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Cyber Policy Center

Semiconductors and a Strategic National Technology Policy

A Proposal Developed for the Technology and Public Policy Project[1]

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Summary

The current regulatory and legislative infrastructure is poorly suited to address the new challenges to U.S. leadership and innovation in key technology sectors. This paper uses the semiconductor industry as a case study to advance a proposal for a strategic approach to technology policy capable of enabling long-term leadership. This proposal, rooted in structural changes to the federal technology policymaking process, would allow the United States to respond more effectively to strategic technology policymaking of China and other rising economic competitors. Initial steps to advance strategic technology policy should aim to revitalize targeted scientific research, grow the science, technology, engineering, and math (STEM) talent development pipeline, and expand highly skilled immigration.

Introduction

The semiconductor industry is crucial to the United States, with a deep impact on innovation, the economy, and its global leadership. Not only does the U.S. semiconductor industry generate nearly half of all global sales and account for an outsized share of U.S. exports (5 percent of exports compared to 0.6 percent of national gross output), but the domestic industry has also led to the creation of a highly efficient global ecosystem that underpins the rapid pace of technological innovation with widespread benefits. Distinctive technology specializations required for semiconductor applications have arisen in countries around the world, and the vast global footprint has also afforded U.S. companies access to manufacturing

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cost advantages, a diverse talent pool, and a large global market on which U.S. innovation and technological leadership is heavily dependent (Exhibit 1). The semiconductor industry also plays a critical role in U.S. national security and defense technology and underpins key platform technologies and industries of the future, including artificial intelligence and autonomous vehicles.

Over the past three decades, the United States has extended its leadership in semiconductors and the broader technology industry, making Silicon Valley the envied epicenter of global innovation, even as innovation increasingly occurs in other areas throughout the country as well as globally. The key differentiators of U.S. innovation have been (1) technical, including the technical and scientific excellence of the universities and research institutes that produce widely disseminated scientific advancements and world-class technical graduates, operating in an environment of openness and collaboration; (2) cultural, enabling an entrepreneurial ecosystem of technical disruption, rapid capital formation, venture capital risk-taking and the expertise to scale platforms globally; and (3) legal, including extensive access to global markets, the alignment of risk and reward by using stock options and equity awards for entrepreneurs and employees, favorable regulatory frameworks enabling employee mobility, supportive tax policies, sophisticated intellectual-property regimes, protection from unfair competition and relatively supportive immigration policies to attract global talent.

Yet two long-term trends are converging to create a period of unprecedented change in the strategically and economically critical semiconductor industry. First, the technological revolution that began over 60 years ago with the advent of the first integrated circuit—the predecessor to the modern semiconductor—has reached a level of maturity, scale and global proliferation such that that no government, economy, industry, organization or person can escape its impact, for better or worse. In turn, leadership in this strategic sector is a primary point of competition among states hoping to win a larger share of the industries of the future. Moreover, the greater importance of technology to daily life and the increased potential for harm invites enhanced government regulation and policy actions, which can impact the competitiveness of domestic industries.

Second, China has evolved into the world's second-largest economy, with ambitions to compete economically, militarily and technologically with the United States, and it is focusing intensely on building a domestic semiconductor industry.

These are threats to the U.S. leadership, exacerbating perennial industry challenges, including declining U.S. government investment in basic scientific research, domestic talent shortages and technology-development complexities.

Government policies within the United States and certain foreign countries have focused on the semiconductor industry as a key driver of technological and economic advancement, and China is only the most recent country to invest heavily in establishing a domestic industry.

Before defaulting to a Cold War–like policy approach to address China's rise, policymakers should understand why the current circumstances are fundamentally different from those that underpinned the U.S. strategy during the Cold War with the Soviet Union. Moreover, policymakers must take a more comprehensive view of semiconductor and technology policy, because the current piecemeal approach is more likely to undermine than enable the long-term leadership of U.S. companies.

Only a fundamentally new policy approach can sustain and advance the long-term leadership of the U.S. semiconductor industry. If the semiconductor industry is to provide a continued strategic advantage for the United States, a new policy framework that addresses economic, technological and national security issues and objectives is necessary. The framework should focus on a three-part mandate: (1) support U.S. technological leadership in the semiconductor industry; (2) optimize the long-term economic value that the industry generates for the United States, both directly and indirectly; and (3) ensure national security concerns stemming from technology are addressed with the appropriate strategic response.

The Challenge

The United States has long been a global leader in semiconductors, but several factors are creating a more difficult environment that could ultimately threaten U.S. leadership. Most notable are the emergence of China as the primary geopolitical U.S. rival and the Chinese government's focus on creating a domestic semiconductor industry to minimize dependence on foreign suppliers and enable leadership and innovation in new areas, such as artificial intelligence, fifth generation (5G) mobile technology and autonomous vehicles. Several significant obstacles—declining U.S. government support and investment in basic scientific research, domestic talent shortages and the decreasing scalability and increasing complexity of the underlying technologies—are further straining the U.S. industry beyond the perennial challenges. The industry is characterized by massive capital investment, expensive research and development to achieve constant innovation across a wide variety of technical disciplines and the orchestration of highly complex, interconnected global supply chains to meet volatile and cyclical demand.

Competition is intense, and global industry leadership has been subject to significant shifts in the past few decades, as the Japanese emerged as leaders in the 1980s, the South Koreans in the 1990s and the Taiwanese in the 2000s (Exhibit 2).[i] Each of these shifts was the result of focused long-term government policy and investment. China has targeted the semiconductor industry as a strategic sector for many years, with relatively little progress for the scale of the investment. However, the current Chinese government is increasingly ambitious, with commitments to invest $100 billion over a decade.[ii]

The level of investment and government commitment is likely to increase even further given the heightened Chinese insecurity following the recent ZTE and Huawei bans by the U.S.

government and the growing number of companies on the Bureau of Industry and Security's Entity List—the federal government's compilation of parties that present national security concerns. Among the most notable recent additions to the list are Sugon, Wuxi Jiangnan Institute of Computing Technology and related entities for supercomputing advancements; and Hikvision, SenseTime and others for technology deployed in connection with human rights abuses against the Uighurs and other Muslim minorities in eastern China (Appendix 2).[iii]

China, Japan, Singapore, South Korea and Taiwan have established government bureaucracies, including Japan's Ministry of Economy, Trade and Industry (METI) and China's Ministry of Industry and Information Technology (MIIT), to orchestrate the development of their technology industries, for which semiconductors have been viewed as the foundation. These foreign governments have employed various tools ranging from support for basic scientific research to tax incentives, easy access to capital and government subsidies as well as protectionist policies and discriminatory government procurement regulations.

As the industry has become global since the 1980s, supply chains, technology expertise, intellectual property and innovation capability have extended throughout the world.[iv] The global industry is driven by scale and led by the companies capable of repeatedly developing the most advanced technology at the lowest cost and with access to the largest markets. Industry leaders work with partners and customers to power the next generation of technology innovation and disruption. The engine of innovation currently depends on the combination of the global supply chain, globally distributed talent and access to global markets (Appendix 3). This reality means that policy decisions about sustaining U.S. technology leadership, undermining established global supply chains or decoupling from large growing markets like China have become far more complex.

Recent U.S. technology-related policies have created challenges for the domestic semiconductor industry by taking simplistic short-term actions, including tariffs and export restrictions ostensibly designed to contain China's technological ambitions. These actions neither address the more complex long-term issues nor provide meaningful levels of prioritized investment and sustained support.[v] The short-term benefits of broad restrictive action may be politically satisfying, but the potential negative consequences—lost market access for U.S. companies, more determined government-backed foreign competition and greater shortages of skilled workers and STEM graduates—could prove to be more devastating to U.S. competitiveness than the original threat of unfair foreign competition, particularly if the unfair competition could be addressed by other means.

The U.S. faces profound domestic challenges related to the human capital necessary for long-term competitiveness in technology. The country does not produce enough skilled engineers to meet the needs of the broader technology industry. The U.S. deficit of STEM graduates, expected to reach to 1.1 million by 2024, is a strong disadvantage.[vi] China has 4.7 million, India has 2.6 million and the United States 568,000 recent graduates.[vii] The United States is

comparable to India for STEM graduates per population (1:5 ratio for Indians and 1:6 for Americans) but well behind China's ratio of 1:3. This deficit is particularly challenging for the semiconductor industry, which needs an array of deep technical skills in the hard sciences as well as skilled technicians and data scientists.

Currently, the United States enjoys a quality advantage in terms of engineering graduates, but many of the graduates are foreign nationals (in 2015, 70 percent of full-time graduate students in science and engineering[viii]; almost a third were from China[ix]). As the United States restricts foreign nationals' access to its universities and technology companies, this challenge will become more acute for the United States, and countries like China and India will benefit, particularly if their current efforts to improve the quality of their education are successful.

Finally, the United States has reduced government-funded science and technology research that is critical for continued U.S. technology leadership. Data from the Organisation for Economic Co-operation and Development (OECD) indicate that, while U.S. government and private spending on science and technology R&D has increased to approximately 2.7 percent of GDP, from about 2.5 percent in the 1980s, the U.S. government's contribution declined from 1.2 percent in 2010 to 0.75 percent in 2017. Note that this decrease came as the government contributions of the European Union and most peer nations, including South Korea and China, were increasing investment (Exhibit 3).[x]

In the U.S. federal government, the lack of a cabinet-level official solely responsible for national technology policy creates a challenge with respect to prioritizing, coordinating and integrating technology-related policies. As a result, technology policy has been subsumed by other national priorities and its responsibility diffused throughout the federal bureaucracy. More important, technology policy can more easily be overwhelmed by the agendas of powerful Cabinet members.

Responsibility for semiconductor industry-related policies is spread over different agencies, including the Department of Defense, Commerce, Energy and Education, among others. Ideally, relevant policy initiatives would be developed, coordinated and supported through an executive branch organization like the National Science and Technology Council (NSTC) and led by the Office of Science and Technology Policy (OSTP) in the White House. However, the NSTC has been ineffective at developing comprehensive technology-related strategies, including those focused on semiconductors. The primary impediments are threefold: lack of cabinet-level leadership responsible for technology policy; insufficient policy support capabilities; and lack of a regular process for prioritizing, formulating, and implementing national technology strategy.

Technology policy is also hindered by a lack of clout and policy-support capabilities in the White House. The OSTP, which evolved from the President's Science Advisory Committee, has often been plagued by the absence of senior leadership that is both knowledgeable about the

specific issues and with the institutional clout to counterbalance the dominant roles of other senior administration officials. At a critical time for developing and implementing U.S. semiconductor and broader technology policy, the director role of the OSTP was recently vacant for almost two years. The OSTP has dedicated, capable leaders and staff who have often produced thoughtful policy positions using external experts. Yet they have been unable to make many major policy decisions because they lack a powerful enough voice in many of the debates. The OSTP, with only 45 staff members, is also under-resourced and underrepresented in the key bureaucratic processes of the federal government. This leads to a lack of coordination on important technology issues, insufficient resident expertise and an outsized role for other stakeholders, namely those connected to national security and defense, in complicated policy issues for which technology is increasingly important.

Finally, the policymaking processes of the U.S. government evolve slowly, with changes triggered by particular crises, often in the national security or economic domain. As a result, the policymaking bureaucracy for national security, including defense and intelligence, is the most muscular and well-developed, followed by those associated with economic policy. While this is understandable given global threats and federal government mandates, the policymaking processes of these two areas can overwhelm or crowd out other areas, including technology policy development.

The Proposal

Addressing the challenges requires a new, comprehensive and balanced framework to guide U.S. technology policy decisions and actions, of which semiconductor policy would be an important element. This Technology Policy Framework should be based on a three-part mandate: (1) create the optimal conditions for U.S. technology leadership and innovation over the long term; (2) maximize the long-term direct and indirect value the industry generates for the U.S. economy; and (3) ensure that national security concerns are addressed effectively. The broader technology policy mandate should also include a social-impact regulatory agenda, which is critical to addressing issues such as privacy, competition and equality but is beyond the scope of this paper.

Just as important would be the creation of a powerful policy orchestration body with the appropriate cabinet-level leadership to champion the technology agenda and counterbalance the national security and economic stakeholders. This National Technology Council (NTC) should be separated from the current National Science and Technology Council (NSTC), which would become the National Science Council (NSC) (Exhibit 4). The NTC would work closely, in a cooperative and synergistic manner, with the NSC because so many of the policy issues, such as in the areas of education, research funding and public-private partnerships, are intertwined. To warrant separation, however, the mandates of the two councils would be different and require different skills and, often, stakeholder participants.[xi]

The NTC should be led by the National Technology Advisor, who would be a member of the President's cabinet. The council would be analogous to the National Security Council or the National Economic Council, formulating national technology policy in a more robust manner than it is under the existing regime as led by the OSTP—which would be split into the Office of Technology Policy (OTP), supporting NTC, and the Office of Science Policy, supporting the National Science Council. Semiconductors would be an important subcommittee of the NTC, and a senior deputy to the National Technology Advisor would lead the cross-functional group to develop the specific semiconductor policy initiatives. An OTP staff that includes domain experts who are well-versed in the technology and industry would support the group. Other areas, such as artificial intelligence, space technology, robotics and advanced manufacturing, biotechnology, could also be represented in subcommittees of the NTC and supported by the OTP. Given the different domain expertise required for information technology and biotechnology, having one senior deputy to the National Technology Advisor from each domain would be critical.

The policy approach should neither devolve into an exercise in central planning nor contribute to an inefficient federal bureaucracy. The NTC should be streamlined and for domain expertise would rely heavily on the research and analysis of industry and academia, as well as various departments of the government. By its very nature, the body would be highly adaptive and collaborative and interact and cooperate with other governmental entities. The goal must be to build on and enhance the U.S. strengths generated by its strong industrial leaders, vibrant competitive markets, leading universities and research institutions and connections to the global technology ecosystem.

The NTC's mandate should include the following five activities:

1. **Develop strategic context for policymakers:** Establish the current forces shaping the global technology industry, including key established and emerging segments, the potential impact on U.S. stakeholders and how the environment may evolve over time. This would involve collaboration with the national security and economic policymaking organizations.
2. **Establish national technology priorities:** Ultimately, the United States should develop a set of national technology priorities through an integrated policy-formulation process led by the NTC and using the strategic context and Technology Policy Framework. The process should include government, academic and private-sector stakeholder input. It should focus on national strengths and the drivers of long-term advantage for the country as well as identifying critical areas of weakness that require reinforcement. The national priorities should inform the policy initiatives, level of investment and trade-offs among alternatives.
3. **Develop and assess policy implementation tools:** Assemble a full suite of policy tools, with an emphasis on strengthening the foundation of the U.S. system of technology development and innovation, encouraging risk taking and experimentation. Use

proven public-private collaboration through approaches like those employed by organizations such as the Defense Advanced Research Projects Agency (DARPA).

4. **Support U.S. technology industry, education and research:** Work closely with the U.S. technology industry, including companies and industry associations as well as universities and research organizations, to identify major challenges and opportunities for action.
5. **Coordinate technology policy implementation across government agencies:** Guide policymaking, analysis and data sharing by government agencies for issues related to technology policy.

Done properly, government-funded R&D efforts, educational initiatives and immigration policies would work synergistically to build on the long-term advantages of the United States and correct some of the growing deficiencies it faces. U.S. policymakers should use the new three-dimensional strategic framework and the NTC-orchestrated process to implement a series of proactive measures that achieve the goal of strengthening the country's longtime technology and innovation leadership:

Basic Research

Increasing U.S. government R&D investment in basic research is essential to sustaining U.S. leadership in technology and innovation. While the federal government might not be able to justify returning to its past investment of 1.2 percent of GDP, a significant increase from existing levels, done properly, would help enable continued U.S. leadership, as follows:

- Increase total technology-related basic research by $10 billion to $20 billion annually. This would enhance long-term competitiveness though it would not close the overall gap between current government research spending and its historical peak of 1.2 percent of GDP. Closing the gap would require an additional investment of more than $100 billion, which would likely be impractical in the current budget environment in light of other government priorities.
- Of that increase, spend $1 billion to $2 billion on semiconductor-related basic research using a comprehensive approach that considers all aspects of semiconductor technology, including novel materials (material science, chemistry, physics), new manufacturing techniques (design tools, methodologies) and new structures, systems architecture and applications (advanced and nontraditional architectures and algorithms).
- Use a DARPA-like model to fund initiatives and research projects that leverage both universities and companies. Evolving the current public-private partnership model would be essential to efficiently leverage U.S. competitive strengths with constrained funding. New initiatives can focus on creating clusters of competence and networks of universities and companies.[xii]

While President Trump's fiscal-year 2020 budget request would reduce investment in basic research with a proposed reduction of $1.5 billion (4.0 percent), Congressional appropriations may nonetheless increase overall research funding for 2020 along with key sources of persistent funding, including the DARPA Electronics Resurgence Initiative and the U.S. Department of Energy Office of Science funding opportunities.

Education and Training

By both promoting STEM fields for U.S.-based students and creating a talent pipeline from abroad—which would require changes to immigration policies—the United States could create a skilled workforce that underpins innovation in the industry and across the tech space. This effort should increase support for STEM education and the necessary training of graduates to ensure that the industry continues to attract and retain cutting-edge talent.

Doing so will require the following actions:

- Expand funding for university programs, technical schools and degrees focused on participation in the semiconductor ecosystem, with the ambitious goal of doubling the number of STEM graduates in the next decade.[xiii] Funding should also look to a public-private model to enhance efficiency and effectively leverage limited public funding.
- Establish new internships and apprenticeships targeting the semiconductor industry and the broader technology ecosystem. This can be reinforced by targeted tax credits to companies that depend on the success of the educational programs.
- Create incentives for deeper relationships among government entities, universities and companies to spur more sustained technical training over the long term. Using the previously discussed DARPA-like model would help with this effort.

The administration has recently articulated an aspiration to give all Americans lifelong access to high-quality STEM education and to make the United States the global leader in STEM literacy, innovation, and employment, detailing federal and local government strategies. If matched with necessary funding—and drawing on this list of proposed education and training actions—such a vision would start addressing the gap in STEM graduates.

Immigration

Because a diverse and skilled technical workforce is crucial for innovation, the U.S. immigration policies should allow access to talent from around the world—thus widening the pool of innovators driving an expansion of the tech industry. The current system, and particularly the proposals set forth by the current administration, make staying in the country difficult for highly educated immigrants and their families.[xiv] Although perhaps difficult to act in the current political environment, strategic and comprehensive immigration policies would

help to remove the barriers to attracting and retaining the world's most capable and competitive workers.

The following are among the actions required:

- Increase highly skilled visas and reduce the government approvals required, particularly for companies moving existing employees between non-U.S. and U.S. locations. In addition, simplify the deemed-export licenses for U.S. companies to bring foreign-nationality employees to work on advanced technology projects in the U.S. (such license processes have become much slower and more restrictive).[xv]
- Institute a communications campaign aimed at shaping public perception and emphasizing that the United States is as an attractive place to study and work in advanced technology and attracting the brightest students and workers from around the world.
- Facilitate the education of qualified foreign students and their transition into the U.S. workforce through coordinated reforms, to ease the path to work for graduating highly-skilled foreign nationals.
- Use targeted immigration reforms to accelerate access to the permanent-residency process for those who qualify for highly skilled immigrant visa categories (national interest, extraordinary ability and outstanding researchers, among others).

As a start, the *Fairness for High-Skilled Immigrants Act of 2019*, passed by the U.S. House of Representatives in July 2019, would create a greater number of visas available for highly skilled employees, including those employed in the semiconductor industry. It would also increase the per-country cap on family-based immigrant visas from 7 percent to 15 percent of the total number of such visas available each year.

Precedents

This is not the first proposal to identify the need for strategic technology and semiconductor policy. Recent studies have focused on the determining the right areas in which to address the same challenges. Both the now-defunct President's Council of Advisors on Science and Technology (PCAST) and the Semiconductor Industry Association (SIA) recently developed detailed policy plans and agenda considerations in an effort to support innovation and growth within the industry. Their goals include ensuring access to global markets, joining with allies and achieving transparency in global policies; creating a deeper government knowledge base of industry expertise in both semiconductor-producing and -consuming industries; applying national security tools to deter and respond to Chinese industrial policies; and building and maintaining a strong talent pool both by grooming U.S. talent and supporting talent from abroad.

Over the past few years, there also has been a series of updates and amendments to legislative and regulatory mechanisms that directly affect U.S. technology and semiconductor capabilities. These include amendments to the legislation of the Committee on Foreign Investment in the U.S. (CFIUS) through the *Foreign Investment Risk Review Modernization Act* (FIRRMA) and export restrictions on emerging technologies enumerated in a rule by Investment Security Office in October 2018).[xvi] Many more may be on the way, with the bipartisan focus on regulating "big tech" and combating China's emergence as a potential geopolitical rival in a wide array of sectors, including biotechnology.[xvii]

While these all appear to be legitimate efforts to achieve policy goals, individually and collectively, they fall short of the need to balance short-term, surgical tactics with long-term strategic policies and initiative.[xviii] The recent episode of Huawei-related policies and governmental actions are a good example of the shortcomings of the current approach. Many legitimate interests are intertwined in the actions of various parts of the U.S. government, from the Department of Justice's pursuit of violations of laws relating to sanctions against Iran through the extradition request to Canada for the Huawei CFO, the Department of Commerce's placement of Huawei on the Entity List (thereby requiring U.S. companies to obtain licenses to provide Huawei with covered technologies), to U.S. intelligence agencies' lobbying foreign governments not to use Huawei equipment in their 5G networks. The challenges are that the interests are not always clearly defined, and the strategies are not necessarily coherent.

The Huawei-related policies have had a direct impact on U.S. technology companies, including a large impact on leading semiconductor companies Broadcom, Intel, Qualcomm and Micron, among others. U.S. technology companies sell Huawei approximately $11 billion worth of technology products annually, the majority of which are semiconductors. In addition, the Chinese government is reportedly preparing an "unreliable entity" list of U.S. companies that will face scrutiny and potential restrictions on access to the Chinese markets.

Perhaps the most damaging long-term impact will be the result of the deep technological insecurity that U.S. actions have instilled in the Chinese government. It is likely that China will react by investing more heavily in creating domestic industries in key areas of technology, one of its highest priorities being the buildout, at any cost, of a domestic semiconductor industry. U.S. technology companies' market opportunities will decline as a direct result. Further damage will by inflicted when foreign governments implement retaliatory restrictions.

There seems to be a default position among certain policymakers that the only appropriate response to an emerging and aggressive China is a new Cold War. This may be the most convenient approach to fit a narrative defined exclusively in militaristic or national security terms. It is easy to articulate, fits with established, albeit outdated, policy-implementation tools and creates an us-versus-them mentality that can be politically expedient. It is also comforting to U.S. stakeholders, as the collapse of the Soviet Union at the end of the first Cold War created a geopolitical environment with the United States as the sole global superpower.

Yet this Cold War mentality is potentially dangerous and lacks sufficient analysis and debate to serve as a foundation for U.S. technology policy. It could undermine global technological advancement, economic growth and the very U.S. technology leadership that policymakers are attempting to preserve. A better approach would take a long-term view and undertake policymaking with a strategy that draws on the full range of national security and economic considerations.

Conclusion

Policymaking for the semiconductor industry has far more strategic implications for the United States now than in the past because of increased geopolitical tensions and competition, and the central position semiconductors play in the broader technology innovation ecosystem. The current policymaking agenda must shift from defensive, ad hoc, and reactive actions to policies that support innovation and technological leadership. This shift will require taking a broader view of policy agendas that have an impact on or are linked to the semiconductor industry, including economic growth, trade, employment, technological advancement and innovation, national security, education, and transportation—and understanding how to integrate, synthesize, and prioritize.

Policy actions must account for a rapidly evolving strategic context in which China's investment in its domestic semiconductor industry threatens U.S. leadership and rising geopolitical tension and trade wars are sending shockwaves through the semiconductor industry. At their foundation, policies should encourage and enable a more constructive distinction between national security and civilian applications, the underlying drivers of a healthy global semiconductor ecosystem and industry, and the conditions that will create the greatest likelihood of U.S. strength and leadership over the long-term.

Given the current challenges in the industry, the policy actions the United States takes now must be designed to better position the country to sustain and advance its long-term technology leadership, as opposed to aiming for the short-term preservation of the status quo. Technology leadership and innovation require constant investment and agility, a healthy global ecosystem, access to large and growing markets and a sizable and highly skilled technical workforce.

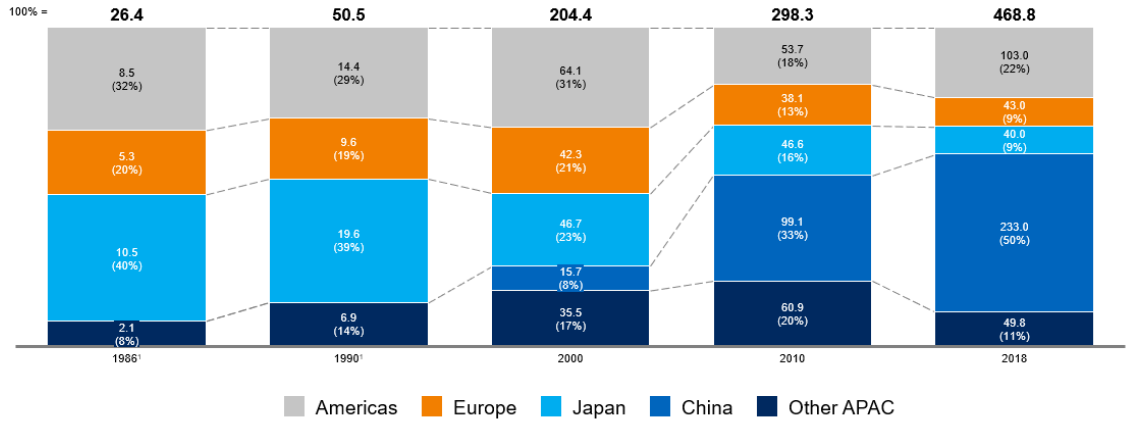
U.S. leadership in the semiconductor industry and the broader technology industry is not an entitlement—the industries will be subject to many challenges, foreign and domestic, during the next 30 years. An exclusive focus on national security will undermine the long-term leadership of the United States, impede transparency and innovation and ultimately weaken U.S. global leadership. The new policies must be formulated using a strategic process that balances technological and commercial leadership on one hand and national security on the

other. Focusing on the long-term drivers of a healthy global ecosystem will yield a resilient infrastructure for innovation while emphasizing areas where U.S. companies are best positioned to lead.

Appendix 1: Exhibits

Exhibit 1

Semiconductor Sales by End Market
1986-2018



1 Sales to China are included in Other APAC for 1986 and 1990

Exhibit 2

Top 10 Semiconductor Companies by Revenue
$B, 1980-2018

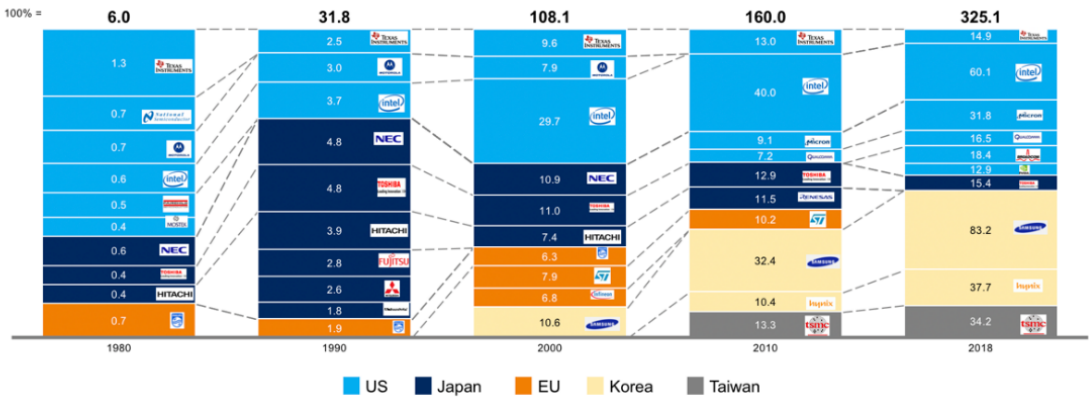


Exhibit 3

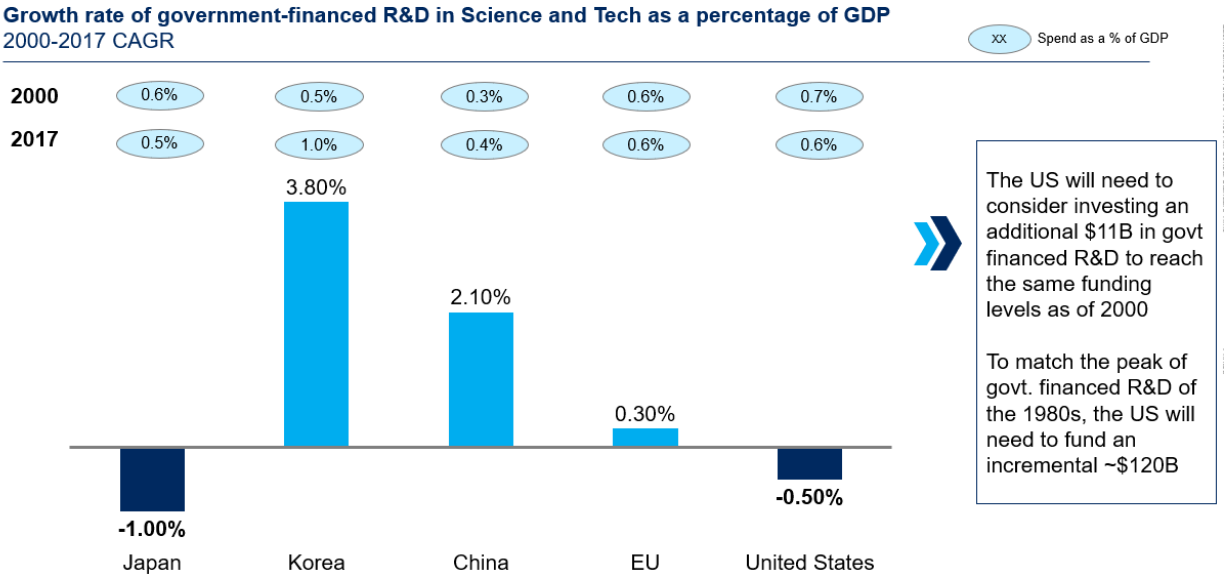
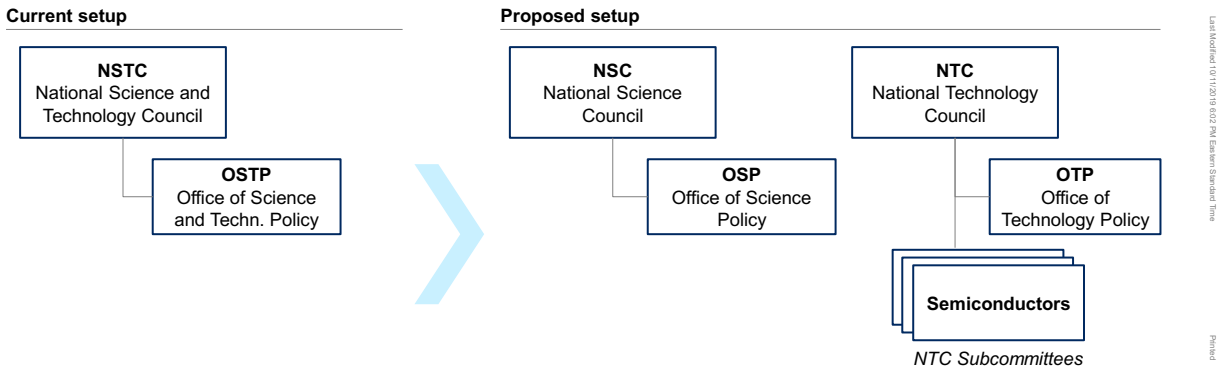


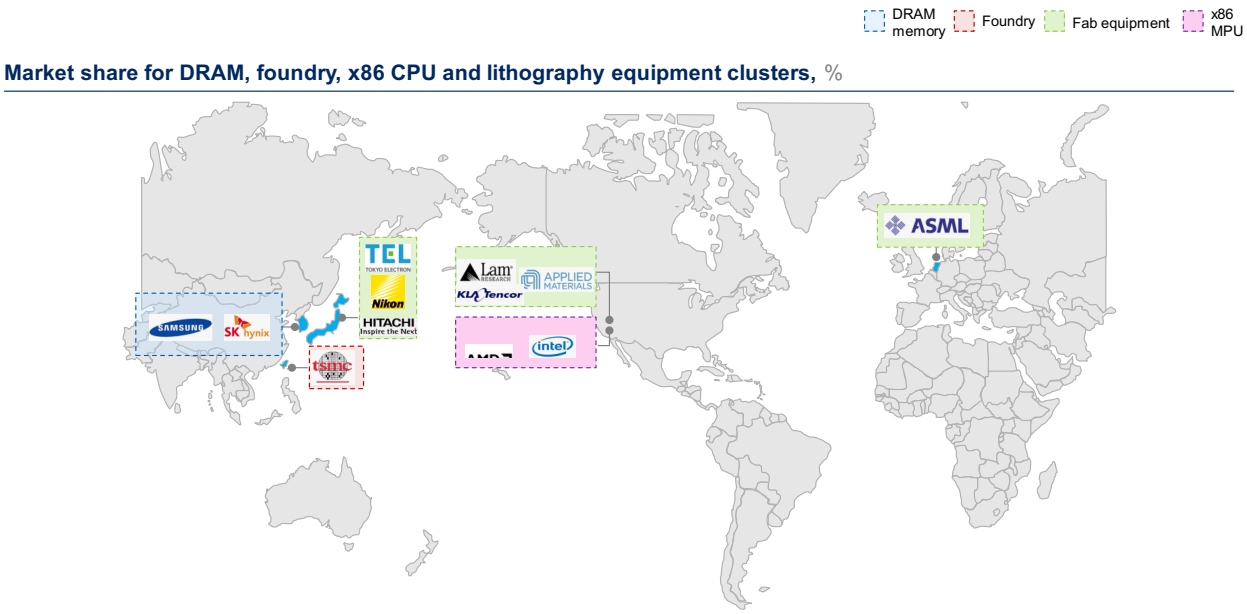
Exhibit 4

Proposed Structural Changes to NSTC and OSTP



- The NTC and NSC would work closely given many policy issues are intertwined and policy initiatives can be cooperative and synergistic; however, the two Councils will have different mandates and require different skill sets and stakeholder participants
- The NTC would be led by the National Technology Advisor, who would be a member of the President's cabinet
- Each Subcommittee of the NTC, including Semiconductors, would be led by a Senior Deputy to the National Technology Advisor leading the cross-functional group in the development of specific policy initiatives, supported by an OTP staff including domain experts well-versed in the technology and industry

Exhibit 5


DRAM memory
Foundry
Fab equipment
x86 MPU
Market share for DRAM, foundry, x86 CPU and lithography equipment clusters, %
SAMSUNG
SK hynix
TSMC
TEL
TOKYO ELECTRON
Nikon
HITACHI
Inspire the Next
Lam
APPLIED MATERIALS
KLA Tencor
intel
ASML

Appendix 2: China's Strategic Investment in Semiconductors as a Foundation to Broader Technology and Economic Policy Initiatives

Technology policy is central to the economic and military goals of the Chinese government. China has focused intensely on developing its technological capabilities as a means of achieving its long-term political, economic, military, social, foreign policy and environmental goals. China has studied the development of other technologically advanced economies and has employed many of the same policy tools for stimulating innovation and technological advancement. China's technology policy, including initiatives related to semiconductors, has been led from within the central government by the powerful MIIT, with support from the Ministry of Science and Technology (MOST) and other government departments. In addition, the financing of technology initiatives, which is estimated to exceed $100 billion over the next five years,[xix] has been funded by both the central government and many local government entities.

Like other Asian countries that developed rapidly into advanced economies, China has targeted the establishment of a domestic semiconductor industry as a primary pillar of its technology strategy. The country has both a defensive and an offensive motivation for establishing the semiconductor capability. In 2018, China imported about $230 billion[xx] in semiconductors and depended on foreign semiconductor technology manufactured in China for additional semiconductors worth approximately $25 billion.[xxi] Chinese officials often point out that the country imports more semiconductors than oil.[xxii]

Even after years of government investment in the domestic semiconductor industry, local semiconductor companies produced only approximately $33 billion worth of semiconductors.[xxiii] The Chinese see this as a strategic vulnerability, given the importance of semiconductors throughout their economy, infrastructure and military.[xxiv]

Moreover, because semiconductors are critical to developing next-generation technologies in strategic areas such as communications, autonomous vehicles, artificial intelligence, robotics, satellites and various military applications, the Chinese government has made domestic semiconductor capability a key part of the broader technology industrial policy originally articulated as "Made in China 2025."[xxv]

China has been investing in its domestic semiconductor industry for over a decade. Early substantial investments did not produce the expected results.[xxvi] The current investment effort is massive and highly coordinated and attempts to infuse government policy with strong market forces and incentives. In 2014, the government launched a huge semiconductor-focused investment fund, the China Integrated Circuit Industry Investment Fund, with initial funding of approximately $20 billion, and in 2018 raised almost $50 billion in addition.[xxvii] These

funds are attempts to accelerate the development of the domestic semiconductor industry with targeted areas such as advanced memory, microprocessors and graphics processing units.

The direct central government investment allocated to the semiconductor industry of $15 billion since 2014 has resulted in the financing and construction of a number of new fabs (manufacturing plants where raw silicon wafers are turned into integrated circuits) in China. Chinese government-backed companies aggressively hire from established semiconductor companies throughout China in an effort to accelerate development and leverage the essential tribal knowledge critical to semiconductor design and manufacturing. These companies have been developing their own intellectual property and licensing it where possible.[xxviii] There has been a series of allegations of intellectual-property theft, including by Micron Technology against Taiwan UMC and Fujian Jinhua, as the Chinese company attempted to enter the dynamic random-access memory (DRAM) market.[xxix]

It is thought that China is making progress in the less technologically advanced segments of the semiconductor industry but remains years behind established industry players in important areas like microprocessors and advanced memory. China's most advanced microprocessor fabs are at the 14-nanometer node and remain in pilot phase—two generations behind their global competitors. In addition, China is at least one generation behind in NAND, still lacks production of DRAM and also lags in analog components, including power and radio frequency.

Chinese companies have among the most aggressive acquirers of advanced capital equipment in the past four years and have accounted for a significant portion of the semiconductor capital equipment industry's growth during that period.[xxx] This effort enables rapid advanced capabilities, because the latest generations of semiconductor capital equipment, which can cost anywhere from $1 million to $100 million per tool,[xxxi] include significant intellectual property that has been developed through multiple iterations with many industry players.

Appendix 3: The Global Semiconductor Ecosystem and Innovation

The semiconductor supply chain leverages a global ecosystem. The most intimate dependence is between semiconductor manufacturers and capital equipment providers. The equipment is extremely sophisticated and expensive and contains a tremendous amount of enabling intellectual property for individual companies and the industry as a whole. The network of suppliers involved in the capital equipment ecosystem is global, with a handful of leading companies in Europe, Japan and the United States. In addition, various clusters of know-how and manufacturing scale have developed in different places, including South Korea, Taiwan, Singapore, Japan, Europe and the United States, with a number of foreign-owned and indigenous fabs having been built in China over the past five years (Exhibit 5).[xxxii]

Critical inputs are also sourced and manufactured on a global basis. For example, the extraction of rare earth elements, which have the magnetic and optical properties that help make semiconductors and electronics more efficient, is highly concentrated in China: according to the U.S. Geological Survey, 71 percent of the rare earths mined last year were from China [xxxiii] U.S.-based companies depend heavily on China and other countries for economically-sound rare earth extraction and refining. Similarly, low-cost Asia-based foundries have increased the viability of fabless semiconductor companies—including those in the United States, which represented the majority of fabless revenue in 2018.

Market access across the ecosystem enables competitive U.S. semiconductor companies to generate revenues that pay for the capital investment and R&D that underpin the benefits of the cycle of innovation and the economic leverage of the industry. U.S. semiconductor companies spend 14 percent of sales on capital investment and 17 percent of sales on research and development[xxxiv]. As market opportunity grows, competitive semiconductor companies enjoy massive leverage in both areas, which allows them to innovate better and faster and provide those innovations to the market at lower costs. This process has continued throughout the past four decades, when U.S. companies became leaders in the semiconductor industry.[xxxv] The U.S. and global economies have also benefited dramatically from the innovation leverage of the industry. Long-term market-access restrictions and technological decoupling between the United States and China will lead to the reversal of this positive trend as well as the negative consequences of reduced competition and the inefficiency of duplicated supply chains.

Innovation in semiconductor technology has also driven productivity gains and accelerated value creation across many industries. New technologies have realized a multiplier effect in value creation because of semiconductors. It is estimated that, in the PC era, companies involved in the value chain from design and production to sale to end users realized approximately five times the revenues of the semiconductor industry; that ratio grew to approximately 10 times with the rise of mobile devices, and analysis shows that the value will grow to approximately 15 to 20 times in the era of connected cars and the Internet of Things.[xxxvi] In addition, semiconductor innovation, in large part due to the constant march of Moore's

law,[xxxvii] has accelerated widespread adoption of technology, with consistent performance improvements and significant disinflationary impact from cost reductions and efficiency gains across the value chain.[xxxviii]

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