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Semiconductors:

Navigating Supply Chain Resilience and Trade

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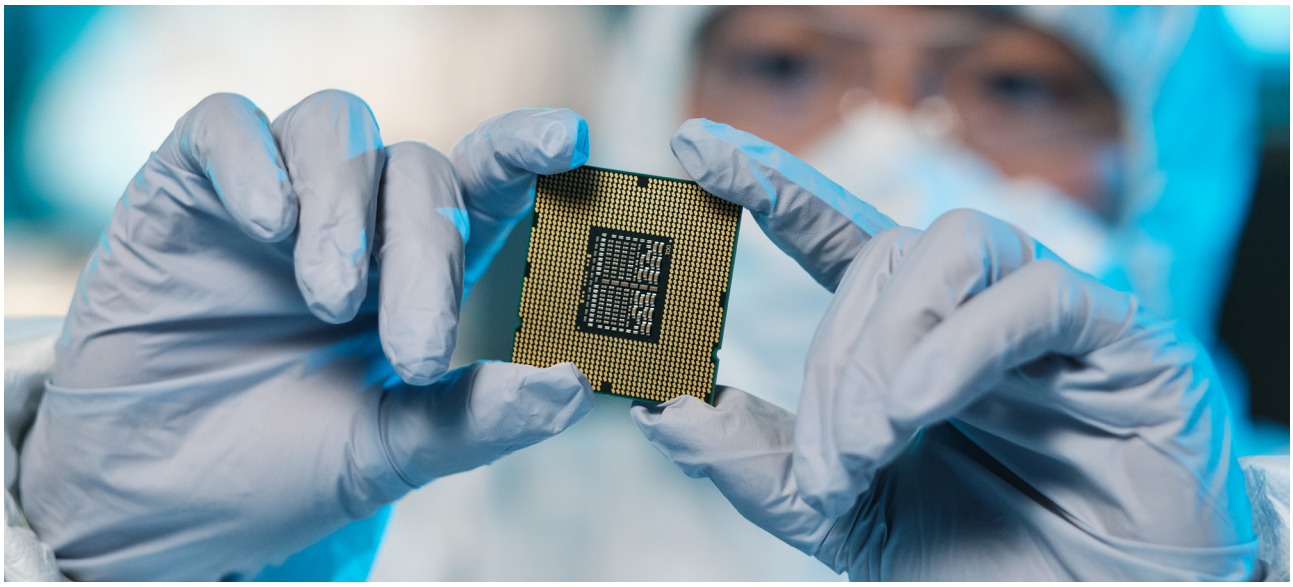


1. Introduction

Prior to the COVID-19 pandemic in 2020, global supply chains had been planned with efficiency in mind. The overriding impetus of supply chain professionals had been to drive down waste and costs, at the expense of limited flexibility when responding to sudden changes to supply, demand, and logistics. The subsequent pandemic, the supply chain bottlenecks that followed, as well as the impact of the conflicts in Ukraine and the Middle East, have almost entirely upended our traditional understanding of supply chains. As pundits have noted, the organising principle of supply chain management has shifted from 'Just in Time' to 'Just in Case' (Diaz, 2021).

This report discusses a summary of the current thinking on supply chain resilience and queries whether stronger multilateral trade integration can promote supply chain resilience. This is investigated through an evaluation of the critical supply chain in semiconductors as a case study. What are the key challenges to supply chain resilience, with a particular focus on Taiwan's and Malaysia's respective positions as critical node and key supporting player in the supply chain? The report also introduces recent arguments that multidimensional free trade agreements such as the CPTPP may help build supply chain resilience.

This report explores the semiconductor supply chain because the advent of policy thinking around resilience was led by the US policy framework on semiconductors, with The Executive Order on Supply Chain Resilience and the CHIPS Act. Semiconductors are also a core pillar of the global technological landscape and of high value trade networks for many countries. Interest in capturing semiconductor investments has grown, with several countries offering costly incentives to coax investors to divert one part of the value chain in. The key components of this sector, commonly referred to as integrated circuits or chips, power diverse objects and systems from mobile devices to military technology, advanced AI components, and data centres. With over 100 billion devices incorporating chips, their ubiquity underscores their pivotal significance in driving global value chains and technological advancement (SIA, 2023).

When the pandemic caused global disruptions to chip supply, policymakers realised that they had not kept up with the risks associated with this complex and globalised network. The supply chain is also facing challenges from the rising trade tensions between the US and China. Overall, the value of

trade in goods and services in 2020 decreased by 9.6 percent due to disruption (WTO, 2021). These factors have prompted a re-evaluation of supply chains from a risk-based and geopolitical perspective. Beyond simply facilitating private-sector led globalisation, bureaucrats and political leaders must now consider how to manage the risks arising from critical chokepoints in supply chains or how they could be weaponised by geopolitical rivals (Farrell and Newman, 2019).

The report begins with a summary of modern semiconductor supply chains, as well as Taiwan and Malaysia's respective positions within them. We proceed to analyse contemporary literature on the idea of supply chain resilience, as well as current semiconductor cooperation between Taiwan and Malaysia. We then discuss the challenges that come with building supply chain resilience, namely the prohibitively large upfront investments needed, potentially high costs that would be passed on to end-consumers, and acquiring the necessary skilled labour. As well, we note that the ongoing decoupling between the US and China may prove awkward for smaller countries seeking to expand their presence within the semiconductor supply chain such as Malaysia, who may eventually be forced to choose either side and lose access to the other's markets. Finally, we end by considering how trade agreements may help facilitate supply chain resilience, and particularly the benefits that Taiwan may accrue through membership of the Comprehensive and Progressive Trans-Pacific Partnership (CPTPP). Even if Taiwan proves unable to join the CTPP due to geopolitical reasons, our brief argues that Taiwan may achieve the same goal by expanding bilateral and multilateral cooperation with ASEAN Member States.

2. Understanding the semiconductor supply chain

Semiconductors (also known as integrated circuits or computer chips) have emerged as one of the most critical sectors of the global economy, rivalling the oil and gas sector in terms of its sheer geopolitical importance. Global annual sales of semiconductors are significant, with annual sales increasing 3.3% in 2022 to reach more than half a trillion dollars (Thadani and Allen, 2023). Future prospects are also encouraging, with one estimate projecting the global semiconductor sector to reach a valuation of USD 1.3 trillion by 2032 at a compound annual growth rate (CAGR) of 8.8% from USD 625.2 billion in 2023 (Market.US, 2024). As of now, the three largest semiconductor corporations in the world - dubbed The Big Three - are Taiwan Semiconductor Manufacturing Company (TSMC), South Korea's Samsung, and the United States' Intel (Chen-Yuan, 2023).

Beyond immediate sales however, the semiconductor industry serves as an irreplaceable enabler of tens of trillions of dollars of annual economic activity worldwide. Semiconductors serve as crucial components of a wide range of goods and services, including data centres, laptops, mobile phones, automobiles, washing machines, light bulbs, weapons guidance systems, and the electrical grid infrastructure. Many key sectors in the global economy depend upon the ready supply of semiconductors. In every modern automobile, for example, there are anywhere between 1,000 to 3,500 semiconductors. Similarly, key aspects of the digital economy including 5G and Internet of Things (IoT) infrastructure are reliant on the availability of cutting-edge microprocessors which only a handful of firms have the capacity to manufacture (Thadani and Allen, 2023, Arcuri and Lu, 2022).

The semiconductor supply chain functions within a highly complex web. The supply chain starts off with research and development, where new techniques and equipment are pioneered to produce ever smaller chips and more densely packed circuits. The second element of the supply chain is the design component and then mass produced in special facilities for fabrication. These activities comprise the

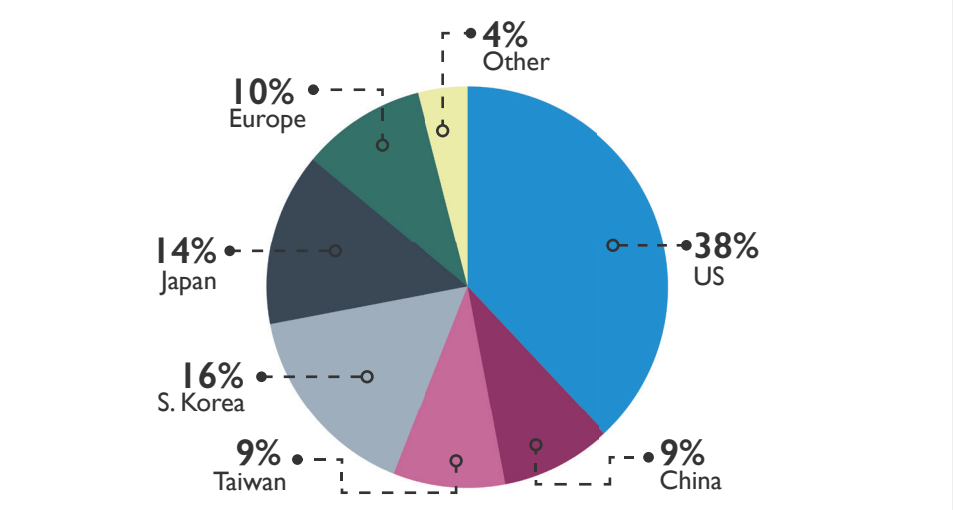
front end of the supply chain. The back-end of the supply chain involves specialised assembly, packaging and testing of the chips before they are sent for assembly on circuit boards and in the device they are intended for (Varas et al., 2021). The highly specialised processes in the supply chain are also supported by complex machinery which in themselves have a sprawling network of suppliers, and many thousands of components. The extreme ultraviolet lithography (EUV) machine that can etch designs on the smallest chips is made up of "100,000 parts, 3,000 cables, 40,000 bolts, and two kilometres of hosing" (Thompson, 2021). More critically, it can only be manufactured by one company, ASML in Netherlands. The semiconductor supply chain involves a high level of complexity and yet is critically dependent on specific nodes or chokepoints for production.

The semiconductor supply chain forms a significant contribution to GDP in many economies. In the United States, although semiconductors contribute merely 0.3 percent to the overall GDP, their significance extends beyond this seemingly modest figure. These electronic components play a pivotal role as a production input, influencing approximately 12 percent of the U.S. GDP. This underscores the substantial second-order impact of semiconductors on diverse sectors of the American economy (Thadani and Allen, 2023).

Examining other major participants shows similar significance to their respective GDPs. The semiconductor sector makes up some 15% of Taiwan's GDP, with American tech firms including Apple, Amazon, Google, Nvidia, and Qualcomm reliant on Taiwan-based contract manufacturers for nearly 90% of their chips (Arcuri and Lu, 2022). In Malaysia, the E&E sector contributes to 7% of GDP where 65.2% of this is from the semiconductor industry (MATRADE, 2023).

Six major regions have a significant participation in the total global output of the semiconductor industry (see Figure 1), with each region specialising in different activities of the value chain (Varas et. al, 2021). In 2019, the United States alone comprised 38% of the total value added of the global semiconductor supply chain. Although Taiwan has the largest market share of chip fabrication, it is largely US-based firms that design and order the chips. Wafer fabrication (the actual manufacturing of the chips) only takes place in a handful of countries, with production mostly concentrated in Taiwan (Varas *et. al*, 2021).

Figure 1: Participation in the semiconductor value chain by region and overall value, 2019 (%)



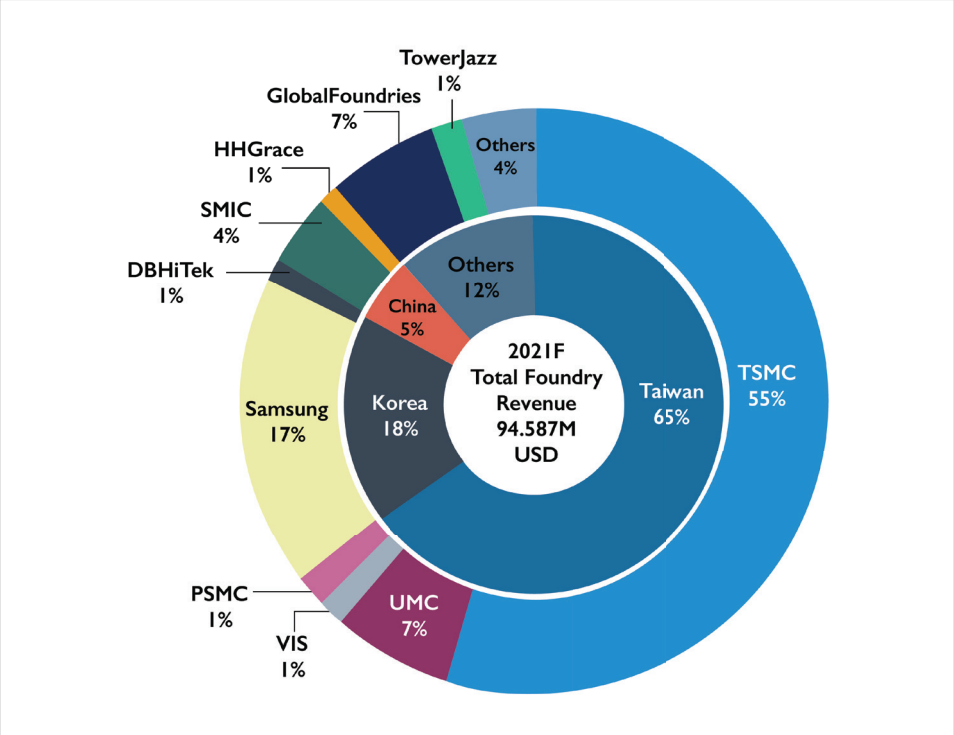
Source: (Varas et al, 2021, p.31)

Compared to most other modern economic sectors, the global supply chains that have developed over the last decade for semiconductors are unique in both their sheer geographical concentration (particularly when it comes to the more high-end operations) as well as their complexity. The various inputs to fabrication of an integrated circuit is estimated to cross international borders 70 times before reaching the end consumer (Alam et. al, 2020). World class chip producers usually have suppliers around the world, with some suppliers so niche that only they produce such technological capabilities at specific performance levels. It is largely agreed that no single country is currently able to achieve end-to-end independence in semiconductor production, meaning at present countries must continue engaging with each other to ensure continued access to semiconductors (Chu *et al*, 2022).

2.1 The outsized role of Taiwan

Although the global supply chain is deeply integrated and diverse across nations, over the years, analysts have pointed to the outsized role of Taiwan in the global semiconductor supply chain, namely in the foundry market. Foundries specialise in mass manufacturing chips which design firms outsource to them, thus splitting the value chain into upstream and downstream sectors. The Taiwanese foundry firm, Taiwan Semiconductor Manufacturing Co. (TSMC) in particular has emerged as an indispensable node to the global supply of chips. By total foundry market share, in 2021 TSMC recorded a market share of 55%, while South Korea's Samsung followed with 17% (see Figure 2) (TrendForce, 2021). By one estimate, TSMC provides 35% of the world's automotive microcontrollers and 70% of the world's smartphone chipsets. The company also dominates in the production of chips for high-end graphics processing units in PCs and servers (Vest, Kratz, and Goujon, 2022).

Figure 2: Market Share of Foundry Firms, 2021



Source: Trendforce, 2021

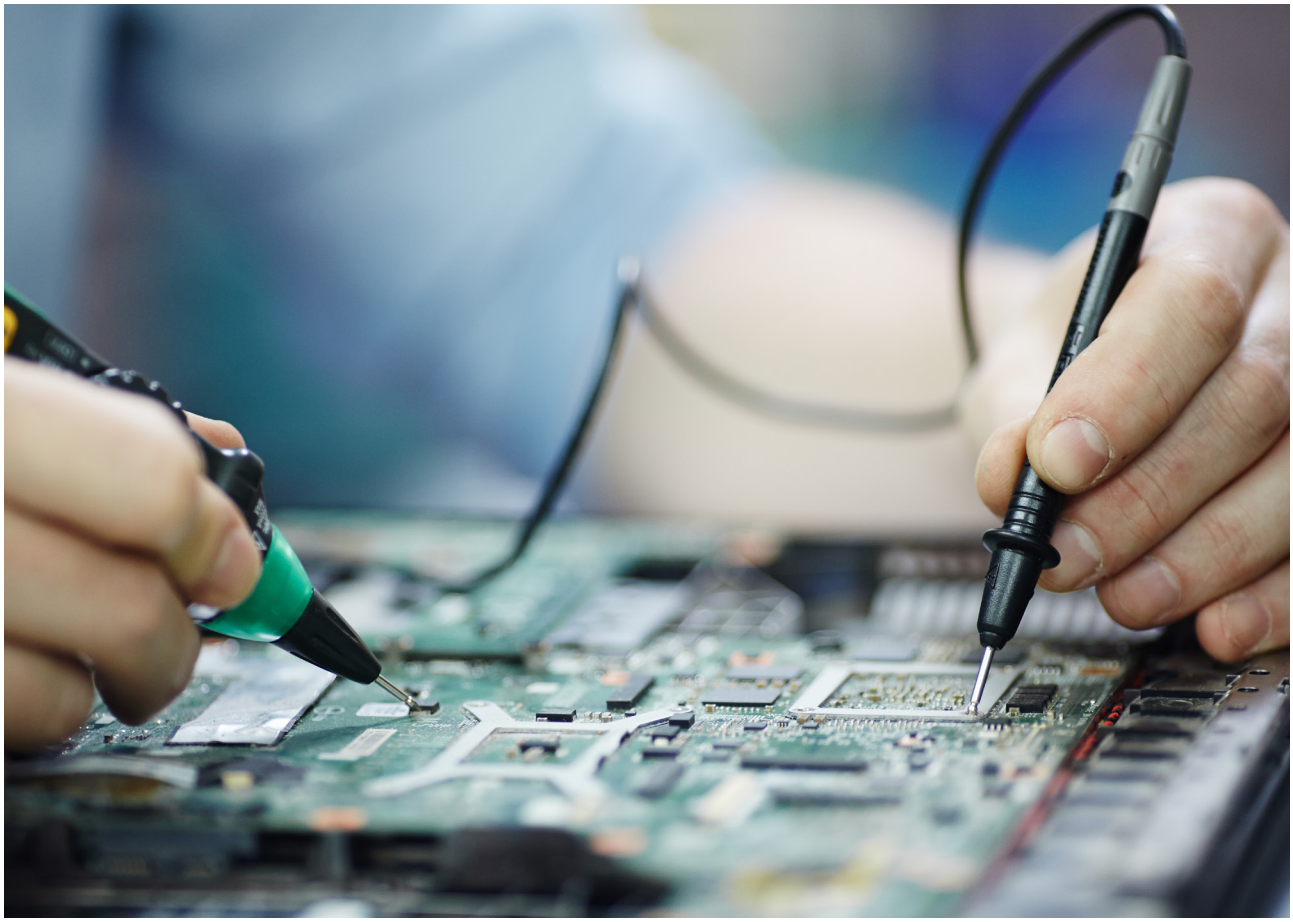
Taiwan and South Korea have emerged as leaders in the foundry business and are currently the only two businesses in the world that can manufacture the most advanced 5-nanometer semiconductors. Estimates from the Semiconductor Industry Association (2021) saw that Taiwan holds a strong 92% of the world's most advanced chips production of below 10 nanometres. TSMC is also among the highest spending semiconductor companies in the world, with the company's capital expenditure (capex) estimated at US$32 billion in 2023, representing 23% of total semiconductor industry capital spending that year. Indeed, the combined expenditure of TSMC and Samsung (which also stood at US$32 billion) stood at 46% of total industry expenditure (Chen-Yuan, 2023).

2.2 Malaysia also plays a significant role

Malaysia, a key player in the global semiconductor landscape, has emerged as a significant exporter of semiconductor devices. With a semiconductor environment that has been established since the early 70s, the nation has played a pivotal role in semiconductor exports over the years. In 2022 alone, Malaysia's IC exports reached a staggering USD 78.9 billion, securing its position as the fifth-largest exporter globally—trailing closely behind Singapore and South Korea. Notably, the exports of integrated circuits (HS8542) surged by an impressive USD 7.1 billion between 2021 and 2022, underscoring its role in the intricate supply chain (OEC, 2022).

Malaysia's position within the global semiconductor supply chain is mostly focused on back-end operations, with a key focus in assembling, testing and packaging (ATP). It is estimated that some 13% global backend operations are currently supported by Malaysia (Malaysian Productivity Corporation, 2023). However, there is much interest by both industry players and the government to push the Malaysian semiconductor industry higher up the value chain towards integrated circuit (IC) designs and wafer fabrication. Currently, Oppstar Technology Sdn Bhd, Infinecs Systems Sdn Bhd, Symmid Corporation and SkyeChip Sdn Bhd are IC design companies which focus on custom IC designs and are the few Malaysian made front-end manufacturers.

Moving forward, Malaysia sees more potential in attracting IC design companies as well as wafer fabrication companies to invest in Malaysia. According to the National Industrial Master Plan (NIMP) 2030, Malaysia aims to increase collaboration with other ASEAN countries in order to combine talent on semiconductor front-end production and push the industry higher up the semiconductor value chain. Through the large share of the Taiwanese semiconductor market together with the known interest of Malaysia to increase its position on the value chain, this produces opportunities for the two economies to further diversify their markets and production plants.



3 Supply chain disruptions and the shift to resilience

3.1 Background

Disruptions from the pandemic in food, medical supplies, and other sectors have sparked an assessment of policy from the perspective of securing critical supply chains. Such was the impact of pandemic-related disruptions that the US President issued an executive order to study the associated risks to ensure "resilient, diverse and secure" supply chains in February 2021 (The White House, 2021a). Although this stance developed from the pandemic, it also considers the longer term context of geopolitical and trade tensions and climate change related disasters. The order expanded on the possible causes of disruption that would be considered a risk: "pandemics and other biological threats, cyber-attacks, climate shocks and extreme weather events, terrorist attacks, geopolitical and economic competition, and other conditions".

The Executive Order on America's Supply Chains called for 100-day reviews of all the gaps, current challenges, and status of supply chains from various sectors, including electric vehicle batteries, critical and strategic minerals, and pharmaceuticals. Semiconductors manufacturing and advanced packaging supply chains were the first-mentioned sectors on the list. The findings from the ensuing report noted the need to rebuild domestic production capabilities, especially given that US semiconductor production is only six to nine percent of global chip production, while Taiwan in comparison comprises more than 60% of overall production and 92% of the production for leading edge chips (The White House, 2021b).

We identify two types of disruptions that pose a risk to critical supply chains:

3.1.1 Disruptions from disasters

The COVID-19 pandemic fueled a surge in demand for chip-containing products like laptop computers, smart phones, and appliances, while governments forced factory shutdowns in places like Malaysia and Vietnam which affected the supply chain. Due to chip shortages, automakers experienced production halts, with analysis by the U.S. Department of Commerce finding that the chip shortage shaved an estimated US$240 billion off U.S. GDP in 2021. The auto industry alone produced 7.7 million fewer cars in 2021 due to lack of chips. Vehicle production in Europe was impacted too - German production dropped 20% while Italian production fell over 25%. (Dimerco, 2023, Thadani & Allen, 2023, M. Attinasi et. al., 2021, Vest, Kratz, and Goujon, 2022, Leslie, 2022).

The 2021 chip shortage also caused delays in electronics product launches, while fueling price inflation around the world for consumers. Apple was forced to announce it was cutting iPhone production by more than 10% due to chip shortages (Leslie, 2022). Meanwhile, export-oriented economies in the Asia-Pacific that depend heavily on the export of electronics, such as South Korea, saw their overall growth impacted (Dimerco, 2023,).

An intense winter storm that impacted Texas in February 2021 helped exacerbate the global chip shortage. Many chipmaking facilities located in the state (which is the centre of semiconductor manufacturing in the US) were forced to shut down due to power cuts, with companies such as NXP Semiconductor, Samsung, and Infineon Technologies reported to have shut down their respective facilities during the storm (Bradshaw and Edward, 2021; King, 2021). The earthquake and tsunami that struck Japan in 2011 also had an outsized impact on global chip production. By one count, 25% of the global production of silicon wafers and 75% of the global supply of hydrogen peroxide (a key element used to cleanse semiconductors substrates) was affected by the disaster. Several fabrication facilities were also shut down for several months (Varas et al., 2021).

The disruption to the global semiconductor sector was but one of many large scale disruptions to impact the larger world economy in the past few years. Throughout 2020, the COVID-19 pandemic would cause significant supply chain bottlenecks across Southeast Asia. Many of these were due to disruptions to trade with China, the first country in the region to implement lockdown in response to the virus. This is due to many industries in the region being heavily dependent on the supply of intermediate parts and raw materials sourced from China for their own operations. Sectors as diverse as electronics manufacture in Malaysia, textiles manufacture in Cambodia and Vietnam, and manufacturing in Indonesia were impacted by the lack of inputs traditionally sourced from China (CARI, 2020).

The COVID-19 pandemic would also place unprecedented stress on almost all segments of global food supply chains. Farm production and food processing were impacted by labour shortages, social distancing rules, and viral outbreaks at facilities. Bottlenecks in transport and logistics disrupted the movement of agricultural products - this was particularly the case for perishable high-value products generally transported by air freight such as fruits and vegetables, since passenger air travel was one of the most affected modes of transportation. As well, lockdown measures forced changes in consumer demand for food products, with consumers shifting away from restaurants, food services and other types of "food away from home" towards food consumed at home, the latter of which would cause

retail demand for food to soar. The differing consumption patterns between the two would create significant logistical complexities for suppliers (OECD, 2020).

3.1.2 Disruption due to geopolitical risks

A more recent disruption to global food supply came in the aftermath of the Russian invasion of Ukraine in early 2022. Prior to the invasion, Ukraine was a major global supplier of wheat, accounting for 6% of exports by volume. Many small, food-insecure countries were especially vulnerable to disruptions of wheat trade: Ukraine accounted for roughly 67% of Lebanon's wheat imports and 84% of the Gambia's. Because of the invasion, global food prices would hit a record high in March 2022, before falling below their pre-invasion levels by December 2022. By January 2024, global food prices had fallen to their lowest level in three years. This seeming return to normalcy by global food supply chains has been attributed to various coping strategies adopted by countries encountering disruptions, including sourcing wheat from countries other than Ukraine and Russia, substituting imports of other grains, such as buckwheat or sorghum; and relying on supplies of wheat accumulated before war broke out to ride out temporary shortages (Ulybina and Rastogi, 2024; Welsh, 2024).

Nevertheless, while global food prices have receded, there remains a global food security crisis introduced by the invasion. Despite global food prices measured in U.S. dollars are falling, local food prices measured in national currencies are rising in many countries. Between September and October 2023, for example, more than a third of low-income countries (LICs) and lower-middle-income countries (LMICs) experienced food price inflation of more than 15%, with food price inflation at 30% for LICs in that period (Welsh, 2024).

Large-scale and prolonged disruption could be anticipated in the event of trade blockades or wars. In a December 2022 study by the consultancy Rhodium Group, the impact of a possible blockade of Taiwan by China on semiconductor supply chains could see as much as US$1.6 trillion in annual losses for industries that are directly or indirectly dependent on Taiwanese chips. The study also found that the global economy would face significant second-order impacts that would likely add trillions more in economic damage. Many industries depend on the availability of goods and equipment containing Taiwanese chips, including e-commerce, logistics, ride-hailing, entertainment, and other industries that collectively employ tens of millions of people around the world. Spare parts and components for critical public infrastructure, such as telecommunications and medical devices, could also become disrupted (Vest, Kratz, and Goujon, 2022).

3.2 A shift towards interventionist policies

It is within this context that policy thinking has moved away from the traditional laissez-faire approach that allowed the private sector to build highly globalised and efficient supply chains towards a more interventionist stance that actively supports supply chain resilience. As the pandemic abated and US-China trade tensions once again came to the forefront, the policy discourse on resilience began focusing on the wider geopolitical concerns about the complex relationship between economic logic and national security.

In this context, the discourse on resilience expanded; it was not just about mitigating the effects of disruption, but also about efforts to re-shore, near-shore, or on-shore vital

production capacity for security and maintaining economic dominance. The 100-day report which was produced as a result of the Executive Order on America's Supply Chains heavily focused on recommendations to promote domestic investment in semiconductors and build the local ecosystem, including funding the CHIPS Act to rebuild domestic production capacity. Only the sixth recommendation included promoting investment diversification with partner countries, whereas the seventh recommendation in fact called for export controls and trade restrictions on China (The White House, 2021). However, are domestication and trade restrictions the best and only options? To what extent would increasing trade integration and diversifying interdependent relationships build resilience? In the next sections, we provide an initial exploration of these questions which would require more extensive evaluation in future.

4. Challenges towards building resilience

Industry experts have warned that countries attempting to bring more production to home ground would face significant challenges, in the form of the prohibitive upfront costs needed, the passing on of incremental costs to end-consumers, and the lack of skilled labour. To some extent, over a period of time these challenges also present opportunities to build a local ecosystem with economic benefits. However, where trade restrictions are concerned, smaller countries and their investors risk having to choose sides should the ongoing decoupling between the US and China continue to escalate. Considering that diversification and access to alternative supply is a necessary factor for supply chain resilience, blocking out one country with a significant trade network is a paradoxical move that could also pose significant challenges to overall resilience.

4.1 High upfront investments

Many major economies around the world are actively seeking to address supply chain vulnerabilities in semiconductors through policies of re-shoring. However, most analysts argue that this would require massive upfront investments on the part of semiconductor firms.

At present, different regions of the world are focused primarily on different activities within the semiconductor supply chain (i.e. the United States focusing on design, East Asia focusing on fabrication, the US and Japan specialising in manufacturing equipment, etc) (Varas et al., 2021). This regional division of tasks has been driven by comparative advantage developed over the past decades of the industry's history. When it comes to chip fabrication, the costs of fabrication increases with technological advancements, and is prohibitive to all but the largest companies. The high level of specialisation and interdependence in the supply chain is such that it is generally agreed that the investment outlays needed for complete self-sufficiency is thought to be non-feasible.

According to one 2021 report, attempting to achieve self-sufficiency in every layer of the semiconductor supply chain would require US$900 billion to US$1,225 billion in upfront investment to cover each region's 2019 consumption levels. Furthermore, any further growth in domestic consumption would require further investments in additional capacity for each region. The report estimated that the global semiconductor industry would incur US$45 to US$125 billion in incremental recurrent annual operational costs (Varas et al., 2021).

According to another estimate, if the global chip industry invests US$100billion annually in capital, then China would have to commit the same for many years, committing over a trillion dollars to catch up (Miller, p.323). Re-shoring chip manufacturing to the US, which had hollowed out its manufacturing capacity over the years, would be not much less prohibitive in terms of costs. It should be noted that in these scenarios, semiconductor firms would be required to make these huge upfront investments while also possibly suffering from the loss of access to major markets due to security-related reasons, thereby leading to losses of revenue (Varas et al., 2021). With chip supply becoming an issue of national security as well as an economic opportunity, government incentives in this area have developed rapidly in the past few years. Even with government incentives, the cost of building in redundancies or eliminating chokepoints in the supply chain may be mitigated but not fully alleviated.

4.2 Rising costs for consumers

As countries seek more resilience in supply chains, analysts warn that semiconductor firms may have to pass on at least a portion of their incremental costs to device makers in the form of higher prices for semiconductors. One study estimated that a hypothetical shift towards fully self-sufficient supply chains could lead to an average increase of between 35% to 65% in the price of semiconductors. Even for strategies for resilience that aim to create only a portion of additional or redundant capacity, there would arguably be some cost increases that cannot be completely absorbed by the industry (Varas et al., 2021).

Disengaging from certain markets as part of de-risking strategies will inevitably lead to loss of cost-effective production. In the case of the United States, for example, a push towards resilient supply chains may require losing access to assembly, testing and packaging (ATP) facilities in China (out of 484 ATP facilities counted in 2021, 134, or 28%, were in China) (Thadani and Allen, 2023). It may also require losing access to several strategic materials used in semiconductor production that China currently dominates in, such as rare earths. By one count, China leads in the extraction of 9 of the 17 critical raw-material inputs and in the refining of 14 of them (Varas et al, 2021).

As such, the end result would ultimately be higher prices for electronic devices for consumers, thereby ending a decades-long trend of electronic devices becoming more affordable over time. There is also a risk that siloed and protected domestic industries would lose out in efficiency and ability to innovate.

While the provision of government incentives may help alleviate the need for semiconductor manufacturers to pass on their incremental costs to end-consumers, depending on the specific country it may require large amounts of incentives nevertheless to cushion consumers from the impact.

4.3 Lack of skilled labour

An acute issue facing many countries including Malaysia in its quest to move up the semiconductor value chain is the lack of skilled labour. It should be noted that wafer fabrication is a very complex, specialised operation that typically takes two to four years to build and put into commercial operation. It also typically requires 3,000 to 6,000 staff to operate, with most being skilled technicians that need to be recruited and trained. In the case of Malaysia, the country currently faces a glaring shortage of engineers. By one count, only 5,000 engineering students graduate annually in Malaysia while the country's electrical and electronics sector alone requires 50,000. Low salaries for engineers, particularly for starting engineers, often sees many Malaysian engineers migrate abroad for better job opportunities.

Supplying the labour expertise needed to move up to the front-end of the chip supply chain may be beyond Malaysia's present capabilities. At present, the semi-skilled workforce comprises the majority of the formal Malaysian workforce, standing at 62.3% in the third quarter of 2022. In the same quarter, the skilled workforce represented 24.9% of the formal workforce, while low-skilled workers only represented 12.8%. While having a large share of semi-skilled workers is not necessarily unusual for an upper-middle income country, it should be noted that this skills breakdown has more or less remained consistent since 2011, suggesting difficulties on the part of Malaysia in developing its skilled labour (DOSM, 2022).

4.4 Geopolitical tensions and trade restrictions

Much of the push towards more resilient global semiconductor supply chains has been led by geopolitical concerns, namely the so-called "Chip War" between the US and China (Miller, 2021). In 2020, the then-Trump administration began blocking the shipment of high-end semiconductors and semiconductor manufacturing equipment to Chinese firms. Later in 2022, the Biden administration would continue to tighten said restrictions, including publishing a sweeping set of export controls which included measures to cut China off from certain semiconductor chips made anywhere in the world with US equipment, as well as cutting edge chip making equipment. Japan and the Netherlands would promptly follow suit from the US that same year. The Biden administration's export controls also saw many China-based facilities of foreign wafer fabrication firms cease operations. In response, China would proceed to double down on its goal of tech self-reliance (Reuters, 2023; Thadani & Allen, 2023).

Globalisation of the chip supply chain has led to asymmetric relationships and chokepoints which could be exploited by economic rivals through so-called 'weaponised interdependence' (Farrell & Newman,2019, qtd. In Miller, 2021). For instance, at present ASML Holding N.V. based in the Netherlands is the only supplier in the world of the latest generation photolithography scanner equipment (extreme ultraviolet, or EUV, lithography machines) used for cutting edge chip fabrication. In 2023, the US was able to leverage upon its relationship with the Netherlands to cut off ASML's cutting edge tech from China, posing a blow for the latter. Although Huawei seems to have produced its own 7nm chips in 2023, it is thought that the current export restrictions will continue to keep China out of the highest technology for chips for many years (Fuller, 2023).

Whether the United States and its partners will extend its tech restrictions to other areas of the semiconductor supply chain remains to be seen. From the perspective of third party countries aspiring to expand their presence within semiconductor supply chains, such as the case with Malaysia, there is a concern that the ongoing decoupling between the US and China may force them to ultimately choose sides and thereby lose access to the other's markets.

In the case of Malaysia, while the country is currently benefiting from the US-China decoupling insofar as its encouraging firms to move shop to Malaysia, there is a question of whether Malaysia and investors here would eventually be forced to choose between the Chinese or American market in the long-run. Since the Trump administration began imposing trade restrictions on Chinese tech (which were maintained and tightened by the subsequent Biden administration), Malaysia has started to see an increase in investments from mainland Chinese companies. By one count, there are now 55 mainland companies operating in Penang in manufacturing (mostly in semiconductors), compared to just 16 before the American crackdown began (Ruehl, 2024). While most of the Chinese firms investing in Malaysia are still focused on back-end operations, there are fears that should these operations move into more sensitive and higher-value sectors, it may invite more targeted restrictions from the US (Ruehl,

2024). However, given the integrated ecosystem in Malaysia, restrictions would likely equally disrupt US companies that are invested here.

In the case of Taiwan, their high concentration of chip fabrication capacity presents a critical choke point in the supply chain. Given that Taiwan is actively expanding cooperation with countries southwards, there are spillover effects into Malaysia as investors seek new land to open plants. Taiwanese firms are more cautious of expansion within China and are looking towards the ASEAN region for future investments (Hsueh, 2023). Recent trends have shown a notable influx of Taiwanese semiconductor investors into Malaysia, including major players such as Foxconn, ASE Technology Holding Co., Ltd, Siliconware Precision Industries Co., Ltd and Taiwan Semiconductor Manufacturing Company (TSMC). Taiwanese investment into Malaysia has fluctuated over time with a value of USD$ 187.6 million in 2012 peaking to 312.72 million in 2017 and falling to USD$ 86.4 million in 2022 (Statistica, 2023). However in 2023, it was estimated that USD$400 million was to be invested in Malaysia (MIDA, 2023). This rise in collaboration will also play a pivotal role in diversifying Taiwan's semiconductor supply chain especially in the presence of US-China and China-Taiwan geopolitical tensions.

5. Strengthening multilateral relationships for resilience

In light of these challenges, countries may find it more prudent and cost effective to establish 'minimum viable capacity' to produce the most critical components and finished products in a time of crisis. For instance, a 2021 report jointly written by BCG and SIA argue that the United States has the ability to reshore production of advanced logic chips, which are associated with critical infrastructure applications including aerospace and defence systems, core telecommunications networks, and supercomputers and data centres for essential sectors such as government, energy, transportation, healthcare and financial services (Varas et al., 2021).

Indeed, this would appear to be the overriding aim of the Biden administration's CHIPS and Science Act, which was signed into law in August 2022. It sets aside US$52.7 billion to increase production of US-made semiconductors, addresses supply chain vulnerabilities by producing more goods in the US, and bolster domestic scientific research. As stated by US Commerce Secretary Gina Raimondo, the end goal of the Biden administration's CHIPS Act is for the United States to become a major producer of advanced logic chips. The US anticipates producing roughly 20% of the world's advanced logic chips by 2030, up from the zero percent produced today. From Raimondo's statements it appears the goal is for US to become home to the entire silicon supply chain for the production of leading-edge chips – from polysilicon production to wafer manufacturing to fabrication to advanced packaging (Kutlu, 2024).

To generalise, countries aiming to secure chip supply as well as benefit from reshoring can aim for partial domestication of the value chain, but it is costly. Various countries are now providing large incentives for attracting semiconductor fabrication into their respective territories (Table 1). Malaysia is well positioned to attract investments in this sector given the existing ecosystem, but like many countries in the low to middle ends of the value chain, would be unable to compete on monetary incentives alone. Moreover, onshoring combined with supply restrictions might provide a temporary economic advantage, but not necessarily supply chain resilience, as the inputs needed for fabrication would still need to be sourced from many countries. Malaysia should therefore consider complementary strategies such as deeper multilateral investment and trade integration so that the net effect reduces costs for investors that rely on complex supply chains.

Table 1: Government strategies and incentives for promoting semiconductor production reshoring or onshoring

Region	Law / Policy	Incentives	Value (where stated)
United States	CHIPS and Science Act	Scientific R&D and Commercialization (USD 200 billion) Semiconductor R&D and workforce development (USD 52.7 billion) 25% investment tax credit for qualifying facilities and equipment (USD 24 billion)	USD 280 billion between 2022 - 2026
India	Semicon India	Match package up to 50% of cost of setting up new semiconductor and display fabs (USD 10 billion) Incentives for electronics and IT manufacturing (USD7.5 billion) Incentives for "allied sectors" such as EVs, solar PV modules, and telecom products (USD 13 billion)	USD 30 billion
Japan	Fiscal 2023 Supplementary Budget allocation	Incentives for Rapidus to manufacture 2nm semiconductors (USD 4.37 billion) TSMC Plant construction and related projects (USD 4.27 billion) Ensure a stable supply of semiconductors and manufacturing equipment (USD 3.89 billion)	USD 12 billion
Taiwan	Statute for Industrial Innovation	25% tax deduction on R&D expenses 5% tax deduction on expenditure for new machinery used in advanced processes	–
South Korea	K-Chips Act	Increase in base tax credits for eligible investments in facilities of national strategic importance (25% for SMEs, 15% for large companies) Additional 10% tax credit for ongoing incremental investment in national strategic technologies	--
China	Measures aimed at attaining semiconductor self-sufficiency	Subsidies to 190 domestic chip firms, namely SMIC and Sanan Optoelectronics (USD 1.75 billion) Tax credits on R&D expenditure in chip technology of up to 220% of taxable income if they qualify for patents Up to 10 years of corporate tax exemption for advanced (28 nm) node fabrication lines and exemptions on import duties for integrated circuit manufacturers to import materials and equipment	--

Source: Notes compiled from various sources.

6. Trade and supply chain resilience

While capturing chip production capability may reduce some of the core risks related to chip supply, it would not reduce the complex interdependency of the overall supply chain, given the number of inputs that go into chip fabrication. As argued above, the US' effort to domesticate leading edge chip fabrication would cost many billions in incentives, as well as time to build up the talent and facilities. Finally, the ongoing decoupling between the US and China may prove awkward for smaller countries seeking to expand their presence within the semiconductor supply chain such as Malaysia, as they may eventually be forced to choose either side and investors may lose access to one market or the other.

6.1 How trade agreements can facilitate supply chain resilience

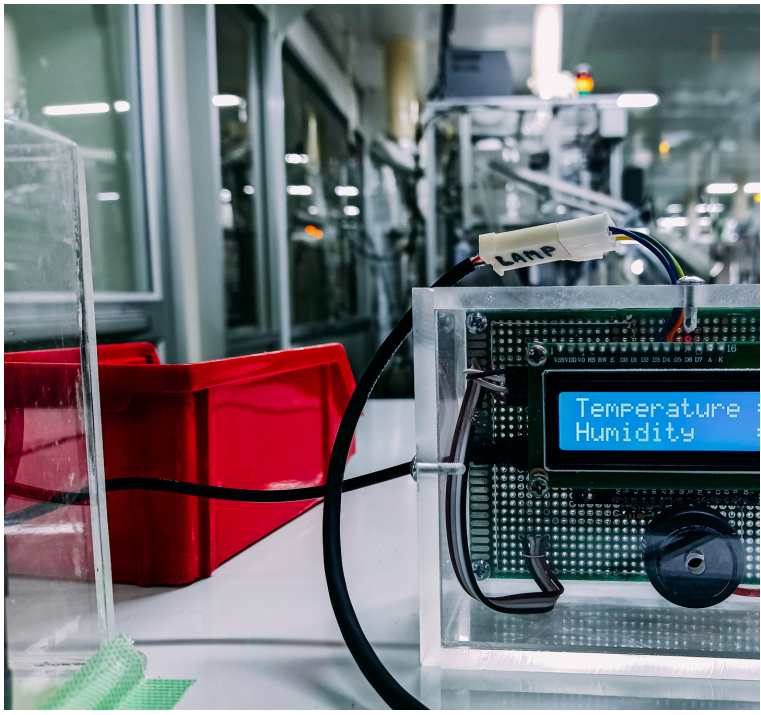
With the increasing complexity of international trade relationships, coupled with the imperative need for resilient supply chains, governments and institutions have to create a semiconductor ecosystem in which regional partners can collaborate, in order to ensure a more resilient network (CSIS, 2021). By ensuring access to multiple sources for critical components, trade agreements enable countries to mitigate supply shocks and reduce macroeconomic volatility. In the wake of the pandemic, the OECD recommended pillars such as predictability, transparency, and international regulatory cooperation to foster open markets, thereby promoting smoother supply chain movements amidst crisis (OECD, n.d). Trade diversification and mechanisms for maintaining cooperation, rather than trade restrictions and reshoring, are encouraged for enhancing supply chain resilience.

With trade tensions between the US and China rising, the emerging discourse on occasion assumes that there is an inherent tradeoff between global trade interdependence and domestic economic security. However, there is evidence to show that deeper trade integration provided more resilience during the disruption of the COVID-19 pandemic. In one 2021 research paper by the UNCTAD looking at the impact of the COVID-19 pandemic on international trade in 2020, it was noted that the pandemic resulted in a decline in trade of around 14% for the average country. However, it was found that trade between countries with regional trade agreements (RTAs) declined by 11%, meaning it was more resilient by three percentage points relative to trade between countries without any form of trade agreement. Furthermore, it was found that trade under deep trade agreements was substantially more resilient than trade under shallow agreements, with trade under a deep RTA falling by about 6 percentage points less than trade under a shallow RTA (Nicita and Saygili, 2021).

When breaking down the impact of COVID-19 on trade by developed and developing countries, it was found that trade under RTAs has been more resilient, by two percentage points for developing countries and by three percentage points for developed countries. However, these effects were only due to lower declines for trade under deep RTAs, with trade under shallow RTAs performing slightly worse than trade under no RTA, at least on average (Nicita and Saygili, 2021).

UNCTAD attributed this greater trade resilience under RTAs to the fact that said trade often benefits from better trade conditions and lower trade costs relative to trade outside RTAs (such as lower tariffs or better cooperation on trade regulatory frameworks and on investment regimes). As such, suppliers benefiting from the lower transaction costs could be relatively more insulated from a fall in global demand, as was the case during COVID-19. Stricter contract enforcement under RTAs may also make the forfeiting of contracts more costly, thus ensuring that trade within these agreements are more

robust. Moreover, RTAs often entail the presence of production networks between domestic and foreign firms, which result in lower bilateral trade volatility. Also, the high cost of establishing the relevant supplier networks that underpin value chains provide firms with an incentive to maintain and adjust their trading relationships with overseas suppliers even during difficult times. The greater trade resilience provided by trade agreements can thus help bolster the resilience of the supply chains that form within these trading relationships (Nicita and Saygili, 2021, WTO, 2021).



Ultimately, the key benefit of an openness to trade and trade agreements is the diversification of suppliers. As argued by Ciuriak et al., (2020), the robustness of supply chains is ultimately not guaranteed by policies of reshoring or nearshoring but through the 'redundancy of sources of supply as a diversification strategy'. Put another way, trade agreements facilitate and lower the cost of access to multiple sources for critical components. Participant feedback from IDEAS' roundtable discussion on supply chain resilience indicates that multinational companies are trying harder to reduce risks from single-sourcing since the pandemic. Additionally, it was suggested that deeper and more diverse trade relationships through joining multilateral agreements such as CPTPP and RCEP could facilitate efforts at diversification (IDEAS Roundtable, 2024). Given this, multi-faceted trade agreements like the CPTPP can play a key role in helping countries diversify access to critical supplies, supporting long-term economic resilience while reducing volatility (WTO, 2021).

The COVID-19 pandemic would reveal that global trade interdependence and open markets do indeed bring inherent vulnerabilities and exposure to hazards for countries, namely by facilitating the transmission of risks to all regions connected to the supply chain (in this case the COVID-19 virus itself). And yet, at the height of the pandemic, global economic integration ultimately proved much more resilient and flexible than given credit for, while also later helping accelerate countries' recovery from the pandemic-induced downturn (WTO, 2021).

Moving forward, stakeholders in global supply chains must prepare for future disruptions, be it extreme weather events brought about by climate change, another potential pandemic, increasing instances of cyber-attacks and data thefts, and geopolitical tensions and conflicts. While there is a temptation to resort to adopting policies of nearshoring and onshoring in response to these challenges, it is pertinent to understand that such strategies bring their own limitations. Rather, also ensuring a commitment towards trade openness can help ensure the long-term resilience of supply chains. For particularly vulnerable and not easily replicable supply chains such as those for semiconductors, this will be especially applicable. While countries concerned about their future access to chips should seek to establish a 'minimum viable capacity' in chip fabrication, they should also seek to couple this with a commitment towards trade openness, in particular trade diversification.

Box 1: Insight on Malaysia, Taiwan and semiconductor supply chain resilience

Experts have noted that the semiconductor sector provides a major avenue for furthering the Taiwanese-Malaysia economic relationship, which is already quite substantial. In 2023, Taiwan stood as Malaysia's fifth-largest trading partner, while Malaysia stood as Taiwan's eighth-largest. Trade in 2023 reached a historical high of US$36.6 billion (RM172.4 billion), a 36% increase compared with 2022. Taiwan represented Malaysia's eighth largest investor in 2022, investing a total of US$14 billion by year-end (MIDA, 2023).

Malaysia has already been identified as holding substantial potential when it comes to Taiwanese semiconductor investments, with more than 50 Taiwanese multinational semiconductor enterprises currently operating in the economy. The Malaysian government has identified the semiconductor sector as a key part of its industrial plan, with ambitions to move the industry further up the value chain towards more front-end activities such as wafer fabrication and IC design (Ruehl, 2024).

Up to now, most semiconductor-related operations in Malaysia have been in backend work, namely ATP. However, more recently, the industry has shifted towards the higher value and technically complex work of packaging smaller chips — chiplets — more tightly together to increase computing power. Recently, authorities have approved a US$7 billion facility at the Kulim Industrial Park in Kedah owned by Germany's Infineon. The site is expected to become the world's largest production site for silicon carbide chips, a type of power semiconductor used in electric cars, wind turbines, and other heavy applications, as well as consumer electronics. Meanwhile, at Bayan Lepas in neighbouring Penang, Intel is constructing its first overseas facility for advanced 3D chip packaging (Ting-Fang and Li, 2023). Many of these firms have been expanding operations in Malaysia in response to the ongoing-Sino-US chip war (Ruehl, 2024).

Analysts argue that Malaysia likewise provides a welcome production site for Taiwanese chipmaking firms looking to diversify their operations away from China. As noted in an op-ed for The Edge published in December 2022 by Lee Chee Leong and Lin Kai Min, the future trend of Taiwanese investments 'will be based on a two-pronged approach that serves to capture both China and the global markets separately. By diversifying their know-how, capital, and technologies into Southeast Asian countries, Taiwanese investors are circumventing the supply chain disruptions emanating from acute geopolitical rivalry and the fluctuating situations on China's domestic front (Lee and Lin, 2022). Given Malaysia's relative political stability, lack of risks of major natural disasters such as earthquakes and typhoons, convenient geographical location, and English-language skills, experts have argued that Malaysia provides an ideal investment destination for Taiwanese firms.

When looking specifically to Malaysia, Taiwan's accession to the CPTPP could increase Malaysia's GDP due to an increase in trade between the two economies. According to IDEAS (2020), Taiwan's accession into the CPTPP could cause GDP to increase by US$ 517 million. Taiwan's accession would also expand the labour market and produce an additional 20,000 jobs in Malaysia. Given that over 75% of Taiwan's exports to Malaysia are semi-finished goods such as semiconductor parts, the elimination of tariffs on imports could attract more investment into Malaysia on top of the already rising interest due to geopolitical factors. An increase of semiconductor investments into Malaysia can boost Malaysia's position in the semiconductor supply chain. Furthermore, given that

Malaysia is equipped with the back-end technology of the semiconductor supply chain, it is possible that when paired with Taiwan's front-end expertise significant opportunities can be manifested for Malaysia that Malaysia is equipped with the back-end technology of the semiconductor supply chain, it is possible that when paired with Taiwan's front-end expertise significant opportunities can be manifested for Malaysia in tandem with Taiwan's potential accession to the CPTPP and the move to diversify supplier locations for resilience.

6.2 Taiwan's bid for the CPTPP and supply chain resilience

The Comprehensive & Progressive Trans-Pacific Partnership (CPTPP) is a free trade agreement (FTA) between eleven Asia Pacific economies: Australia, Brunei, Canada, Chile, Japan, Malaysia, Mexico, New Zealand, Peru, Singapore, and Vietnam signed on 8 March 2018. The CPTPP, which covers about 14 percent of global GDP, is the third largest free trade area in the world after the North American Free Trade Agreement (NAFTA) and European Single Market. On the 22nd of September 2021, Taiwan formally sent in a request to join the CPTPP. However, Taiwan has not yet been ratified into the agreement.

Despite this, Taiwan has well established trade relationships with some members of the CPTPP. In 2017, one-fourth of Taiwan's trade was with CPTPP Members. Among these members, Japan, Singapore, and Malaysia ranked among Taiwan's top 10 trading partners. Moreover, around 30.4% of Taiwan's total FDI came from CPTPP members, while over half (54%) of its outbound investments were likewise directed to them. This data underscores Taiwan's existing economic integration with CPTPP member countries, as evidenced by the substantial imports (Yun-Chieh, 2022).

There are a few gains that could be present if Taiwan's request to become a member of the CPTPP is fulfilled. In general, a study found that some of Taiwan's trading partners already enjoy low tariff rates due to the most favoured nation (MFN) treatment. For example, Japan, who imports 40% of integrated circuits from Taiwan, would not enjoy any more tariff reductions if Taiwan joined the CPTPP because they already enjoy zero tariff rates under Most Favoured Nation (MFN) treatment (Wang, 2022).

Taiwan's potential accession into the CPTPP can benefit other sectors with globalised supply chains. Malaysia's service sectors are expected to experience significant growth, while the light and heavy manufacturing sectors are projected to expand considerably due to increased industrial collaboration between Malaysia and Taiwan (IDEAS, 2020). As trade costs decrease, collaboration between the two economies can deepen, resulting in overall output growth and enhanced competitiveness across various sectors. The semiconductor supply chain however, is of key focus given the initiatives by Malaysia in increasing the value of the supply chain, coupled with the significance of the semiconductor industry to Taiwan and the push for geographical diversification in light of geopolitical tensions.

Apart from that, diversification of trading partners also emerges as a compelling driver for Taiwan's CPTPP membership. The disruptive impact of unforeseen measures, such as China's abrupt import bans on Taiwanese agricultural products in 2021, underscores the vulnerabilities associated with overdependence on a single trade partner. By entering CPTPP, Taiwan could mitigate such risks by reducing trade barriers

among member countries, thereby fostering a more resilient economic environment. The prospect of enhancing trade relationships and reducing potential losses in the face of unilateral restrictions from significant partners underscores the strategic imperative of Taiwan's CPTPP participation.

6.3 In lieu of the CPTPP, focus on bilateral or multilateral cooperation

While membership of the CPTPP brings myriad benefits for Taiwan, it is also unlikely in the near-to-medium term given geopolitical reasons. It should be noted that China submitted its application one week before Taiwan did, effectively forcing member countries to consider both applications alongside the fraught relationship of Taiwan and China. China has voiced outright opposition towards Taiwan's bid (China vows to keep Taiwan out, 2021). Should China successfully accede to the CPTPP, it would be able to use the requirement for consensus to accept new members to permanently block Taiwan.

Both economies offer important considerations in deepening trade integration towards supply chain resilience – China, for its general position at the start of many global supply chains and key trading partner for many of the CPTPP members, and Taiwan for its position in highly valued, critical semiconductors despite its smaller trading position. With many ASEAN economies seeking to move their manufacturing into more high-end operations in green tech and the digital economy, Taiwanese-manufactured chips will no doubt play a major role and should be leveraged upon. Establishing chip production in Southeast Asia-based facilities would facilitate supply chain resilience by spreading out chip fabrication across a wider geographical footprint rather than being concentrated in Taiwan alone. In the event of an extreme supply chain disruption such as a Chinese blockade of Taiwan, Taiwanese chips would still be able to be physically delivered to end-consumers based in Southeast Asia, be it Thai automakers or consumer electronics manufacturers in Malaysia and Vietnam. Supply chains would still be able to operate, thereby reducing the number of supply chain chokepoints and promoting greater long-term resilience (Chin, 2023).

However, Taiwan faces significant challenges in its accession bid. China's diplomatic pressure has often made it difficult for Taiwan to gain government-to-government consultations with countries that tacitly comply with the "one China" policy. Although China is not a CPTPP member and arguably may not meet the necessary benchmarks to join, its public opposition would cause countries to shy away from engaging in the necessary preliminary consultations for gaining consensus. (Stephens & Sargent, 2024). The application should be considered fairly given that Article 5 of the CPTPP agreement (the accession article) clearly permits "any State or separate customs territory" to accede. This seems to have been worded specifically for Taiwan's complicated sovereign status vis-a-vis China, as the former's WTO membership is based on being a separate customs territory (Stephens & Kucharski, 2022).

China's own accession seems unlikely given several challenges, such as discrepancies between Chinese policy and CPTPP standards in the areas of labour, the environment, state-owned enterprises, and digital commerce (Wiendieck and Stark, 2023). The US' strong stance towards China also should be taken into consideration; if China as an external party can pressure member countries through its economic relationships not to entertain Taiwan's accession overtures, the US can do the same vis-a-vis China's overtures. Yet it may be difficult for smaller CPTPP members to ignore China's economic heft.

A likely outcome is that both countries cannot obtain consensus to accede to the CPTPP due to the geopolitical tensions. This is not an optimal outcome given the emerging evidence that deep trade

integration is important for supply chain resilience. If Taiwan accedes to the CPTPP, deeper integration and opportunities to secure investments and trade in the semiconductor supply chain in segments important to the US market would be a key advantage. The consensus rule is double-edged: it may also provide safety in numbers, where China could not itself afford to punish the combined strength of CPTPP member economies for the long term if all countries end up agreeing to Taiwan's accession. As a major trading power, China would have other means to build up integration and ensure supply chain resilience between the other countries with sufficient bargaining power on its own, without the CPTPP. However, overall the incentive for member countries to consider Taiwan would have been greatly strengthened had the US been part of the CPTPP, or were it to indicate future interest in the CPTPP, which also appears unlikely.

Nevertheless, even without membership of the CPTPP, an IDEAS roundtable discussion suggested that Taiwan can still expand bilateral or multilateral cooperation with individual ASEAN Member States (IDEAS roundtable, 2024). The potential for further economic cooperation between Taiwan and Southeast Asia is considerable given the converging economic specialities of both parties - Taiwan as a major producer of semiconductors, and many Southeast Asian countries as manufacturers of electronics goods which require chips. The roundtable participants also highlighted that increased cooperation between Malaysia and Taiwan can help reduce costs and improve the movement of goods between the two countries. Furthermore, the importance of having a healthy environment of suppliers from multiple countries and sources was said to be vital when it comes to increasing semiconductor supply chain resilience (IDEAS roundtable, 2024).

7. Conclusion

In the intricate web of global commerce, the interplay between geopolitics and supply chain resilience has become a focal point of inquiry. Supply chain disruption should be considered in terms of disruption to supply and demand due to economic or natural disasters, as well as geopolitical challenges, which are separate issues from the supply chain security issues envisioned in US foreign policy. Hence, the appropriate response to disruption is not ensuring technological and supplier advantage, but about deepening trade integration and diversifying trusted supplier networks. Governments, particularly those of smaller trading nations, need to find ways to increase their participation in regional trade integration despite geopolitical tensions increasingly demanding alignment towards specific economic superpowers. Through the lens of the semiconductor supply chain, this paper has argued that diversified and secure supply chains based on deeper regional integration offer an important pathway towards maintaining predictable, rules-based trading on a common framework.

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Appendix: The Semiconductor Supply Chain - a detailed explanation

From a bird's eye perspective, the average supply chain for semiconductors can be broken down into research and development, design, fabrication, and assembly, testing and packaging. Firms that only design chips are known as fabless firms and largely concentrated in the US, while firms that only fabricate chips are known as pure-play foundries, such as TSMC in Taiwan. There are few vertically integrated firms that retain both capabilities, the main exception being Intel (Varas et al, 2023).

Table 2: Semiconductor supply chain

Stage	Description	Estimated Value Add
Research and development	The research and development stage leads all other sectors of the supply chain. It includes pre-competitive, exploratory research on foundational technologies and competitive research directly advancing the leading edge of semiconductor technology.	15% to 20% (of total industry R&D)table
Design	The actual manufacturing process begins at the design stage, where the blueprint of the chip is sketched out to optimise for certain parameters (i.e. cost, power consumption, capacity etc) based on the needs of the chip in question. While chip designs were once drawn on paper, highly specialised software called electronic design automation (EDA) is often used now given the complexity of modern chips. Certain portions of a chip's design are built using reusable pieces of intellectual property (IP), called core IP, that firms licence from the IP owners. The United States leads in chip design, with US firms controlling more than half of the 2019 market share in core IP. US companies are also the exclusive providers of EDA with the requisite capabilities required to design cutting-edge chips.	50%
Fabrication	Fabrication refers to turning the designs into actual chips. It requires several inputs, including raw and manufactured materials (silicon wafers, photomasks, photoresists, and chemicals) as well as s**emiconductor manufacturing equipment (SME)**. SME can include wafer fabrication on the front end as well as semiconductor assembly, test, and packaging equipment for back-end fabrication. Much of chip wafer fabrication currently takes place in the Indo-Pacific. In 2022, South Korea ranked first in wafer production capacity at 22%, while Taiwan ranked second at 21%. China ranked third at 18% of the world's capacity (including domestic and foreign-invested companies in China), followed by Japan at 15% and the United States at 10%. When it comes to global SME market share, US and Japanese firms dominate. US firms alone occupy more than 40% of global SME market share, followed by Japanese companies at 29%. Together with the Netherlands, the three countries dominate the supply of SME.	24%

Stage	Description	Estimated Value Add
Assembly, testing, and packaging	Assembly, testing, and packaging (ATP) refers to the back-end of the semiconductor supply chain. It is generally more labour intensive compared to any other part of the supply chain. The vast majority of ATP facilities exist in the Indo-Pacific, with a heavy concentration of OSAT providers in Taiwan, China, and Southeast Asia (particularly in Singapore, Malaysia, Vietnam, and the Philippines).	6%

Source: Authors' notes compiled from various sources, including Thadani and Allen, 2023; Khan, Mann, and Peterson, 2021; Varas et. al, 2021)

Notes

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