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Siliconpolitik: The Case for a Quad Semiconductor Partnership[1]

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Summary

The Quad should make semiconductors a focus area within its expansive technology cooperation agenda. Since each Quad member enjoys a comparative advantage in a specific sub-domain of the semiconductor supply chain, this grouping is well-placed to collaborate. This paper outlines some of the guiding principles and makes specific recommendations to kick start a Quad semiconductor partnership.

Introduction

A significant outcome of the first-ever Quad summit-level meeting on 12 March 2021 was the announcement to establish working groups on vaccines, critical and emerging technologies (C&ET) and climate change. Of these three, details of the C&ET working group are the least forthcoming. Indeed, the Quad Summit Fact Sheet does not identify the technologies deemed to be "critical and emerging" by all four states, indicating that a lot of consensus-building remains to be done.[2]

In the geopolitical realm, the term C&ET is new. The Donald Trump administration adopted and popularised it in its October 2020 report titled *National Strategy for Critical and Emerging Technologies*. That report defined C&ET as technologies that "are critical, or to potentially become critical, to the United States' national security advantage, including military, intelligence, and economic advantages." The report listed 20 technologies deemed important from a strategic perspective, "semiconductors and microelectronics" being one of them.[3] Given this expansive list, perhaps the first item on the agenda of the C&ET working group would be to prioritise cooperation on a few of them.

Beyond prioritisation of specific technologies, there also appears to be no decision yet on the mechanics of collaboration. The current scope, as outlined in the summit fact sheet, is extensive. It includes disparate initiatives such as coordination on technology standards development, developing a statement of principles on technology design, development, and use, operating technologies according to shared interests and values, cooperating on

[1] I thank my colleagues at Takshashila Institution – Nitin Pai, Mihir Mahajan, and Rohan Seth – for their insights and feedback on the paper.

[2] Ministry of External Affairs, Government of India, "Quad Summit Fact Sheet", 12 March 2021, https://www.mea.gov.in/bilateral-documents.htm?dtl/33621/Quad_Summit_Fact_Sheet. Accessed on 24 March 2021.

[3] "National Strategy for Critical and Emerging Technologies", October 2020, https://trumpwhitehouse.archives.gov/wp-content/uploads/2020/10/National-Strategy-for-CET.pdf.

telecommunications equipment, and convening dialogues on critical technology supply chains.[4]

Taking this positive and ambitious technology agenda forward, I argue that Quad countries should go beyond convening dialogues on critical technology supply chains. Instead, I make the case that “semiconductors and microelectronics”, identified as one of the 20 C&ETs by the Trump administration, should be made the focus area of technology collaboration. The rationale is that concrete successes in this one ‘metacritical’ technology can pave the way for building confidence to resolve the more vexing issues of global technology standards and technology use principles.

The ‘Metacriticality’ of Semiconductors

A geopolitical and geoeconomic snapshot of today’s world illustrates the criticality of semiconductors. Geopolitically, semiconductors have become a front in the United States (US)-China confrontation. Sensing that semiconductors are a weak link in China’s otherwise impressive technology stack, the Trump administration imposed export controls restricting Chinese semiconductor companies from accessing essential equipment, software, and intellectual property. The intention was to thwart its *Made in China 2025* plan – an industrial policy initiative to achieve 70 per cent self-sufficiency in semiconductor production by 2025. The Joe Biden administration has maintained many of these restrictions, mainly controls on cutting edge semiconductor manufacturing equipment. For example, at the time of writing this, Taiwan Semiconductor Manufacturing Company (TSMC), which uses manufacturing equipment from Applied Materials, a US company, remains banned from supplying chips to Huawei.[5]

This ongoing ‘siliconpolitik’ extends far beyond the US, China and Taiwan. Take the case of the Dutch company ASML, the world’s only supplier of extreme ultraviolet (EUV) lithography systems which are critical for leading-edge semiconductor manufacturing (5 nanometres and below). As of this writing, ASML had not secured an export license from the Dutch government to supply these systems to Semiconductor Manufacturing International Corporation, China’s top semiconductor manufacturer. Reports claim that the US government has advised the Dutch government to refuse permission.[6]

Meanwhile, relations between China and Taiwan have worsened. The latter, which alone accounted for 73 per cent of the world’s global contract foundry revenues and 54 per cent of the world’s outsourced assembly, testing and packaging revenues in 2018,[7] remains the

4 Ministry of Foreign Affairs of Japan, “Japan-Australia-India-U.S. Leaders’ Video Conference”, 13 March 2021, 2021, https://www.mofa.go.jp/fp/nsp/page1e_000310.html. Accessed on 17 March 2021.

5 Iain Morris, “Huawei Chips Crisis Shortens Odds on China-US Conflict”, LightReading, 23 March 2021, https://www.lightreading.com/5g/huawei-chips-crisis-shortens-odds-on-china-us-conflict/d/d-id/768303. Accessed on 7 April 2021.

6 Ellen Proper, “ASML Stays Positive Despite Being Caught by U.S., China Rift”, Bloomberg, 14 October 2020, https://www.bloomberg.com/news/articles/2020-10-14/asml-expects-low-double-digit-growth-next-year-resumes-buybacks. Accessed on 7 April 2021.

7 John F Sargent Jr, Michaela D Platzer, Karen M Sutter, “Semiconductors: U.S. Industry, Global Competition, and Federal Policy”, Congressional Research Service, 26 October 2020, https://fas.org/sgp/crs/misc/R46581.pdf.

most significant bottleneck in the global semiconductor supply chain. Amid the rising tensions, there are reports of increasing cyberattacks on the Taiwanese semiconductor industry. A possibility of a Chinese attack over Taiwan and consequent takeover of its semiconductor facilities is no longer a far-fetched possibility that companies and governments can afford to ignore.[8]

Geoeconomically, a semiconductor shortage arising out of the COVID-19 demand shock is likely to wipe off US$60.6 billion (S$80.76 billion) in revenue from the global automotive industry in 2021 alone.[9] Chips used in car infotainment, driver assistance and control systems are in short supply globally. Though COVID-19 is the proximate reason for this situation, the pandemic only exposed the already existing bottlenecks. Operating as a globalised high-value supply chain, the industry forsook resilience for specialisation and cost-effectiveness long before the pandemic. While this model paid rich dividends in accelerating innovation, the lack of resilience is increasingly being viewed as a strategic handicap by nation-states.

This supply chain has long been susceptible to three systemic risks. One, manufacturing and testing bases are heavily concentrated in East Asia. The result is that even localised health, political or social crises can halt all industries utilising semiconductor chips. Two, ensuring business continuity is difficult because of the dominance of just one global player in several highly specialised steps across the semiconductor supply chain. A delay in shipment from one company can hit the production road maps of thousands of downstream companies. Three, several choke points in the semiconductor supply chain make it an attractive geopolitical tool. Nation-states can seek to block one or more of these for political purposes.[10]

Realising these peculiarities, several countries have accelerated efforts to reshore semiconductor manufacturing. In May last year, TSMC announced a plan to build a US$12 billion (S$15.99 billion) chip production plant in Arizona. Likewise, many countries have unleashed several industrial policy incentives to set up local semiconductor facilities.

Beyond the current predicament, semiconductors are 'metacritical' in the sense that advancements in most other C&ETs are reliant, in turn, on progress in semiconductor technology. For example, Artificial Intelligence (AI) applications require new semiconductor architectures that can speed data movements between the processor and the memory.[11] This architectural change demands a move away from general-purpose technology to specialised processors, colloquially referred to as AI chips. Similarly, advancements in the

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8 Oriana Skylar Mastro, "The Precarious State of Cross-Strait Deterrence", Statement before the US-China Economic and Security Review Commission on "Deterring PRC Aggression Toward Taiwan", 18 February 2021, https://www.uscc.gov/sites/default/files/2021-02/Oriana_Skylar_Mastro_Testimony.pdf.

9 Michael Wayland, "How Covid Led to a $60 Billion Global Chip Shortage for Automakers", CNBC, https://www.cnbc.com/2021/02/11/how-covid-led-to-a-60-billion-global-chip-shortage-for-automakers.html. Accessed on 8 April 2021.

10 Pranay Kotasthane and Jan-Peter Kleinhans, "How Covid-19 Changes the Geopolitics of Semiconductor Supply Chains", South China Morning Post, 2 June 2020, https://www.scmp.com/tech/enterprises/article/3086998/how-covid-19-changes-geopolitics-semiconductor-supply-chains.

11 "Semiconductors and Artificial Intelligence", IEEE IRDSTM, https://irds.ieee.org/topics/semiconductors-and-artificial-intelligence. Accessed on 8 April 2021.

automotive industry such as autonomous driving, higher safety standards, and electric vehicles will require better processors (general-purpose and application-specific), analog integrated chips (ICs), memory ICs and sensors.[12] Finally, 5G digital communication technology uses edge computing to achieve low latency, which requires new baseband chips and power amplifiers that work over a wider frequency range.[13] Given this 'metacriticality', any future technology policy needs to pay special attention to semiconductors.

In essence, there are geopolitical, geoeconomic and technological imperatives for securing semiconductor supply chains.

What makes the Quad Suitable for Strategic Cooperation in Semiconductors?

Multilateral Cooperation on Semiconductors is a Necessity, Not a Choice

The metacritical and strategic nature of semiconductors underscored by recent events has inspired some states to attempt indigenisation of this supply chain. For example, a bill titled 'Creating Helpful Incentives to Produce Semiconductors for America Act' (CHIPS for America Act) was introduced (but not passed) in the 116th US Congress in 2020 to provide an income tax credit for investment in semiconductor equipment or manufacturing facility in the US.[14] Similarly, the Indian government launched a host of schemes in April 2020 to 'crowd in' investment for building an electronics manufacturing ecosystem.[15] Japan was also considering multi-year financial incentives for chipmakers to work with domestic companies for building advanced semiconductor manufacturing facilities.[16] All these policies mentioned above might well end up creating a few national champions but are unlikely to achieve the goal of national semiconductor "self-sufficiency" for two reasons.

One, such initiatives, if they work, can at most plug existing deficiencies but are inadequate for achieving future self-sufficiency in manufacturing. Significant upfront and recurring costs of semiconductor manufacturing mean that producing semiconductor chips profitably today is no guarantee for doing so just three-four years later. For instance, after much cajoling by the US government, TSMC plans to establish a 5-nanometre plant in Arizona at a reported cost of US$12 billion (S$15.99 billion). Even so, this plant will enter production mode by 2024, by which time the 5-nanometre manufacturing node will cease to remain cutting-edge.[17] Upgradation to the next advanced node will again require significant investment,

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12 "Semiconductors – the Next Wave, Opportunities and Winning Strategies for Semiconductor Companies", Deloitte, April 2019, https://www2.deloitte.com/content/dam/Deloitte/cn/Documents/technology-media-telecommunications/deloitte-cn-tmt-semiconductors-the-next-wave-en-190422.pdf.

13 Paula Doe, "5G Increases Compound Semiconductor Demand", SEMI, https://www.semi.org/en/5g-increases-compound-semiconductor-demand. Accessed on 8 April 2021.

14 Michael T McCaul, "H.R.7178 - 116th Congress (2019-2020): CHIPS for America Act", https://www.congress.gov/bill/116th-congress/house-bill/7178.

15 "Government Incentives for India's Electronics Industry", Consultancy.in, 12 October 2020, https://www.consultancy.in/news/3358/government-incentives-for-indias-electronics-industry. Accessed on 8 April 2021.

16 Joseph Waring, "Japan Targets Global Chipmakers for Domestic Project", *Mobile World Live*, 20 July 2020, https://www.mobileworldlive.com/asia/asia-news/japan-targets-global-chipmakers-for-domestic-project.

17 Ryan Smith, "TSMC To Build 5nm Fab In Arizona, Set To Come Online In 2024", *AnandTech*, 15 May 2020, https://www.anandtech.com/show/15803/tsmc-build-5nm-fab-in-arizona-for-2024.

not something that many companies or even states can do without incurring substantial opportunity costs. These costs were the primary reason why a profitable contract manufacturing ecosystem emerged in East Asia. This phenomenon allowed thousands of 'fabless' companies to emerge worldwide while manufacturing costs were borne only by a handful of companies and states. To overturn this economic logic of comparative advantage ultimately would require states to continually divert their scarce resources to build, sustain, and support homegrown semiconductor manufacturing.

Two, even a robust homegrown semiconductor manufacturing industry is no guarantee for semiconductor self-sufficiency. The reason is that manufacturing is just one, albeit an important, step in the semiconductor ecosystem. It comprises other steps such as a leading-edge research base demanding a high skilled workforce, a testing and packaging capability made competitive by low labour costs, and finally, many Original Equipment Manufacturers (OEMs) that can build consumer products with semiconductor chips. For example, even Intel, which until now manufactured most of the chips it designed, requires 450 supplier factories and 16,000 suppliers spread across the globe.[18] A hyper-globalised ecosystem means that no one state can eliminate choke points in all the semiconductor industry stages. Even the US, with its formidable war chest, will find it challenging to indigenise all steps of the semiconductor supply chain, as is evident from its struggles to reshore printed circuit board and memory chip manufacturing, which have become unremunerative in the US.[19]

The above discussion shows that national self-sufficiency in the semiconductor supply chain is an unrealistic goal. Instead, I argue that states' primary purpose should be to ensure redundancy in the global semiconductor ecosystem such that this supply chain does not get dominated by an adversary. Their secondary goal should be to have enough expertise in all parts of the supply chain to outpace and even constrain the adversary.
A notable distinction in this formulation is that neither of the two goals requires full indigenisation. In fact, both goals can *only* be achieved through multilateral strategic cooperation between states. This approach seeks to take advantage of states' existing comparative advantages instead of duplicating them locally. Such an approach will share the high costs and complement each other's strengths to accelerate innovation. In other words, for a sustainable, cutting-edge semiconductor supply chain of the future, multilateral cooperation is a necessity, not a choice.

Why the Quad is Suited for Cooperation on Semiconductors

Having identified the imperative for multilateral cooperation on semiconductors and microelectronics, this section deals with where the Quad stands in this regard – do the four countries have complementary strengths? And crucially, do they have enough collective firepower to achieve the two goals outlined earlier?

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[18] Craig Chvatal and Anil Varhadkar, "Transforming Intel's Supply Chain with Real-Time Analytics", IT@Intel, White Paper, September 2017. https://www.intel.com/content/dam/www/public/us/en/documents/white-papers/transforming-supply-chain-with-real-time-analytics-whitepaper.pdf.

[19] Jeanne Whalen, "U.S. Companies Lobby against China Tech Bans", The Washington Post, 12 October 2020, https://www.washingtonpost.com/technology/2020/10/12/us-companies-oppose-china-trade-ban/.

It is to this discussion I turn next by understanding the strengths and weaknesses of the Quad countries in the semiconductor supply chain. To do this, I divide the supply chain into its three stylised stages. One, chip design, a human capital intensive stage where blueprints of semiconductor chips get made. Two, chip manufacturing, a capital-intensive stage dominated by a few foundries where blueprints are converted into a physical IC. Finally, assembly, testing and packaging, a labour-intensive step in which chips are assembled in a manner that allows them to be connected to the rest of the device. A discussion locating the Quad countries with respect to these three stages follows.

The US: The Design Behemoth

The US is an undisputed global leader in semiconductor design. Of the world's top 10 fabless companies by revenue in 2019-20, six were American. In 2018, US-based companies accounted for 62 per cent of global fabless firm revenues. It is also home to the world's leading integrated design manufacturers (IDMs), design houses that fabricate their own chips, such as Intel. In 2018, US-based firms accounted for 51 per cent of global IDM revenues.[20]

American companies also dominate two key sub-stages upstream to the design processes – electronic design automation (EDA) and licensed intellectual property.

Chip design is done using EDA software, the market for which is heavily concentrated due to high research and development (R&D) costs. The three primary players in the space — Cadence Design Systems, Synopsys and Mentor Graphics — are located in the US. The first two are American companies, while Mentor Graphics was acquired by the German multinational conglomerate Siemens in 2017 but continues operating from the US.
In addition to EDA tools, the other important aspect of semiconductor design is licensed intellectual property, especially for processors. The most critical player in the space is ARM Holdings which licenses its processor cores to design companies. This one company alone powers 90 per cent of mobile phone application processors and 34 per cent of the entire market of chips with processors.[21] Until 2020, ARM was based in the United Kingdom. However, in September 2020, Nvidia (a US company) acquired it for US$40 billion (S$53.31 billion).

Despite the overpowering advantage in the design stage, US-based semiconductor manufacturing has declined since the 1980s. First, Japan and later, South Korea and Taiwan-based companies displaced American companies in this sector due to the growing differential in manufacturing costs. Similarly, higher labour costs made testing and packaging an unattractive proposition in the US, motivating a relocation of this segment to East and Southeast Asia. Nevertheless, in one sub-stage of semiconductor manufacturing — specialised equipment, tools and software — the US continues to play a dominant role. Of the five top semiconductor manufacturing equipment (SME) producers, three are

[20] John F Sargent Jr, Michaela D Platzer, Karen M Sutter, "Semiconductors: U.S. Industry, Global Competition, and Federal Policy", Congressional Research Service, 26 October 2020, https://fas.org/sgp/crs/misc/R46581.pdf

[21] ARM Limited, "Roadshow Slides Q1 2020", https://group.softbank/system/ files/pdf/ir/presentations/2020/arm-roadshow-slides_q1fy2020_01_en.pdf. Accessed on 5 April 2021.

headquartered there. It is through export restrictions on companies utilising these SMEs that the US has sought to constrain Chinese semiconductor companies.

Japan: The Powerhouse in Semiconductor Manufacturing Materials

While the US has a comparative advantage in semiconductor design, Japan has established a stronghold in semiconductor manufacturing materials and chemicals necessary for manufacturing chips. One such piece of equipment is a photoresist, a light-sensitive material used in patterning the substrate. Japanese companies such as JSR Corporation, Tokyo Ohka Kogyo, Fujifilm Electronic Materials and Sumitomo Chemical dominate this space.
Japan also has a stronghold in the etching gas market. Etching gas makes it possible to remove unwanted material from the chip with high precision. Japanese companies meet nearly 70 per cent of the global etching gas demand.[22]

Besides, it also leads the market in silicon wafers, substrates on which semiconductor ICs are built. Five firms account for 90 per cent of the world's silicon wafer production, of which two Japanese companies, Shin-Etsu Handotai and Sumco, account for 30 per cent and 27 per cent of the global market share, respectively.[23]

Despite its strength in the semiconductor manufacturing segment, the Japanese semiconductor design industry has declined after impressive growth in the 1980s. As of 2018, Japanese fabless companies accounted for just one per cent of global fabless firm revenue. Similarly, higher costs have made outsourced testing and packaging unremunerative in Japan compared to South Korea and Taiwan.

Australia: A Provider of Basic Materials

Australia does not have a significant presence in any of the three main stages of the semiconductor supply chain. However, it occupies an important place in the broader electronics supply chain due to the availability of critical materials and advanced mining capabilities.

For instance, Australia has significant silica deposits that can be used in traditional complementary metal-oxide semiconductor fabrication. It also has gallium and indium deposits, which are critical elements for producing composite semiconductors that surpass silicon-based semiconductors' performance in specific applications such as solar cells, microwave frequency ICs, and laser diodes. Besides geographic availability, Australia also

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[22] "Japan to Tighten Export Rules for High-Tech Materials to South Korea: Media", Reuters, 30 June 2019, https://www.reuters.com/article/us-southkorea-japan-labourers/japan-to-tighten-export-rules-for-high-tech-materials-to-south-korea-media-idUSKCN1TV089; and "Japan to Tighten Export Rules for High-Tech Materials to South Korea: Media", Reuters, 30 June 2019, https://www.reuters.com/article/us-southkorea-japan-labourers/japan-to-tighten-export-rules-for-high-tech-materials-to-south-korea-media-idUSKCN1TV089. Accessed on 8 April 2021.

[23] Mark Lapedus, "Mixed Outlook For Silicon Wafer Biz", Semiconductor Engineering, 21 February 2019, https://semiengineering.com/mixed-outlook-for-silicon-wafer-biz/.

has material science R&D expertise to convert these capabilities into semiconductor domain opportunities.[24]

Australia is the world's largest lithium producer, an element used for making rechargeable batteries present in electric vehicles, phones, and laptops. It is also the world's leading supplier of Neodymium, used in powerful electromagnets for electric vehicles.

Australia's weaknesses are an absence of any large semiconductor design, fabrication or test companies, shortage of risk capital and a shallow talent pool.

<u>India: A Semiconductor Humanpower</u>

India has a comparative advantage in trained human capital. Semiconductor design requires large numbers of skilled engineers and this is where India's strength lies. Many global semiconductor firms built up robust operations in India, starting with Texas Instruments in 1985. Today, of the largest semiconductor companies by revenue in 2019, eight have design houses in India. Crucially, Indian design centres have the expertise to handle the entire design cycle. Over time, many Indian design services companies have also sprung up to serve this large design market.

Apart from semiconductor design, India also has developed some expertise in the downstream assembly of electronic components. For instance, Foxconn recently announced its intent to invest US$1 billion (S$1.33 billion) in India.[25] Simultaneously, Samsung built the world's largest mobile phone manufacturing plant in India, where it tests new devices and assembles them for export.[26] This expertise provides a solid base for venturing into upstream stages like assembly, testing and packaging.

The missing element in the Indian semiconductor design ecosystem is a lack of focus on intellectual property. While professional talent in the semiconductor domain exists, a lack of risk capital has meant that companies prefer to provide design services to existing semiconductor firms rather than build their own products. There are also no large-scale commercial players in the country in the manufacturing segment despite multiple attempts to invite IDMs and contract manufacturers to set up foundries in India.

In summary, each Quad member has unique comparative advantages in the semiconductor value chain. While each member also has structural weaknesses, combining their comparative advantages can help the Quad achieve the two goals of semiconductor supply chain security. Instead of each Quad member trying to build a semiconductor supply chain by itself, a partnership is likely to serve them better.

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[24] New South Wales Government|Chief Scientist & Engineer, "Australian Semiconductor Sector Study: Capabilities, Opportunities and Challenges for Increasing NSW's Participation in the Global Semiconductor Value Chain", December 2020. https://www.chiefscientist.nsw.gov.au/data/assets/pdf_file/0005/339647/Australian-Semiconductor-Sector-Study.pdf.

[25] Sankalp Phartiyal and Yimou Lee, "Exclusive: Apple Supplier Foxconn to Invest $1 Billion in India, Sources Say | Reuters," Reuters, July 10, 2020, https://www.reuters.com/article/us-foxconn-india-apple-exclusive-idUSKBN24B2GH.

[26] Sankalp Phartiyal and Heekyong Yang, "Samsung Crafts India Comeback as Anti-China Wave Surges", Reuters, 3 August 2020, https://www.reuters.com/article/us-samsung-elec-india-focus-idUSKBN24Y0T3.

Kickstarting the Collaboration

The previous section outlined why the Quad grouping is a favourable platform for a strategic partnership on semiconductors. However, converting comparative strengths into tangible outcomes would require purposive action from all members. This section identifies a non-exhaustive list of principles that the Quad Working Group on C&ET could take up to kick start this partnership. Further, specific recommendations derived from each of these principles are listed below.

Principle 1: Think security and ecosystem, not indigenisation and manufacturing

As the previous section states, the Quad members' primary goal regarding semiconductors should be to build enough redundancy in the supply chain such that it is not dominated or threatened by the China. The secondary goal should be to have enough expertise in all parts of the supply chain to outpace China in semiconductor technology and even constrain its access to such technologies in case of worsening ties. To achieve these two goals, the Quad members need to think beyond national self-sufficiency in semiconductor manufacturing and instead invest in building a robust joint semiconductor ecosystem. The motivation should be to create a resilient, collaborative semiconductor ecosystem that encompasses all upstream and downstream stages of this complex supply chain.

Two specific recommendations arise from this principle.

1. *Form a Quad consortium aimed at building a diversified semiconductor manufacturing base.*

The US's industrial policies are focused on attracting investment for leading-edge semiconductor manufacturing (5-nanometres and below). Even if the US is successful in this endeavour, this node will not remain leading-edge when it starts production. Moreover, the demand for some of the older manufacturing nodes (28-nanometres and above) will not disappear anytime soon. Future applications such as 5G radios and electric vehicles will continue to require manufacturing at these nodes. Instead of duplicating efforts and competing with each other to gain access to reliable production at all these nodes, the Quad members can form a consortium that pools resources to build fabrication capabilities across these four countries. Not only will this approach be cost-efficient, but geographic diversification will make the supply chain more resilient. From a strategic angle, fabs constructed as part of this consortium could give preferential access to fabless companies within the Quad grouping.

2. *Cooperate on developing new standards such as RISC-V and GaN manufacturing*

Like in other industries, global standards are setting the tone for competition in the semiconductor sector. If a standard becomes internationally dominant, companies using these standards gain a disproportional competitive edge, as the Chinese efforts in the 5G-standards-setting process have demonstrated.

For example, RISC-V is an open-standard instruction set architecture that holds a lot of promise. Currently, Intel's x86 and ARM are two dominant instruction set architectures; their licenses are costly, deterring academia and small companies from using them. RISC-V, by contrast, is more customisable, free, and open-source. It is ideal for powering several Internet of Things devices. However, this open standard requires significant investment in research and encouragement for global adoption. This is where Quad centres of excellence for RISC-V could be of immense help. Similarly, collaboration on industry-wide security standards and semiconductor composites such as Gallium Nitride (GaN) can help companies based in the Quad to maintain a long-term competitive advantage throughout the supply chain. Proactively building these common standards will also build trust in each other's companies and business environments.

Principle 2: Coalesce "bubbles of trust" carefully

Taking a pragmatic stance on the hectic efforts to bring together techno-democracies, Nitin Pai writes:

> "Even if political changes around the world rekindle interest in multilateral approaches to world trade, technology and climate change, New Delhi must prioritise deepening relationships with its geopolitical allies. Like air bubbles for international travel during the pandemic, first create bubbles of trust bilaterally with strategic partners and then explore whether these can coalesce into larger bubbles that include more countries."[27]

This "bubbles of trust" metaphor serves as a helpful principle for the Quad semiconductor partnership. Even the combined might of the Quad cannot achieve complete dominance over the entire semiconductor ecosystem, and neither should it try to do so. Instead, the Quad engagement on semiconductors should become a platform that, over time, brings onboard other siliconpolitik powers such as Taiwan, Vietnam, South Korea, Israel, Singapore and the European Union (EU). The Quad semiconductor partnership's explicit position should be to become a starting point for forming larger "bubbles of trust" instead of aiming to be an exclusive industrial bloc.

Following the above principle, a specific recommendation emerges. Given that the Quad collectively lacks leading-edge semiconductor manufacturing capabilities, it can form a larger bubble of semiconductor manufacturing involving Taiwan and South Korea. Similarly, on semiconductor R&D and semiconductor design standards, a larger bubble with the EU and Taiwan as partners could be beneficial. The idea should be to start small within the Quad and then collaborate with other partners on specific issues.

Principle 3: Governments should do what companies can't or won't

Semiconductor companies are better judges of efficiency rather than governments. In pursuit of efficiency, semiconductor companies figured their comparative advantages and

[27] Nitin Pai, "India Should Create Bubbles of Trust with Its Geopolitical Allies", Mint, 8 November 2020, https://www.livemint.com/opinion/columns/india-should-create-bubbles-of-trust-with-its-geopolitical-allies-11604842963933.html.

then utilised relatively free global trade flows to optimise costs. In turn, consumers across the globe benefitted. In recent times, governments are trying to reverse this trend by subsidising local semiconductor manufacturing and resorting to export controls. A better approach instead would be for governments to do what companies won't or can't. Specifically, governments should:

1. Encourage strategic R&D cooperation between companies within the Quad

R&D cooperation between semiconductor companies could be of the following types: licensing agreements, cross-licensing agreements, technology exchange, visitation and research participation, and joint development. In each of these areas, governments have a role in easing the process. For example, faster visa processing and lower employment barriers for semiconductor professionals in the Quad member countries could facilitate higher technology exchange and joint development levels. Similarly, removing technology transfer restrictions in the Quad' bubble' could make licensing and cross-licensing agreements easier. Easing capital flows in this sector could again foster more joint development projects.

The Intellectual Property system, particularly patent protection, has been a critical enabler in accelerating R&D in this domain. A robust patent system has allowed for extensive cross-licensing without fear of being sued for patent infringement.[28] Governments can play a significant role in strengthening this system within the Quad. For example, a Quad-wide patent prosecution highway can accelerate patent prosecution, prevent IP theft, reduce examination workload, and improve patent quality.[29] Such a lubricating mechanism can smoothen R&D exchanges within the grouping.

2. Allow preferential access for EDA tools to Quad companies

EDA tool license costs are one reason why India's world-class semiconductor services sector is not able to transition into creating its own products. By creating a joint funding mechanism, the Quad members can enable preferential access to EDA tools at lower costs, leading to a diversification of fabless design beyond the US.

3. Increase trust in each other's legal enforcement mechanisms

Although geopolitical imperatives can motivate governments to align with each other, they aren't enough to convince semiconductor firms and investors. A precondition to enable alliances between private players from different countries is to cultivate trust in each other's legal systems, specifically in contract enforcement and regulatory practices. Quad governments can play an important role here. For instance, export control regimes and trade secrets protection of the four countries vary widely. Harmonising these systems will

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[28] Francesca Guadagno, Sacha Wunsch-Vincent and Thomas Hoeren, "Breakthrough Technologies – Semiconductor, Innovation and Intellectual Property", World Intellectual Property Organization, Economic Research Working Paper No 27, 2015, https://www.wipo.int/publications/en/details.jsp?id=3998&plang=EN.

[29] I thank Mihir Mahajan for this recommendation.

prepare the ground for semiconductor companies to enter into mutually beneficial partnerships.

Conclusion

Having outlined specific measures to kick start a Quad semiconductor partnership, I now discuss three factors that could inhibit Quad states from acting together.

One, the pursuit of national self-sufficiency might prevent multilateral collaboration. All four states might decide to compete instead of cooperating on semiconductors. This option might be most attractive for the US since it already has a commanding presence in upstream semiconductor design and downstream semiconductor manufacturing equipment. However, as I detailed in earlier, even the US is highly unlikely to achieve self-sufficiency in all the supply chain stages.

Two, a stance that Taiwan, South Korea and the EU need to be on board before moving ahead with other Quad members. This approach makes sense from an economic perspective since all three — Taiwan, South Korea and the EU — have their distinct comparative advantages in the supply chain, complementary to the Quad members' strengths. However, this approach would not make strategic sense as it is only the Quad that has the most precise geopolitical motivation for outpacing China's technological growth. Other states might prefer to hedge their bets or adopt a wait-and-watch approach. To avoid such delays, I argued in the section on 'Kickstarting the Collaboration' that it is better for a smaller Quad "bubble of trust" to make progress first before bringing in others outside this formation.

Three, an expansive technology agenda might deter progress on semiconductor cooperation. Aligning positions on thorny issues such as competition in the digital economy, data protection and technology governance will be challenging. There is significant dissonance on these topics between the Quad members. These divergent outlooks run the risk of dissipating collaboration altogether. Hence, I argued in earlier that semiconductors, an area where the Quad states already have complementary strengths and similar objectives, should be made the focus area to begin with.

Finally, the semiconductor supply chain is far too complex for protectionist measures and industrial policies to succeed over the long term. If the goal is to outpace (and even constrain) a geopolitical adversary, multilateral cooperation is a necessity, not a choice. A successful Quad partnership on semiconductors could build the mutual confidence to collaborate on other C&ETs.

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