022

Curtailing China's ability to domesticate its manufacturing capabilities is a key foreign policy goal of the U.S. China's demand for chips far exceeds its manufacturing capacity and the U.S. sees this is a huge point of leverage in their competition with China (Wolf and Brown, 2022). Strict export bans on manufacturing technology are much easier to implement because they do not ship in the volumes even close to the chips themselves and represent a lower revenue percentage of these companies. For example, Applied Materials' revenue from China only represent 4.5% of its annual revenue (Bloomberg, 2022).

KLA only receives 3.98% of its annual revenue from Chinese companies and its leading customers are either consumer electronics producers or assembly and packagers, the lower end of the semiconductor supply chain (Bloomberg, 2022). Moreover, the Biden Administration's export bans will not target lower-level manufacturing equipment for processors because they are not viewed as a national security threat or significantly contributing to China's AI development (DOC – Bureau of Industry & Security, 2022).

Figure 14



LAM Research 2022 10-k Annual Filing, p. 29

LAM Research has an average revenue exposure of 24% to the Chinese market and an 8.1% compound annual growth rate over the past seven years (LAM Research, 2022). However, the Bloomberg data does not indicate any Chinese customers for LAM. Closer analysis however reveals that has five customers operating in China, three U.S. companies and two Korean companies (Bloomberg, 2022) This poses an interesting dilemma because based on recent laws passed by China and an already poor rule of law, the Biden Administration is likely to limit U.S. companies from purchasing advanced equipment for their factories in China due to the high probability of intellectual property theft. Moreover, it is important to note that many companies may have high revenue exposures to China than the one Bloomberg estimates because it only accounts for Chinese companies and not foreign ones with factories or assets in China (mention specific Chinese law here).

License & Enforcement Issues:

The trends across the data illustrate why the Biden administration have taken such a strong stance on these advanced chips. ZTE and Huawei were placed on the entity list by the Trump administration, but they are still receiving chips from Xilinx, Intel, Nvidia and AMD despite the national security relevance of their products (Wolf and Brown, 2022). These companies have clearly found loopholes in the system and are still selling their chips to them. This has crucial implications for the Biden administration as it institutes a far broader ban on all advanced logic chips and attempts to compel international companies as well through their U.S. suppliers.

My industry source confirmed that although ZTE and Huawei were on the entity list, the U.S. semiconductor companies selling to them were getting licenses from the U.S. government allowing them to sell to those companies. According to my industry source, "until recently the U.S. was handing out licenses to big U.S. companies like Halloween candy" (Industry Source # 1, 2022).

Sullivan's speech and other rhetoric coming from the Biden administration indicates a far more hawkish stance that will likely result in less licenses doled out by the Bureau of Industry and Security (Sullivan, 2022). Moreover, the risks of violating these bans have risen for companies from both a legal and public relations point of view as the world has been exposed to China's human rights abuses and aggressive rhetoric regarding Taiwan.

U.S. Allies' Control over Supply Chain Chokepoints:

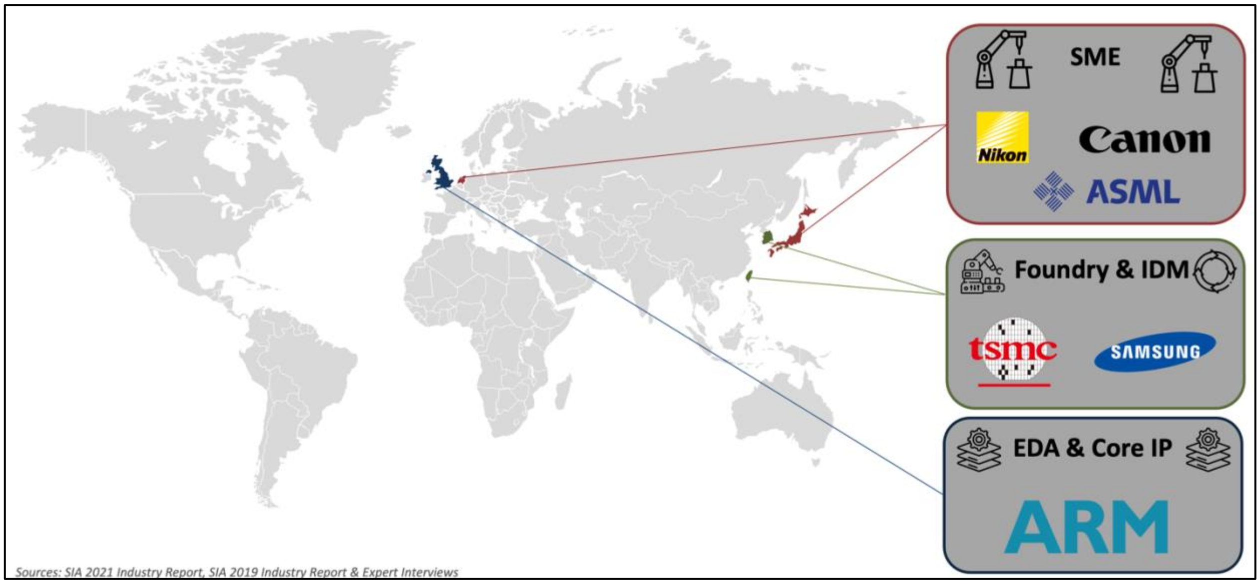
The U.S. remains reliant on its allies, specifically four countries, that control key supply chain chokepoints to limit China's access to advanced chips and sometimes competing priorities illustrate why a total decoupling will not occur. U.S. allies play a crucial in both parts of the logic chip supply chain, and specifically Taiwan, South Korea, the Netherlands, and Japan. Together, those countries and the four companies headquartered there, hold enormous power over supply chain choke points that are sources of innovation and output for advanced logic chips. Japan and the Netherlands hold monopolies over key semiconductor manufacturing equipment, lithography, and Kr Afi gas respectively, that are necessary components to manufacture advanced logic chips. ASML in the Netherlands is the only company in the world that can make the most advanced lithography machines needed to imprint the 5 and 10 nanometer wide nodes on the semiconductor (. According to one of my experts, the lithography machines have over 47,000 parts sourced from across the world and require extensive expertise to build and maintain.

Moreover, TSMC in Taiwan and Samsung in South Korea, manufacture 100% of the advanced (10 nm or less) logic chips in the world. These companies not only have a monopoly on the factories themselves but have developed a robust pipeline of engineers trained to maintain the foundries and attain optimal output levels. Kevin McGinnis, from the National Security Commission on AI pointed out that trained labor for semiconductors remain a big weakness for the U.S. and is a crucial aspect of semiconductor manufacturing.

Although these countries have control over the technology, all of them rely on U.S. suppliers to build their products. The U.S. has the necessary leverage to mandate their participation in export bans such as the ones recently released by the Biden Administration. However, these companies have significant market exposure to China and cannot afford to completely lose their access.

These companies and their home governments will seek to protect their company's financial health while navigating any U.S. export bans or sanctions. However, enforcement and compliance issues abound for export bans on large markets such as China. The U.S. and the allied governments need to be adhering to the spirit of the law and suspicious of shell companies that China utilizes to circumvent these bans. to effectively hinder China's semiconductor industry and restrict its access to the advanced logic chips necessary for running AI systems.

Figure 15



Nikon & Canon have too diversified a business model and wide range of products to analyze just their KrF & ArFi scanners.

Although the U.K. and the Netherlands are in line with U.S. foreign policy, especially towards China, it is by no means a guarantee, illustrated by the U.K.'s decision to allow Huawei to build its 5G network despite protests from the U.S. government. ARM, the British company, is crucial in designing chips for consumer electronics such as phones and IoT devices. ARM is owned by Softbank, a Japanese bank, and as a result is not listed as a separate entity on Bloomberg so there is not any financial data on the company. Moreover, although the company is owned by a Japanese bank, its headquarters location in Cambridge, England places it under the regulatory control of the U.K. government. However, the U.K.'s Core IP market share of 43.4%

is also ARM's market share of the global Core IP market, illustrating the dominance of one company. Miller pointed out that ARM utilized the RISC architecture that was more power efficient and better suited than Intel's x86 architecture, the dominant existing architecture before ARM. Although China wants to break free of these architectures and move to an open-source architecture that is both free and not subject to export controls, ARM and its U.S. counterparts remain crucial within the supply chain.

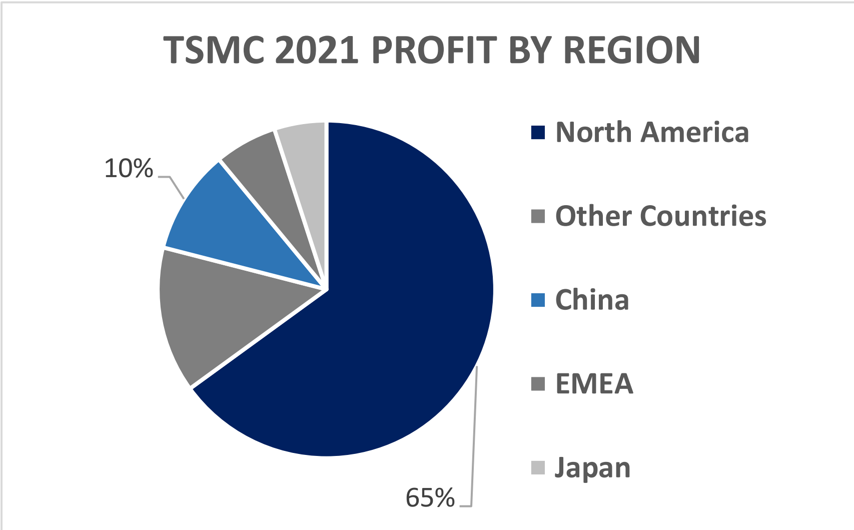
According to one of my industry sources that worked at Intel, Taiwan, South Korea, and Japan are not always in lockstep with the U.S. when it comes to trade policy with China. All three countries have enormous amounts of trade with China and access to the Chinese market is crucial for the financial health of these companies and their overall economy. My industry source from Intel placed South Korea and Japan in one tier and described Taiwan as in a different tier itself. Examining the two sides of the logic chip supply chain, my industry source hypothesized that the logic chip companies will feel the pain of any U.S. export bans and push back against them more than the logic chip input companies. My source identified two reasons for this conclusion. The first is the issue of margins on high-end microprocessors or logic chips. These are the ones being directly targeted by Biden's recent bans. Although the end-use of the chips is what is driving the reasoning behind the bans, the supply chain is so complex that U.S. policymakers cannot ensure a high performing chip that is being sold to a non-threatening entity will not transfer that chip into a more nefarious AI system once in China. As a result, the bans applied to the chips do not discriminate based on their potential end-uses but on their level of advancement. Based on language from the ban and conversations with exports, any chip with 14 nanometers or less is subject to the bans. These chips, according to the industry source, have a margin in the hundreds of dollars per chip while the lower end logic chips have a margin around

5 dollars. As a result, even if these hips do not make up a majority or even a large slice of TSMC and Samsung's sales to China, any ban on them would have an outsize impact on their profit margins. As the only two companies with the capability of manufacturing advanced chips smaller than 10 nanometers, the entire world remains dependent on innovations within their foundries to design even smaller and more advanced chips in a cost-effective manner.

For logic chip input companies, their financial outlook is considerably less bleak in the face of these export bans. Although these bans place strict limits on the equipment involved in manufacturing advanced chips to China, China already trailed the rest of the world in advanced chip manufacturing. China's approach to semiconductor manufacturing has always been investing enormous amounts of state capital into huge conglomerates, which allowed them to gain market share in low-end chips and the assembly and testing of finished logic chips. Moreover, the push by the U.S. and some of its allies to onshore semiconductor manufacturing will benefit these companies enormously. The CHIPs Act offers 39 billion dollars in subsidies just for onshoring manufacturing and semiconductor companies will be purchasing more manufacturing equipment, likely offsetting most of the losses from the Chinese market because of Biden's export bans.

Analysis of data from TSMC and ASML, the key Taiwanese and Dutch companies that dominate key supply chain chokepoints and represent both sides of the logic chip supply chain. Examining TSMC's recent annual 10-k filing, which details their revenue breakdown we see that 10% of their profit came from China (see Figure 16).

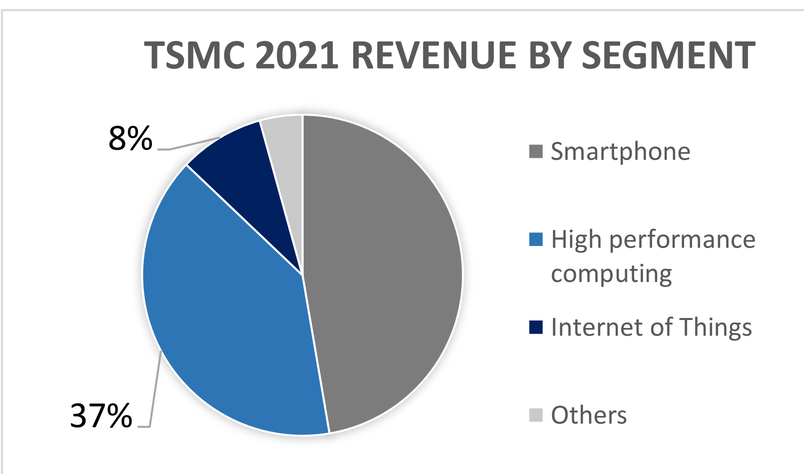
Figure 16



TSMC 2021 10-k Annual Filing, page 14

Figure 17 details their product breakdown and high-end computing is almost completely advanced logic chips. Moreover, nearly all the chips in Apple's iPhones are manufactured by TSMC so most of those chips in the smartphone sector are going to North America.

Figure 17



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China is the second largest country that TSMC sells to and since most of their smartphone sales are to Apple in North America, their other products are more prevalent in China and directly subject to Biden's export bans. Moreover, the 10% profit margin to China is misleading because TSMC is just a foundry, so the chips return to their designer once they are finished. TSMC manufactures Nvidia's advanced GPUs because it lacks the capacity to manufacture chips themselves. Last year, Nvidia paid TSMC 21.79 billion dollars last year to manufacture its chips. That profit margin is calculated as profit from North America, but Nvidia has a 21% average revenue exposure to China over the past 10 years (see Figure 6). The Biden's Administration's export bans directly target Nvidia, but they will adversely impact TSMC's margins as well as the bans ripple down the supply chain.

Advanced Micro Devices (AMD) paid TSMC 33.05 billion dollars last year to manufacture its chips, Intel paid them 6.59 billion dollars, Lattice Semiconductor paid them 698.21 million dollars and Xilinx paid them 88.91 million dollars.[7] The data from Bloomberg model also notes numerous other U.S. semiconductor companies with significant revenue contracts with TSMC, but the focus of this thesis is on logic chips specifically, not all semiconductors, so they were not included in the analysis (Bloomberg, 2022).

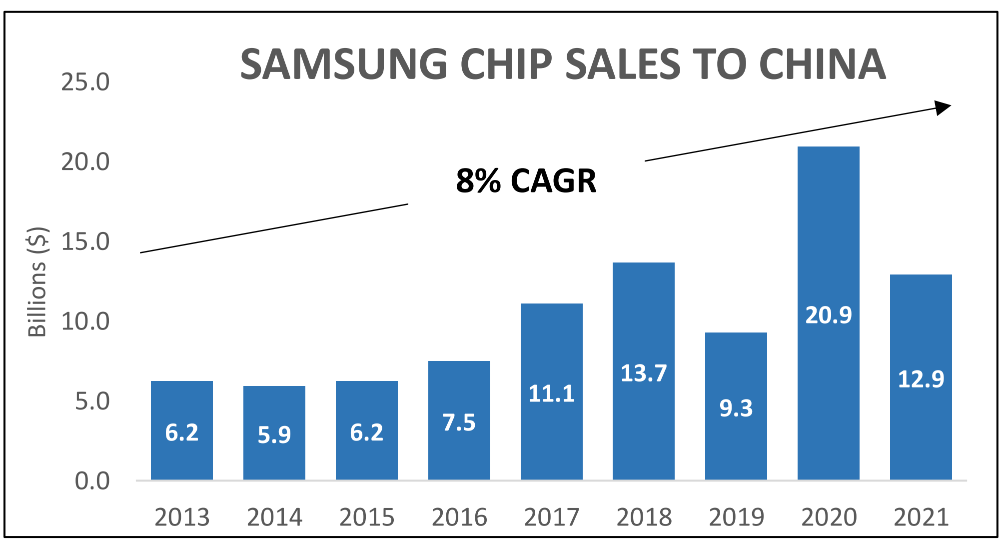
Biden's export bans, as illustrated in the previous section will significantly reduce these those U.S. semiconductor companies' revenues which will trickle down to TSMC. Moreover, these types of logic chips are being held up as one the core products driving the reasoning behind these bans because of the role they play in AI. However, the advanced logic chips also have the highest margins among TSMC's products which means the bans will have an outside impact on the company's profit margins. TSMC is the undisputed industry leader. Jimmy Goodrich states that they "manufacture 92% of the world's advanced logic chips", a dominant position that makes U.S. companies dependent on TSMC's foundries to make its most advanced products (Goodrich, 2022).

[7] Tesla was listed as a customer of TSMC, but Bloomberg did not have a monetary value for how much Tesla paid TSMC

However, TSMC must adhere to these export bans because they rely on EDA and Core IP from U.S. companies. According to Bloomberg data, KLA, which manufactures a lot of semiconductor equipment, received 504.93 million dollars from TSMC for their equipment last year. Moreover, TSMC paid LAM Research 305.32 million dollars for their etching and cleaning equipment, a key process in the semiconductor manufacturing process. Although these U.S. companies do not have a monopoly, they dominate aspects of the logic chip input supply chain and TSMC needs their products to operate its foundries (Bloomberg, 2022).

While Samsung only produces 8% of the world's most advanced logic chips according to an expert source, Samsung has some of the most advanced foundries in the world and has close economic ties with China (Goodrich, 2022). Figure 18 illustrates Samsung's revenue to China over the past 10 years. Although China on average is only around 5%, the same margin issue applies as Samsung sends a lot of advanced chips to China and cutting off those chips has an outside impact on profit margins (Wind, 2022).

Figure 18



Wind Financial Database

Samsung is a foundry like TSMC so the data on sales to China can be deceiving. Although there is no available data on their supply chain exposure, they have numerous U.S. fabless firms as customers and those companies' inability to sell to China will adversely impact Samsung's profit margins (Goodrich, 2022).

These issues illustrate why there will be pushback on Biden's export bans from these allied countries as it threatens enormous companies that supply thousands of jobs. These company leaders must comply with regulations, but they have a duty to their shareholders and will retain as much presence in China for as long as possible to protect their profit margins.

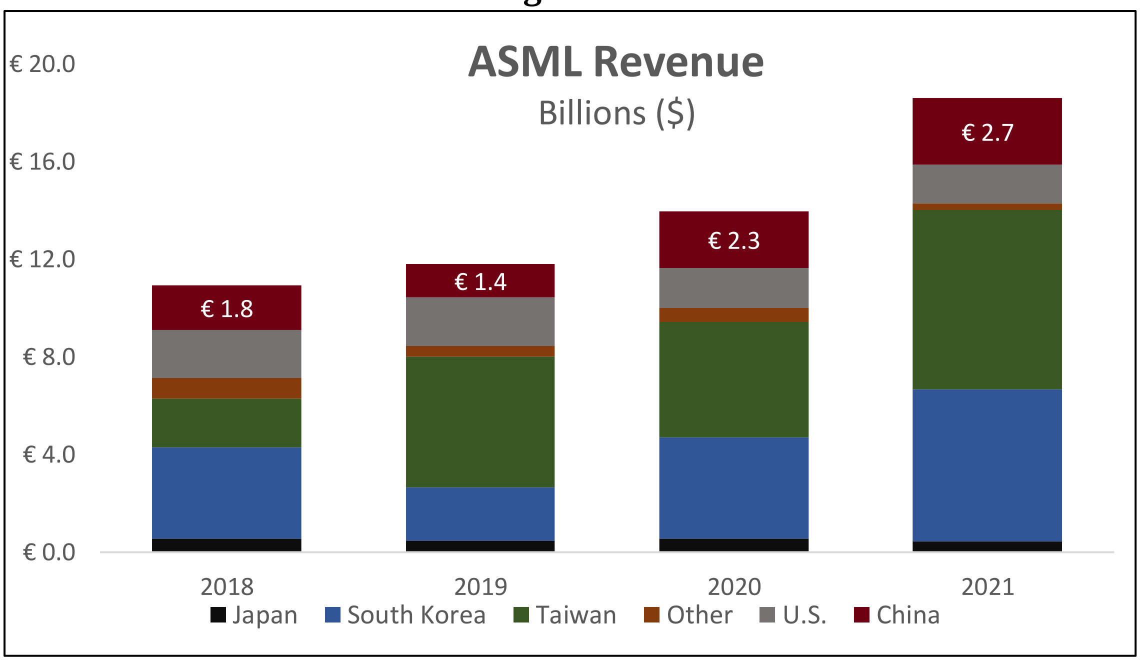
Even within the U.S., companies will resist decoupling for as long as possible to maintain profit margins. My industry source from Intel reaffirmed this intuition based, stating that Intel, for example, will try to keep their foundry in Delian China open as long as possible. Even though Intel will have to slowly moving down the value chain from less advanced chip to less advanced chip as the restrictions tighten, keeping the foundry open and producing lower margin chips is still more profitable than closing it due to their enormous up-front costs. The industry source established a clear financial motive to not only keep foundries open in China when possible but also strong incentive to apply for licenses that allow companies to circumvent the bans (Industry Source # 1, 2022). Therefore, it is safe to assume companies in U.S. allied countries will pursue the same strategies. As a result, the effectiveness of the bans will be determined by allied government's enforcement of the bans and buying into the strategic rationale behind the restrictions.

ASML faces a different story upon closer analysis of the data. Figure 19 illustrates ASML's revenue exposure to China over the past 10 years. Although ASML has a 15.3%

average revenue exposure to China, the data can be deceiving in the context of the export bans (ASML, 2022).

According to an expert interview from the Semiconductor Industry Association, and data from their internal database, China already lacked access to the advanced lithography equipment necessary to manufacture advanced chips (Goodrich, 2022). Trump as early as December of 2020 placed stringent export controls on SMIC, China's largest semiconductor manufacturer, on all semiconductor manufacturing equipment involved in manufacturing the most advanced chips. This policy served as the precursor for Biden's export bans that targeted semiconductor technology based on level of technological advancement (Wolf and Brown, 2022).

Figure 19



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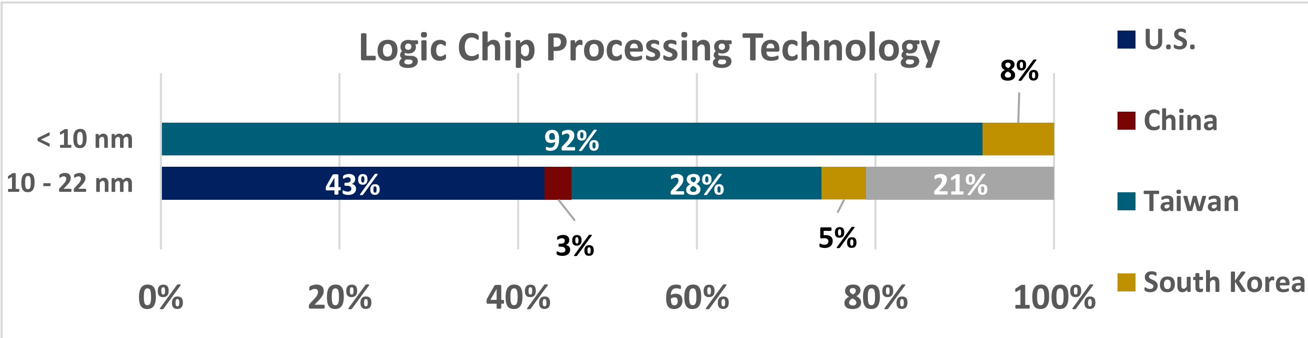
China makes none of the most world's most advanced logic chips and only 3% of the 10-22 nanometer logic chips (see Figure 20), the next level of advanced chips (BCG & SIA, 2021).

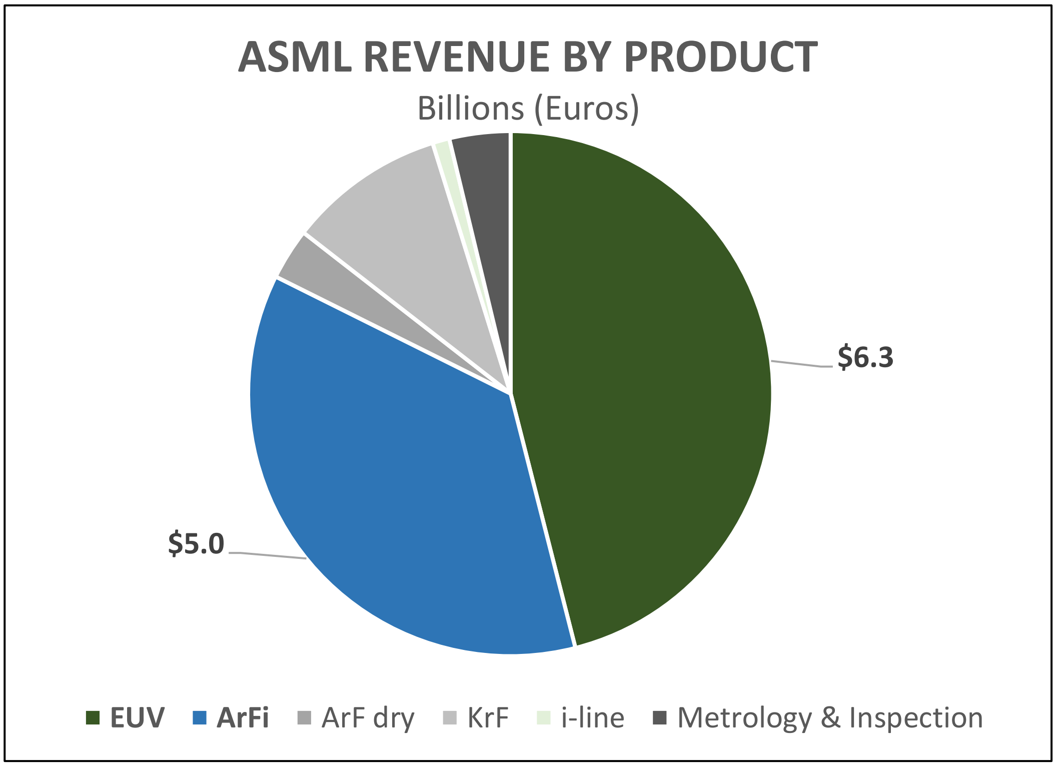
Figure 20



SIA & BCG State of the Industry Report & Expert Interview with Jimmy Goodrich

Meanwhile, TSMC, Samsung and Intel have all announced plans to open foundries in the U.S. due to subsidies from the CHIPs Act, which will further increase demand for ASML's products (Industry Source # 1, 2022). Furthermore, a breakdown on ASML's revenue by product illustrates shows that 46% percent of its revenue comes from Extreme ultraviolet lithography (EUV) equipment (see Figure 21), equipment China has never had access to in the first place (ASML, 2022, p. 187). Meanwhile, demand for their EUV and ArFi equipment is poised to skyrocket as companies such as Intel, Samsung and TSMC build new foundries in the U.S. and other western countries as part of the Biden Administration's onshoring strategy. Therefore, the margin issue around the advanced equipment does not apply to ASML and the input side of the manufacturing supply chain. Onshoring due to geopolitical reasons inherently helps companies such as ASML because a certain number of machines placed all over the world as part of the globalized supply chain can fulfill current global demand but onshoring artificially inflates the number of machines needed due to resiliency and national security.

Figure 21



ASML 2022 10-k Annual Filing, page 187

The financial motives behind each of these companies necessitate a global and multilateral export bans on advanced logic chips. My industry source outlined how if the bans are not multilateral in scope, countries could tweak their own bans to benefit their home companies, providing a business advantage to one semiconductor company over another (Industry Source # 1, 2022). Kevin Wolf, the former Assistant Secretary of Commerce for Export Administration during the Obama administration echoed my expert in a recent trade forum about the issue, stating that "when you have U.S.-only controls, by definition you are giving those markets to their non-U.S. competitors… you need massive amounts of exports in order to fund the massive amounts of R&D to do the innovation". Wolf pointed out that unilateral controls will only be effective in the short term and the data illustrates foreign companies and their home governments need to adopt their own bans to cut off Chinese access and mitigate disruptions to the industry (Wolf and Brown, 2022).

Taiwan especially faces a complex geopolitical environment that could make them unwilling or unable to fully comply with U.S. export bans. For example, even though TSMC is participating in the CHIPS Act and building a factory in Arizona, they are retaining the most advanced level of chips, less than 5 nanometers in Taiwan. Many of my expert interviews referred to it as Taiwan's "Silicon Shield", with the idea that the U.S.'s economic dependence on TSMC's chips makes it more likely to come to Taiwan's aide in the event of an invasion from China (Academic Source #1 and Goodrich, 2022).

These factors emphasize the limited reach of the U.S. and the reasoning behind a partial but not complete decoupling. Restricting even the most advanced level of logic chips will not be easy and the U.S. will have to constantly weigh concerns from its allies and company leaders worried about their profit margins.

China's Market Power Discourages Total Decoupling:

China's enormous demand and market share within the semiconductor market encourages both countries to maintain the supply chain and prevent a total decoupling. According to an industry report by the Semiconductor Industry Association, China alone made up for 34.4% of the semiconductor, purchasing over 150 billion dollars' worth of chips. However, China only has 16% of total global manufacturing capacity (BCG & SIA, 2021). Their economy remains dependent on U.S. semiconductor companies as more and more Chinese move online and fuel its appetite for semiconductors.

Meanwhile, the U.S. wants to limit the impact of its bans so that semiconductor companies can operate in an environment of predictability. The pandemic exposed on a macroscale how misjudgments in demand can have crippling effects for the U.S. economy. During the pandemic, semiconductor companies initially revised their forecasts on chips due to the onset of COVID-19. However, after a couple weeks demand exploded for PCs as everyone begin to work from home. Entire automotive assembly lines ground to a halt as they were unable to ship their cars without chips and consumer electronic companies like Apple placed similar delays on their products. Although the impact was mitigated, if the industry faced a potential cut-off of the entire Chinese market, it would not only imperil the financial future of these companies but cut them off to the assembly and packaging aspect of the supply chain that integrates the chips into their end devices (Miller, 2022).

According to multiple experts, the U.S.'s strategy is not a total decoupling but retaining a gap between China's chips and American chips, placing them always a step behind. According to my industry source, this allows policymakers to ensure U.S. semiconductor companies are not advancing China's AI capabilities beyond our own without imperiling the financial health of companies at the cutting edge of innovation. The industry source outlined a situation in which China invaded Taiwan and predicted a 20% increase in the cost of automobiles and consumer electronics, triggering inflation across the U.S. economy. "Resiliency within the supply chain" is crucial to preventing widespread inflation and the negative shock effects that world got a taste of during the pandemic. In many ways, one could argue that preventing that situation is more important and relevant to national security than limiting access to advanced technology (Industry Source # 1, 2022).

Chris Miller verified this strategic approach and explained its historical roots. At the height of the Cold War, the Soviet Union and the U.S. were acutely aware of the power of semiconductors to modernize warfare with precision guided missiles and bombs. Military leaders on both sides saw them as decisive for warfare. The Soviets as a result adopted a “copy it” approach, using their extensive spy network to infiltrate U.S. companies and universities and build up their own manufacturing base of advanced chips. The Soviets were remarkably successful in stealing U.S. designs and recreating it in Russia with access to enormous amounts of state funds. However, due to the speed of semiconductor innovation and the enduring presence of Moore’s Law, by the time they began manufacturing those chips and integrating them into their systems, the U.S. had already started producing the next generation of chips. Even though they had the chip designs, it took them so long to build out the equipment and processes necessary to manufacture them that they were always a step behind (Miller, 2022).

The U.S. wants to continue that approach on a bigger scale, aware of China’s higher level of integration into the global economy than the Soviet Union ever was. The U.S.’s current strategy is modelled after that approach, but with a higher emphasis on lower-level chip sales remaining for the sake of the semiconductor global market.

Although National Security Advisor Jake Sullivan called the strategy a few generations ahead not enough, the new export controls represent the first comprehensive effort to actually enact that few generations ahead strategy due to China’s high level of integration into the global economy. The idea of maintaining “as large a lead as possible” is cajoling the entire western world to accept serious financial costs and cut-off China’s access to certain chips (Sullivan, 2022). China’s enormous demand for chips and immense market power will ensure it is a complex, painful and slow process for the U.S. and its allies (SIA, 2021).

Although Chinese rhetoric and state policy has called for independence from foreign suppliers, China's lack of retaliation to Biden's export bans illustrate the dependency it has for U.S. made chips (Wolf and Brown, 2022). China faces a landscape in which its demand far exceeds its manufacturing capacity, and like the U.S. its economic growth hinges upon semiconductor powered technologies (SIA, 2021). After the pandemic illustrated the economic fallout of widespread chip shortages, it is safe to say that neither China nor the U.S. wants a total decoupling to occur in the short term.

Hampering Innovation Hypothesis:

The state of innovation of semiconductors has for the past 50 years relied on semiconductor companies designing new chips and developing innovative new ways to test them. When semiconductors were first replacing vacuum tubes, huge government defense contracts were steering the direction and innovation of these chips. However, by the early 1970s consumer electronics and other commercial industries dwarfed the defense industry and Silicon Valley became the source of semiconductor innovation. These companies have kept Moore's Law alive and kept the price of semiconductors down despite increasing levels of advancement.

Moore's Law has not just increased the computing power of semiconductors but also fueled SWaP-C innovations. Size, Weight, power, and cost have all seen enormous efficiency gains. Chips have gotten smaller, lighter, more power efficient and cheaper which has increased their use cases and the types of systems they can be integrated into (Hodiak, 2022). All these innovations will be hurt by the partial decoupling.

Build Walls or Run Fast:

U.S. policymakers face a dilemma when it comes to the state of innovation and strategic competition with China. One can either build walls or run fast. In other words, build walls around sensitive technology, hampering your own innovation in the process or attempt to run faster and continuously innovate, knowing that limiting the share of knowledge in a globalized world is incredibly difficult. This policy debate surrounds the entire AI technology stack but particularly semiconductors because they are the easiest part of the stack to erect walls around (McGinnis, 2022).

As discussed above, the building walls approach will face numerous issues as the U.S. struggles to initiate a partial decoupling surrounded around the most profitable types of chips in 440-billion-dollar globalized market (SIA, 2021). The efforts to accelerate innovation through government subsidies will play out over the next few years but they are dependent on the political will of the government supporting them and profit margins they produce for the companies behind the innovation.

Economics of Chip-Making:

Understanding the economics and tight margins of chip manufacturing is crucial to understanding any policy recommendations around this issue. The per unit cost of a semiconductor chip has fallen from $0.98 in 2001 to $0.68 in 2020, however there have been fluctuations throughout that period reflecting the volatility of the industry. Moreover, the number of transistors has doubled ten times throughout that period in line with Moore’s Law (SIA, 2021 p. 27).

The SIA 2021 Industry Outlook and a BCG/SIA report, obtained from the same expert interview source, offer slightly different numbers but tell the same narrative. Semiconductor innovations have been fueled by enormous R&D expenditures. R&D expenditures as a percent of sales has averaged roughly 18% since 2000 and was 18.6% in 2020. This places semiconductors as the second most R&D intensive industry in the world, behind pharmaceuticals (SIA, 2021, p. 40-44). Moreover, semiconductor equipment, or the input companies within the logic chip supply chain, is the fourth most R&D intensive industry in the world at 10.8%. The U.S. also has the highest R&D expenditures as a percentage of sales in the world, followed by Europe at 17.1%. China lags far behind in fourth place with 6.8% of sales towards R&D (BCG & SIA, 2021).

The BCG & SIA report placed semiconductors as the most R&D expenditures as a percentage of sales at 22%, edging out pharmaceuticals at 21%. However, this report offers further insights into R&D expenditures. Within the 22% of R&D expenditures, 12% goes to design while 6% goes to manufacturing and the remaining part goes to the rest of the value chain. Moreover, semiconductors are also the highest capital expenditure as a percentage of sales at 26%. These capital expenditures include new equipment and state-of-the-art factories. Breaking down the capital expenditure, chip manufacturing makes up 20%, while design only makes up 3% and the remaining 3% is devoted to the rest of the supply chain (BCG & SIA, 2021).

These numbers help explain several phenomena. The U.S.'s status as the global leader in R&D expenditures can be explained by the fact that most of the world's fabless firms are in the U.S. while manufacturing remains concentrated in Asia. My industry source confirmed this phenomenon by stating that when he left Intel, many in the company were questioning the viability of the IDM model considering the significantly higher margins of the fabless model (Industry Source # 1, 2022). This explains why the U.S. has seen so much off shoring of manufacturing in the past decade as firms seek to increase their margins, lowering costs and increasing investments in R&D. This trend has undoubtedly benefited the American consumer, and more broadly the global consumer.

Data from the 2021 SIA Industry Outlook further reinforces this point since the gross capital expenditures as a percent of sales in the U.S. across the industry rests at 12.6% compared to 16.4% for IDM companies. Furthermore, the U.S. and Europe make up 94% of the EDA & Core IP design capacity in the world and 75% of logic chip design but only 21% of wafer manufacturing capacity. This explains why the U.S. and Europe far outpace China in R&D expenditures because they dominant the top of the value chain (SIA, 2021). Although efforts to onshore manufacturing from a supply chain security point of view are essential, it will hamper innovation and slash R&D expenditures even with government subsidies. This data exposes issues within the Biden administration's core legislation to address many of the vulnerabilities within the semiconductor supply chain.

CHIPS Act: A Small Step in the Right Direction

Throughout my interviews, there were two consistent themes about the CHIPS Act, it was insufficient, and the R&D funding was what people should be focusing on. Both my industry source and Kevin McGinnis pointed to the 13 billion dollars in R&D funding as huge step in the right direction because it is easy to allocate funding for new factories that produce jobs but investing in the technology that forces companies to innovate is more politically fraught. However, the 39 billion dollars in subsidies and tax credits dwarfs the R&D investment reflecting the political motive behind the legislation and the fear of supply chain vulnerabilities (Industry Source #1 and McGinnis, 2022).

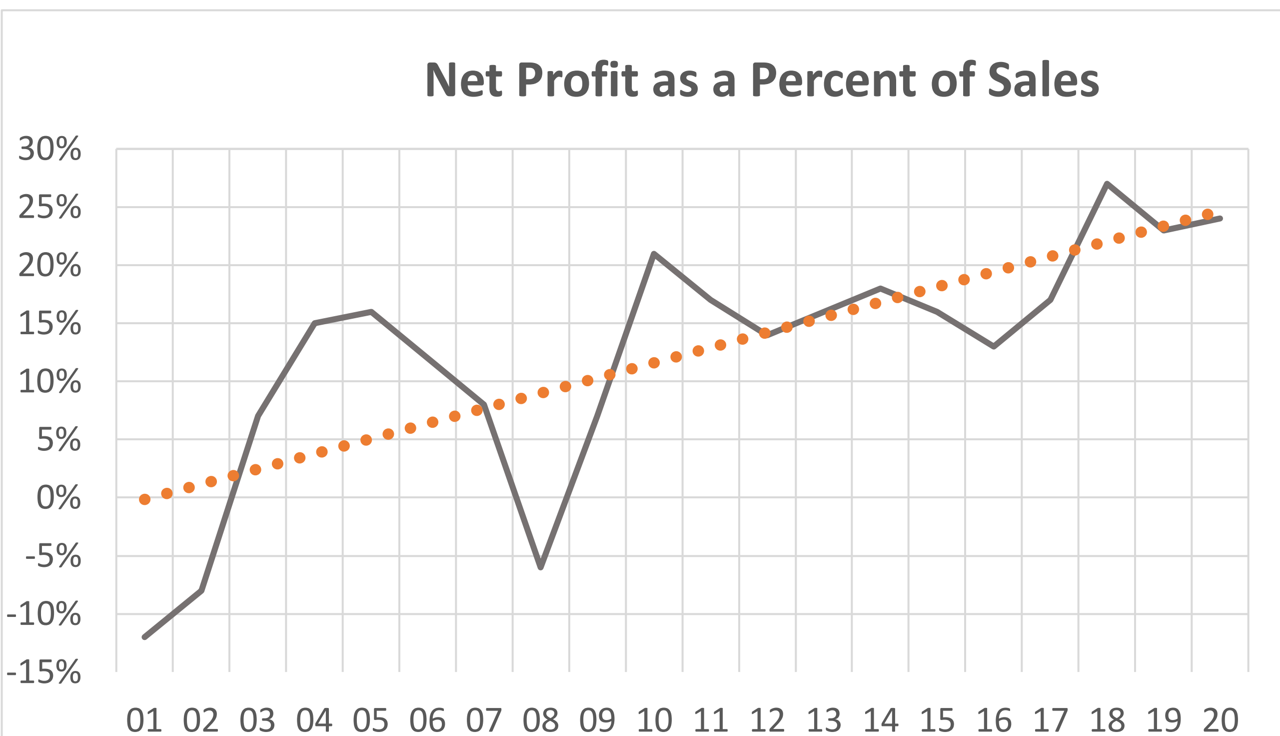
However, many experts believe it is insufficient to addressing the strategic vulnerabilities of offshore manufacturing in geopolitical hotspots. My industry source argued that to really shore up vulnerabilities and prevent widespread inflation caused by chip shortages, the CHIPS Act needs to be “10 times” larger than the 52 billion dollars that the current legislation allocates (Industry Source # 1, 2022).

McGinnis highlighted the consequences of the onshoring drive, noting that consumers will have to accept that to access “trusted” semiconductors they will have to pay more for them. McGinnis also mentioned that the CHIPS Act is addressing another glaring issue within U.S. semiconductor manufacturing ability, the lack of trained labor. Semiconductor manufacturing is highly technical and requires extensive training even at the blue-collar level. Although it is not enough in McGinnis’s opinion, the lack of trained labor is a significant hurdle the U.S. must overcome if it wants to on shore semiconductor manufacturing (McGinnis, 2022).

SIA data illustrates why semiconductor manufacturing moved offshore and the negative consequences onshoring will have on the economics of semiconductors, even with the CHIPS Act. The average pay of a U.S. semiconductor manufacturing job in 2020 was $176,594 per year, compared to the $73,398 per year average for all manufacturing jobs in the U.S. Moreover, the manufacturing jobs in the industry have seen a compound annual growth rate of 4.34% for the past two decades (SIA, 2021 p. 49-56). These jobs require a high level of training and usually an advanced degree in math or science or a highly technical vocational degree. As Miller stated earlier, this as the reason why semiconductor manufacturing initially moved to Asia. Engineers from Asia could work assembly lines for a quarter of the salary compared to their U.S. counterparts. Offshoring reduced the costs of semiconductors, increasing demand and opening to new markets (Miller, 2022). This fueled profits which funded R&D efforts that developed the next chip that was more advanced and cheaper. This self-perpetuating cycle fueled innovation and Moore's Law. Trends from the past twenty years alone illustrate the powerful effect of this cycle. Figure 22 shows net profit as a percent of sales over the past two years, and the trend line shows the strong increase in profitability across the industry, recovering from fluctuations such as the 2008 financial crisis (SIA, 2021).

The industry report cites advanced products and the adoption of the "fab-lite model" or a push towards fabless companies as two of the main reasons behind this increased profitability along with industry consolidation and economies of scale. The Biden administration's export bans restrict companies from selling advanced chips to the single largest semiconductor market in the world and the CHIPS Act onshores manufacturing, eroding at the financial viability of fabless companies as the cost of manufacturing increases for the foundries that make their chips (SIA, 2021).

Figure 22



SIA 2021 Industry Outlook

As the U.S. seeks to reverse this cycle, legislation such as the CHIPS Act goes a long way but there's only so much 52 billion dollars can do to a 440-billion-dollar global market (SIA, 2021). The impacts of Biden's export bans have already been reflected in the lower stock prices of key U.S. semiconductor companies such as AMD and Nvidia, illustrating the bans adverse impact on the companies' profitability (Noonan, 2022). Reduced profit margins will undoubtedly have an impact on R&D expenditures and as two of the industry leaders in AI logic chips have already felt the impact of the bans (AMD and Nvidia) this will have significant implications for the global state of innovation. My industry source confirmed this intuition, stating that R&D innovation would be one of the first things to suffer in a downturn. For example, Intel funds Intel Labs, an innovative research laboratory looking at advanced semiconductors in new fields such as quantum computing would be one of the first parts of Intel that would receive funding cuts in any sort of downturn as company executives seek to implement costing-saving measures across the board (Industry Source # 1, 2022).

Ending Moore's Law:

Throughout my research process, many of my academic and government sources alluded to an end to Moore's Law but an inside industry source confirmed that it has already ended. My industry source, who left Intel two years ago, confirmed that Moore's Law, by its own definition had more than five years ago at Intel, but that Intel was "redefining Moore's Law on the fly" to match their own level of innovation. Five years ago, Intel's ability to double the number of transistors on a chip fell to every three years. Moreover, the conversation around Moore's Law has shifted from node size and the number of transistors to other metrics of performance. One of the most important ones, for example, is performance per watt (Industry Source # 1, 2022).

These innovations used to be a supplementary and accompanying innovation to Moore's Law because as chips got smaller and more powerful, they also got more power efficient and cheaper because each chip could do more.

However, as Moore's Law flattens out, those performance metrics will become the singular focus of chip designers. Drawing on a concept introduced earlier, these are continuing the innovations of SWaP-C minus the size aspect as size becomes a limiting factor for semiconductors. As AI powered systems consume increasing amounts of power to crunch complex algorithms, even a 1-2% improvement in power efficiency across a data center with thousands of chips would have an enormous effect and determine how many systems AI can be integrated into, from a drone to a smartwatch (Industry Source # 1, 2022). However, the question of whether in a world without Moore's Law, chip advancements around power and cost efficiency will be as profitable as producing chips with double the computing power of the previous generation of chip remains to be seen.

This insight aligns with public statements made by senior executives at Intel. When Riccardo Masucci, Global Director of Private Policy at Intel, came to Duke and gave a lecture about the company and the future of the semiconductor supply chain, he was asked about the continuation of Moore's Law at Intel. Masucci responded by stating that the law is alive and well at Intel and its engineers continue to innovate its chips in line with its overarching principles. There was no mention of the doubts expressed by my industry source (Masucci, 2022).

DARPA's Strategic Bet:

Although there is a lot of debate on whether Moore's Law is still alive or not, the government is investing in initiatives due to its impending demise to maintain the U.S. government's lead. According to Justin Hodiak, a contractor at DARPA, the Pentagon is making a “strategic bet” on new paths and technologies that may allow the number of transistors on a chip to increase on the assumption that Moore’s Law will end, and nodes can only be shrank down so much further. As Hodiak, explained, the aim of an organization like DARPA is to fund unproven technologies not being funded or researched by the commercial sector. Their job is to find holes not addressed by any private sector actor or existing government project and fund initiatives to accelerate U.S. investment and research into those technologies. For the sake of this issue, the “strategic bet” is focused on the materials science behind vertical stacking. As nodes get smaller, leading firms, such as AMD and Intel, decided to go vertical through 3D stacking in an implicit acknowledgement that Moore’s Law is largely over and going vertical is the only way to keep increasing computing power (Hodiak, 2022).

For example, 3D vertical stacking has been used by AMD, and to a smaller extent Intel, in server chips for specialized data centers and supercomputers, vastly enhancing their performance and power efficiency. The process involves placing silicon wafers on top of silicon wafers to maximize the number of transistors on a chip. DARPA has been funding an initiative called “3D heterogenous integration”. This follows the concept of stacking wafers but using “dissimilar materials” because the commercial sector is investing billions to “wring out” the last of Moore’s Law using silicon on silicon stacking on ever shrinking nodes. However, everyone in the industry knows that will soon come to an end because nodes can only get so small. Hodiak called this a “technological plateau”, and it is a strategic vulnerability for the U.S. due to its current comparative advantage over China in semiconductor manufacturing. Hodiak pointed to the Biden Administration’s recent export bans as evidence of the U.S.’s intent to slow China’s progress towards that same “technological plateau” (Hodiak, 2022).

Many at DARPA, including Justin Hodiak, believe that the "silicon scaling story will end in the next decade" but also that most subsequent semiconductor innovation will come from those scaling efforts. Therefore, the strategic bet prepares for this eventuality by accelerating investments in other materials that may yield alternative paths to increase the computing power and transistors so that industry has a strong basis to launch from once they pivot from silicon innovations. The core question DARPA is looking at focuses on stacking and integrating different materials into a complex semiconductor. Although this research has shown some progress, Hodiak emphasized that big reason DARPA was focusing on it is because it is being overlooked by industry (Hodiak, 2022).

Government agencies such as DARPA are critical for identifying new paths forward and discovering innovative new technologies. However, consistent throughout the interview was the importance of private sector innovation because it has a larger R&D budget than DARPA and because the U.S. government is not innovating in obvious and less risky paths forward, entrusting it to the private sector. Moreover, Hodiak acknowledged that when it came to AI and logic chips, silicon chips were likely to be more relevant to AI development than chips with other materials. The materials science research would likely benefit the DAO chips that provide sensory data for logic chips to process as part of an AI system such as an autonomous vehicle. These trends further illustrate the critical nature of U.S. semiconductor companies' R&D budgets in advancing U.S. AI capabilities and development as they are the largest source of innovation (Hodiak, 2022).

AI ASIC Start-Up Data:

According to Pitchbook, there are 611 Chinese fabless chip design start-ups focused solely on developing AI ASIC. These chips are optimized for AI systems. 311 of them are focused on China's domestic information technology industry, helping China collect and sift through the enormous amount of data it has stored on the cloud (Pitchbook, 2022). My industry source brought this up as a concern, saying AI based cloud computing was an area China dominated, with Chinese tech giants providing its cloud services to foreign companies and governments alike (Industry Source # 1, 2022). As Justin Hodiak described in our interview, what makes these AI ASIC types of chips so powerful is that they can be optimized to work specifically with a type of AI algorithm for increased efficiency and power, the perfect blend of hardware and software. The current issue is the economics of not mass-producing chips but ordering smaller batches, as this vastly increases the price per chip (Hodiak, 2022). However, this burgeoning Chinese start-up economy is fueling those innovations and helping China develop robust capabilities. Alarmingly, many of these start-ups have received funding from U.S. or western financial institutions and venture capital firms. However, as the U.S. seeks to impose restrictions on those investments, many of 2,000 U.S. AI ASIC start-ups will similarly lose access to Chinese funding, illustrating the corollary effect of export and financial restrictions (Pitchbook, 2022).

VII. POLICY RECOMMENDATIONS

Policy Recommendations

1) *Multilateralism*

Global Subsidies & Western Onshoring - If the U.S. wants to mitigate inflation on semiconductors and the adverse impact any level of decoupling with China will have on the state of semiconductor innovation, their policies must be global in scope. Although politically difficult, the U.S. must work to spread its subsidies across Europe to avoid duplicate and wasteful subsidies. Ricardo Masucci, at a talk at Duke, mentioned how a European CHIPS Act is in progress. That is a waste of money. There is no fear of Europe being invaded or decoupling from the U.S. economy. A similar CHIPS Act would only serve to waste taxpayer money on more manufacturing capacity that does not align with market demand. Moreover, the U.S. should seek to offshore manufacturing to less developed friendly nations that are not in geopolitical hotspots. For example, McGinnis mentioned how building out foundries in Mexico would be far more cost effective than the U.S. due to the lower cost of living and offer the same level of supply chain resiliency as an American factory. While politically it makes sense to onshore as much manufacturing in the U.S. as possible, generating high paying jobs, the economic data tells us a different story. Unless the U.S. perpetually subsidizes these chips, the cost of U.S. made semiconductors will be significantly higher. Considering chips are integrated into nearly every device we use; those costs will be felt across the entire economy and every American consumer will pay the price.

Multilateral Export Bans - Multilateral export bans are the only way to remove politics from determining industry leaders. Semiconductor manufacturing has an extremely high barrier to entry and if some companies gain access to the Chinese market, but others do not, they will quickly gain market share and erode their competitor’s capacity to compete. Moreover, if some companies are still giving technology and chips to China, they could be inadvertently helping China surpass the U.S. while U.S. companies are scrambling to find new markets to replace China.

2) Quantum Computing

According to Lauren Kahn, senior research at the Center for Foreign Relations, building out the hardware for quantum computing would have revolutionary changes for AI. Current semiconductors have transistors mean to process 1s and 0s, the binary language of computers. Quantum computing uses a qubit, which can be a 1 or a zero at the same time. Kahn stressed that AI is just one of the realms quantum computing could potentially transform. Quantum computers can sift through and process data, providing exponentially more computing power in a fraction of the time (Kahn, 2022).

One of the reasons underlying quantum computing's promise and importance is that there are a lot of software improvements that can be done to improve AI as a system. However, we currently lack the hardware or the semiconductors to fully create a quantum computing machine despite its revolutionary nature. Kahn stressed that although it is not an immediate issue, quantum computing is "right over the horizon" and many of its implications are unknown (Kahn, 2022). Moreover, my industry source at Intel said that one of the projects at Intel Labs is quantum computing hardware, illustrating its promise as a future innovative technology that leading companies are investing in (Industry Source # 1, 2022).

VIII. CONCLUSION

National security policymakers have some difficult decisions ahead as they navigate this complex business landscape. There are trade-offs to every national security policy and this thesis illustrates the trade-offs associated with a partial decoupling. However, the partial decoupling is incredibly necessary due to China's aggressive foreign policy and use of AI to challenge the U.S. on a military, economic and ideological level.

The U.S. must navigate all of these pitfalls along with the issue of Taiwan, which plays an incredibly significant role in the political and economic dynamics that are shaping the strategic competition between the U.S. and China.

The Issue of Taiwan:

It would be remiss not to mention the significance of Taiwan from a geopolitical and industry perspective. Taiwan represents a core foreign policy issue for the Chinese Communist Party and "reunification" with Taiwan is a high priority for party leadership. At the 20th National Congress this fall, Xi elevated the "unification" of China and Taiwan as one of the most important objectives of his third term in office. Although he acknowledged that China would "continue to strive for peaceful reunification," he also said that China reserved the right to use military force and "all measures necessary" to achieve unification. President Xi warned that China will "firmly oppose and suppress Taiwanese independence" and determine when and how to bring about unification (Guillermo).

This is the same country that produces 92% of the world's advanced semiconductors and TSMC's foundries are the most advanced in the world. Taiwan is at the epicenter of a hundred-billion-dollar supply chain and a potential ignitor of a large conflict between the world's two largest economies.

Many experts agree that the CHIPS Act was largely born out of increasing rhetoric from China regarding Taiwan and the strategic vulnerability it is for the U.S. to be so dependent on one country for all its semiconductors. Morris Chang highlighted these concerns and the worrying trend at a speech to mark the first equipment delivery to TSMC's new factory in Arizona on December 7th, 2022. The factory was a direct result of funding from the CHIPS Act and the first TSMC factory in the U.S. in twenty years. Chang stated that the semiconductor industry has seen an enormous "geopolitical situation change in the world" and as a result "globalization is almost dead and free trade is almost dead". Chang went on to state his belief that he does think it will ever come back, lamenting that the old, globalized nature of the supply chain was no more (Ting-Feng, 2022).

At 91 years old, Chang has recognized that his country's "silicon shield" has become too valuable for the rest of the world and Taiwan can no longer depend on that alone to defend its independence. Taiwan's security stemmed from its integration to the globalized economy and the fact that an invasion would disrupt key supply chain. However, now he is seeing globalization retreating as the U.S. and its allies begin to onshore manufacturing and mitigate their strategic vulnerabilities.

Next Steps for Future Research:

There are numerous research questions that branch off from this thesis that I could research. The first is the political and economic implications of the CHIPS Act as the supply chain becomes less globalized. Measuring the effectiveness of the CHIPS Act on stimulating research and development and increasing the U.S.'s advanced semiconductor manufacturing capacity will offer important insights for policymakers debating future legislation. The costs of onshoring manufacturing for the average consumer and for prices across the industry would be another great metric to measure in one or two years to estimate the financial cost of onshoring and the impact subsidies had on it.

The distribution of license exemptions as well as enforcement issues surrounding the export bans will offer fascinating policy insights around export bans of such a massive economy.

Never has a country so integrated into the global economy been forced into retreat due to geopolitical tension. China’s ability or inability circumvent the bans will not only be an interesting policy analysis but a stark indicator of the power and influence of the U.S.

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