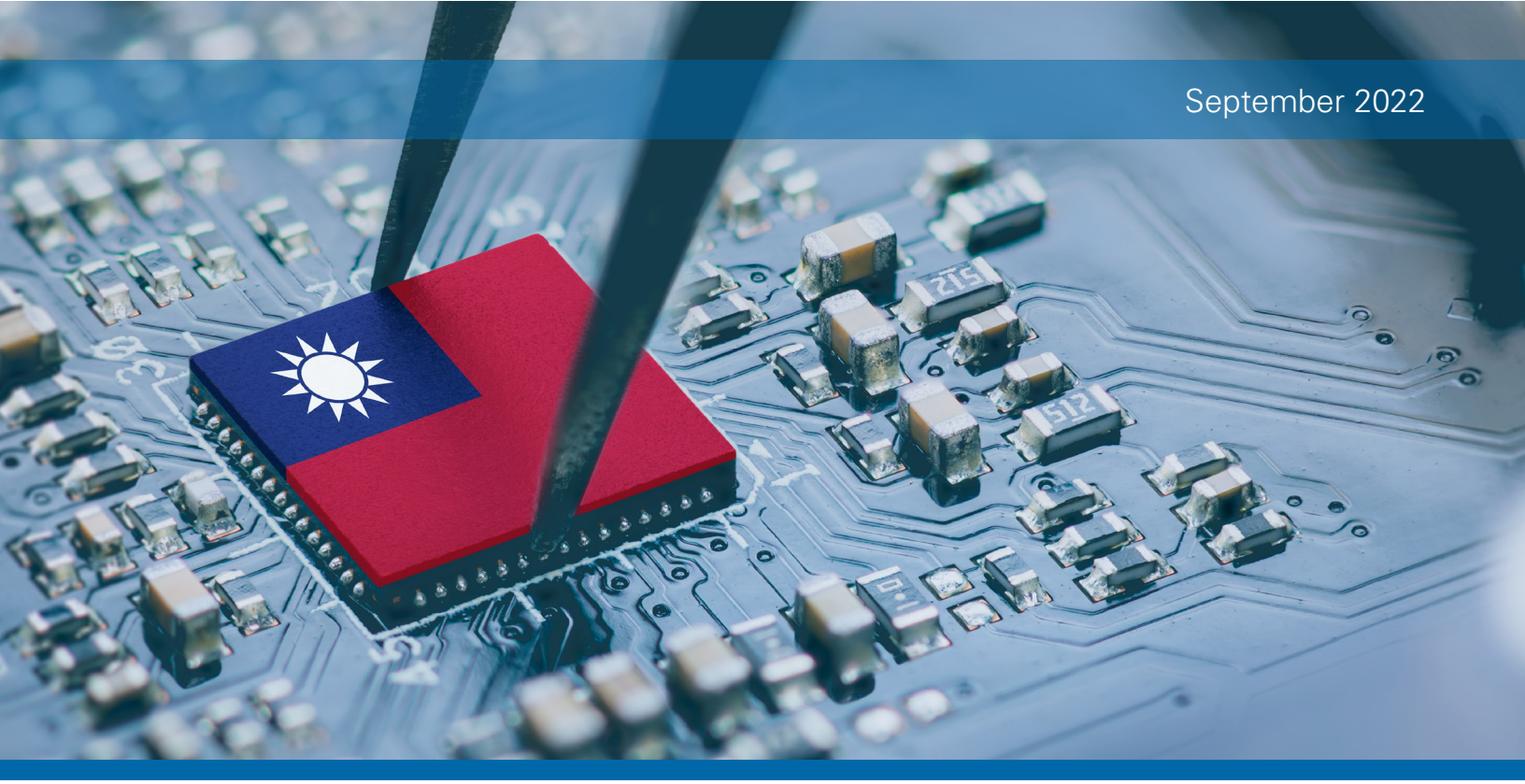

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Taiwan as a Partner in the U.S. Semiconductor Supply Chain

By Kristy Tsun Tzu Hsu

Semiconductors are critical for industries in the 21st century. They also play a key role in defining economic competitiveness and national security, the worldwide shortages of semiconductor chips in the past years resulting from supply chains disruption and the COVID pandemic demonstrates the challenge to accessing semiconductors in global markets. As a result, the United States, Europe, and Japan have made securing semiconductor supplies as part of their national security strategy.

The United States has long felt the side effects of offshoring critical industries to Asia. Since President Barack Obama's Reindustrialization Program, both President Donald Trump and President Joe Biden continued to address the supply chains issues while trying to promote manufacturing industries back to the United States

On February 24, 2021, President Biden signed an Executive Order (E.O. 14017) for a comprehensive approach to assessing vulnerabilities in, and strengthening the resilience of, critical supply chains. The Biden administration also took steps to address supply chain vulnerabilities.[1] While the structural weaknesses in supply chains threatens the U.S. economic and national security, the United States is nonetheless well-positioned to maintain and strengthen its innovative leadership and rebuild productive capacity in key sectors and value-chains.

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Meanwhile, President Biden also proposed the Indo Pacific Economic Framework, or IPEF, as the centerpiece of his economic strategy toward the critical region. The IPEF consists of four "pillars" of work: (1) fair and resilient trade; (2) supply chain resilience; (3) infrastructure, clean energy, and decarbonization; and (4) tax and anti-corruption. The issue of supply chain resilience, both at domestic and global level, will be reviewed from the Indo Pacific regional strategic perspective and concrete initiatives and programs are being discussed.

Taiwan too can play a key role in the U.S. strategy to reassessing its supply chains. U.S. initiatives, including IPEEF, the CHIPs and Science Act and other new initiatives have attracted new investments to reshore industries to the United States, greater efforts and financial resources are needed to prevent the current phenomena from becoming short lived. Yet there is a gap between the U.S. strategy and the business perspectives, with scope for U.S. policy makers to improve their policy designs to make the semiconductor supply chains more resilient, stable, and most of all, commercially viable, for U.S. national interests.

Geographic Specialization and Regionalized Semiconductor Supply Chains Structure

The semiconductor industry is technology- and capital- intensive. After more than three decades of collaboration among countries with their comparative advantages, the global structure of semiconductor industry today reflects the results of specialization in various activities in the supply chains. The high degree of specialization has also led to geographical concentration, making it difficult for newcomers.

Over 75 percent of semiconductors in the world are manufactured, or fabricated, in East Asia. The United States and Europe account for only 13 percent and 8 percent respectively.[2] Guaranteed access to chips, especially advanced semiconductor chips is becoming a key policy goal when assessing national security and economic competitiveness to counteract sudden disruptions to supplies.

In the past decades, typhoon, earthquakes, infrastructure shutdown due to power shortage or fires at the manufacturing sites, were the major causes for supply disruption.[3] While in recent years, escalating geopolitical tensions and governments' counter-measures, including potential military conflicts, trade sanctions and stringent export control mechanisms, may threaten supply chains more than traditional risks.[4]

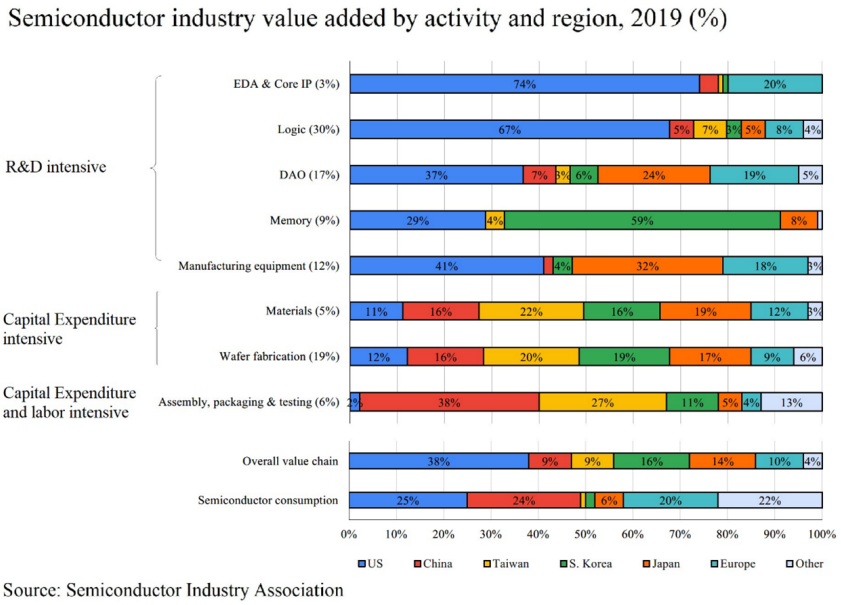
Yet an over simplified approach to examine who needs what in the complicated semiconductor world overlooks business reality of the trillions dollar supply chains and the deep interdependence between players in the eco-system. There are different layers (sub-sectors) of the semiconductor supply chains, including IC design, materials, equipment and tools, and manufacturing, the latter includes wafer fabrication, assembly, packaging and testing (APT).[5] The United States, Europe and Japan dominate IC design, materials, equipment and tools, while East Asia, mainly Taiwan, South Korea and China, take the lion's share of manufacturing. In the interdependence relations, IC design houses and Integrated Device Manufacturers (IDMs)[6] in the United States and Europe contract manufacturing to specialized manufacturers, including fabrications (Fabs), Outsourced Assembly and Test (OSAT), in East Asia for mass production. On the other hand, East Asia depends on R&D, IP, equipment and tools

provided by the United States and Europe for their manufacturing activities, they also need Japan and a handful of other countries to provide critical materials such as photoresist, specialty chemicals and the materials needed for manufacturing. For example, in the aftermath of Russian invasion in Ukraine in February 2022, possible supply disruption of Neon from Ukraine threatens the semiconductor industry.[7]

Geographical specialization is key to technological advancement and cost efficiency which have enabled strong growth of the semiconductor industry for two decades. The clustering effects also led to over concentration of the supply chains, in particular the manufacturing activities, in only a few countries. According to Semiconductor Industry Association (SIA), in 2019, not only more than 75 percent of chips were manufactured in East Asia, more than 82 percent of them were assembled, packaged and tested in the same region, too. Around three quarters of semiconductor manufacturing capacity is located in China, Taiwan, South Korea, and some in Singapore and Malaysia. However, what was regarded as the most cost effective business models was re-assessed in the aftermath of the semiconductor shortages since 2020. The overdependence on East Asia becomes a dangerous sign to national security as geopolitical tension in East Asia continues to escalate.

Furthermore, according to SIA, for all of the world's manufacturing capacity of chips in nodes below 10 nanometers (10 nm), currently the most advanced technology, 92 percent is located in Taiwan, while 2 percent is located South Korea. Although only 2 percent of the global capacity is on nodes below

Figure 1: Sub-sectors of semiconductor industry by region (2019



Source: Semiconductor Industry Association

10 nm today, these advanced chips are widely used and will have the fastest growth. It will impact almost all strategic technology industries if supply disruption happens.

Among the different layers or sub-sectors of manufacturing of semiconductor, the wafer fabrication (front-end manufacturing) is the most technology- and capital- intensive, making it very difficult, and expensive, to have new competitors in the short term. It also requires strong supports from the public and private sector to share capital expenditure and R&D costs. And while the stage of APT (back-end manufacturing) requires much less technology and capital intensity than the wafer fabrication, it nevertheless is still highly specialized. As fabrication technology improves, advanced packaging and testing also becomes more technology-intensive.

Another feature is labor intensity required at the production sites. Taiwanese manufacturers had been relocating APT capacities to China since the late 1990s to take advantage of its abundant labor force and low labor cost. Since then, China has emerged as the world leader with its share in value added in global APT supply rising to 38 percent, while Taiwan is now ranked second with a share of 33 percent. Taiwan's focus is more in advanced packaging.[8] Some developing countries are also participating in the sub-sector, such as Malaysia, Philippines, Thailand and Vietnam in Southeast Asia. Under the current trends of diversification of semiconductor supply chains, these countries are competitive in their young labor force and comparatively lower labour cost than China. When considering geopolitical tensions in the region, these countries also have lower geopolitical risks.

The manufacturing activities, from fabrication to APT, are the United States' greatest weaknesses in the whole semiconductor supply chains. In 2019, U.S. share of global fabrication, and assembly, packaging and testing was 12 percent and 2 percent respectively. SIA estimates that the country will need to invest an extra total of $350 to $420 billion in manufacturing capacity in order to establish the complete semiconductor supply chains in the United States and may be able to reach the goal of self-sufficiency.

State of Play of in Taiwan's Semiconductor Industry

Taiwan started developing its chip sector in late 1970s, when the government tried to promote a transformation of vertical integration of its consumer electronics manufacturing activities so semiconductors could be domestically sourced. The goal was to localize manufacturing of semiconductors and the equipment and devices needed in order to support its consumer electronics industry, with the semiconductor industry in Taiwan becoming a catalyzer to boost electronics industries, instrumental to Taiwan's leadership positions in Information, Communication and Technology (ICT) and electronics industries. Concentrating on contract manufacturing, or Original Equipment Manufacturing (OEM) and Original Design Manufacturing (ODM) for international brand clients, Taiwan has been the world's largest manufacturer of smartphones, laptop computers, printed circuit boards, data center servers, and dozens of other products.

The similar ODM mode was applied when Taiwan started its semiconductor industry. Taiwan Semiconductor Manufacturing Company Limited (TSMC), the most important and largest fabrication in Taiwan and in the world, and other fabrications in Taiwan, adopted the contract

Table 1: Major Sub-sectors/Layers of Semiconductor Industry in Taiwan (2021e)

Sub-Sectors/ Layers	Number of Companies	Revenues (2021 Est) NT$100 Million*	Share in Global Market	Global Ranking	Number of Employees	Number of R&D Staff	Market Leaders
Total	285	38,050	–	2	256,526	52,740	–
KC Design	235	11,133	20.8	2	49,533	36,010	MeidaTek, Novatek, Realtek
Wafer Manufacturing (Fabrication)	13	20,898	75.2	1	109,176	9,707	TSMC, UMC, Nanya, Winbound
Assembly, Packaging and Testing (APT)	37	6,019	58.0	1	132,893	5,000	ASE,PTI, KYEC

* Note: The average exchange rate of US dollars to Taiwan dollars in 2021 is around $ 1= 29 New Taiwan dollars.

Source: 2021 Taiwan Semiconductor Yearbook, July 2021, IEK, ITRI, Taiwan

manufacturing model to provide manufacturing services ("foundry") for the United States and Japanese semiconductor companies without semiconductor fabrication factories (fabless). Contract manufacturing allowed the fabless companies concentrate on research and design. Gradually, Integrated Device Manufacturers (IDMs)[9] including Intel and Micron in the United States, Japan and Europe also began to rely on Taiwan contract manufacturers for a portion of their manufacturing needs. This business model has become the backbone of semiconductor manufacturing in Taiwan. It has also helped develop IC design and back-end (or downstream) manufacturing of APT in Taiwan.

Given its small domestic market, the industry has targeted international markets since the beginning. In 1990s and 2000s, Japan, the United States and Europe together represented around 40 percent of the export market, while since 2000s, exports to China and Southeast Asia quickly picked up, indicating a shift of the semiconductor supply chains moving towards Asia.

According to the Industrial Technology Research Institute (ITRI) of Taiwan, as of 2021, the United States was Taiwan's largest client, accounting for 40 percent of total revenue, followed by China, accounting for 28 percent. By sub-sectors, China accounted for more than 50 percent of Taiwan's IC design revenue, while the United States was

the largest client for both wafer fabrication and APT. The share was 54 percent and 50 percent respectively.[10] These figures suggest that Taiwan has developed separate and different business relations with the United States and China, its two largest clients. Taiwan serves for IC design firms and IDMs in the United States by providing manufacturing capacity, while provides IC design and contract manufacturing to Chinese clients for matured or commodity chips and commercial end-use applications. These clearly defined separation systems allow TSMC and other leading companies in the semiconductor supply chains continue to be their U.S. clients' trusted partners and suppliers.

The key to the success of Taiwan's semiconductor industry is the ability to manufacture efficiently and cost-effectively with the highest quality/yields in the world. According to TSMC, Taiwan has developed a dynamic ecosystem that provides infrastructure, know-how, human talents, and close relations with both Western and Asian clients. Most of all, Taiwan is also home to the ICT and electronics manufacturing activities, where products embedded with the semiconductors are assembled and shipped to international market. This unique model of vertical integration of semiconductors and applied industries is the back bone to Taiwan's dominant position in both the semiconductor and electronics supply chains.

East Asia is currently the largest integrated manufacturing hub for electronic devices, together manufacturing more than 60 percent of the global supply of consumer electronics, smartphones, and PCs. The clustering effects increase benefits of geographical proximity of the hub to Taiwan –as well as within Taiwan- in shipping components to be assembled into devices. However, to mitigate risks of geographical concentration, the ICT and electronics supply chains are also facing pressing needs for diversification.

The Taiwanese government too has key role in guiding and managing the development of Taiwan's core technology in the semiconductor industry in the past 2 decades. As a result, despite close business ties across the Taiwan Strait, Taiwan's semiconductor industry continues to keep its manufacturing facilities and R&D functions at home. As of 2021, nearly 95 percent of Taiwan's manufacturing capacity is located in the island. Only 3.5 percent of capacity is placed in China and 1.7 percent in other regions. This is partly attributed by a very stringent outbound investment screening mechanism adopted for China. Currently only 200 mm (8 inch) and 300 mm (12 inch) wafer fabrications are allowed for investments in China, meaning all investments of advanced manufacturing in China are prohibited.[11] Furthermore, for national security and the need to maintain competitiveness, Taiwan recently passed amended National Security Law to create a new clause to regulate act of economic espionage, particular the adversary force in China, Hong Kong and Macao.

The United States Needs a Longer Term Supply Chains Strategy

To respond to U.S. government's call to increase self- sufficiency of strategic products and to benefit from a series of U.S. investment incentives, the semiconductor industry has recently announced approximate $80 billion new investments in the United States during 2021 through 2025, according to SIA. These investments will not only create tens of thousands of good paying jobs in the United States, but will also secure U.S. role in the global semiconductor supply chains.[12]

In 2021, the global semiconductor market reached $430 billion, and is estimated to increase to

$772.03 billion by 2030 at a compound annual growth rate (CAGR) of 6.6 percent from 2021 to 2030.[13]

Since Congress passed the Creating Helpful Incentives to Produce Semiconductors (CHIPS) for America Act in January 2021, foreign corporate interest to invest in chips has expanded as well. TSMC announced a $12 billion project, Samsung will invest $17 billion factory in Texas, and SK Group will develop a R&D center. In addition, ASML of the Netherlands will spend $200 million to expand its facility in Wilton, Connecticut. The project aims to support fabrication of advanced chips in the United States

U.S. companies too are also getting ready to reshore manufacturing. Intel plans to invest $20 billion facility in Ohio, Texas Instrument will spend $30 billion in Texas, Cree is planning a $1 billion expansion of its factory in North Carolina, and Micron plans to expand U.S. production too.[14]

Investing in new foundries is critical to enhance long-term resilience of the semiconductor supply chains in the United States However, shifting or relocating supply chains may reduce productivity and decrease profitability. It may also lead to overcapacity in chip making. So while new investments could reduce supply chain bottlenecks, the White House needs to develop a longer term supply chain strategy that is flexible and commercially viable.

In fact, Asia is increasingly worried of a possible slowdown in the semiconductor industry, including overinvestment in fabrication. A downturn is already being felt in Taiwan and South Korea, and if global demand continues to weaken, further worsened by growing inflation in almost all major economies, investors may reconsider and postpone their investment plans. This will post uncertainty to the development of supply chains in the United States

Meanwhile, state subsidies and other government initiatives have their limits. The CHIPS and Science Act establishes investments and incentives to support U.S. semiconductor manufacturing, research and development, and supply chain security. The Act will provide $52 billion to manufacturers in the semiconductor industry located in the United States and an income tax credit of 25 percent. It will also subsidize semiconductor equipment, materials or other manufacturing facility investment through 2026.

The SIA estimates that the $50 billion incentive program would enable the construction of around 19 fabrications in the United States, and that the cost for building an advanced fabrication in the United States ranges from $10 billion to $20 billion. Considering it would cost at least $10 billion to build the factory in Taiwan, the cost in the United States may even double or triple, taking into account the high inflation and difficulty to source necessary materials locally. Thus, the state subsidies under the CHIPS and Science Act may only partially cover the investors' capital expenditures. The U.S. government will need to consider any other subsequent funds to support continuous investments if the money runs out. The government will also need to address decades of underinvestment in the country's infrastructure, workforce, small businesses and rural economies.

Large companies such as TSMC may be able to self-fund fab construction through the equity and debt markets, but small business and startups will need financial support from the government and private sector.

Workforce development is another challenge. TSMC has expressed concerns about recruiting

talent including operators, technicians and engineers in the United States. It should be noted that the corporate culture of Taiwan and South Korea require full commitment and rigid discipline at the workplace. For instance, most Taiwan semiconductor companies very often arrange two shifts of workers a day to fully utilize their manufacturing capacities. Such practices at workplace is not usual in the United States.

At the same time, even in an industry that is automated over 99 percent, highly educated staff are needed to handle the complexity of advanced technology, and a large talent pool of different education levels. Yet the United States has had a talent shortfall partly because of decades-long under-investment in university programs.[15] The fight for talents will soon arise if the United States, Japan, South Korea, and Taiwan fail to well prepare themselves for developing a new generation of talents in technology industries.

The Science/Research Act will allocate around a total of US $250 billion in the R&D and talents development, which will provide a significant boost to US industry. U.S. educators will need to promote awareness and interests in the manufacturing activities given U.S. university graduates still tend to focus on the IC design and startups in the industry rather than working in factories. Failure to address the challenges of creating sufficient, skilled human talent in the United States will undermine the highly expected job-creation function of the semiconductor industry in the country.

A recent survey of the non-government semiconductor association SEMI of U.S. member companies indicates that more than 5 percent of engineering positions are presently unfilled. This suggests that that the U.S. higher education system currently does not supply enough fresh talent to the semiconductor industry. SEMI estimated that the U.S. microelectronics workforce development (WFD) needs will more than double as CHIPS Act programs create tens of thousands of new jobs.[16] The need for highly skilled engineers and technicians in the next few years will be a challenging issue for both the investors and the state governments hosting the investments.

Taiwan's Response to U.S. Supply Chains Resilience Initiatives

Taiwan is a leading investor in manufacturing industries in East Asia with footprints across China, Southeast and South Asia. Since U.S. - China trade frictions escalated in 2017, Taiwan has adopted strategies to mitigate increasing risks of its investments in China. Taipei has adopted a series of investment incentives to encourage reshoring back to Taiwan or diversification of investments away from China. Programs include the "Return to Taiwan" package[17] and the New Southbound Policy (NSP) for promoting closed economic ties with selected Southeast or South Asian countries.[18] Taiwanese companies have looked to relocate or expand facilities in neighboring Asian countries, most notably Vietnam and India. Some are also considering reshoring to the United States or nearshoring to Mexico and other Latin American countries. Taiwanese investments in Vietnam, India, the United States and Mexico have increased considerably over the past several years.

The 2020 New Southbound Policy has promoted further business ties between Taiwan and main Southeast Asian partners, including Vietnam, Thailand, Malaysia, Philippines, Indonesia and Myanmar, in the aftermath of U.S.-China trade conflicts and COIVD-19 pandemic. Vietnam,

Thailand, Indonesia, and Malaysia have become particularly attractive for consumer electronics supply chains. Vietnam, Taiwan's largest FDI destination in Southeast Asia, has benefitted from relocation of the Apple supply chains, thanks to increasing Taiwan contract manufacturers of Apple products investing in north Vietnam. According to the Taiwan Representative Office in Vietnam, accumulated FDI from Taiwan in Vietnam amounted to $80 billion to $100 billion, creating 1.5 million jobs in the emerging Asian factory.

Another reason for Taiwan's continuous investments in the region is the accelerating economic integration in the regional and with global markets, most notably the CPTPP. Integrated market opportunities and preferential treatments these mega FTAs provide keep attracting Taiwan investments.

Taiwan's investment in the United States showed strong growth momentum. In 2020, registered Taiwan capital outflows to the United States amounted to $4 billion, making the United States the second largest destination for Taiwan capital outflows, only next to China.[19] The changing pattern of investment decisions of Taiwan companies reflects a growing interest in relocating supply chains directly in the destination markets, bringing potential paradigm shift in Taiwan-U.S. economic relations.

U.S. technology companies are also expanding their operations in Taiwan since 2015. Google, Yahoo, Micron, Applied Materials, Microsoft, Facebook, and Apple have established data centers, R&D centers, and AI centers in Taiwan. Micron and Applied Materials also continue to expand manufacturing facilities in Taiwan.

Given US-Taiwan economic partnership being highlighted by both governments, there is ample potentials for the two sides to work together on semiconductor supply chains in the U.S. TSMC's $12 billion project in Arizona is one such case. In May 2020, TSMC announced its intention to build an advanced semiconductor fab in Arizona. The facility will utilize TSMC's 5 nm technology for semiconductor wafer fabrication, with a 20,000 semiconductor wafer per month capacity, and create over 1,600 high-tech professional jobs. Construction started in 2021 with production expected to begin in early 2024.

TSMC's total capital expenditure approximately reached $12 billion from 2021 to 2029. The reasons for the investment are to better support U.S. customers and partners and to attract global talents. TSMC also has a fab in Camas, Washington and design centers in both Austin, Texas and San Jose, California. The Arizona facility is TSMC's second manufacturing site in the United States[20]

What is no less noteworthy is the recent investment project of GlobalWafers to build a state-of-the-art 300-millimeter silicon wafer factory in Sherman, Texas.[21] GlobalWafers is Taiwan's largest and world's third-largest wafer manufacturer providing wafers as materials for fabrication. According to the company, the 3.2 million-square-foot factory will support around 1,500 jobs with production volumes reaching 1.2 million wafers per month, estimated to start in early 2025.

The new factory is the largest advanced silicon wafer manufacturing facility in the United States over two decades. According to GlobalWafers USA (GWA), the production will support advanced fabrications in the U.S. GWA's factory signals the beginning of 300-millimeter silicon wafer fabrication in the United States, filling another "gap" of U.S. efforts to develop a complete semiconductor eco-system in the country.

Meanwhile, MediaTek, the world's 2nd largest IC design company based in Taiwan, signed into an MOU with Purdue University in June 2022. The University's College of Engineering will open MediaTek's first semiconductor chip design center to research on next-generation computing and communications chip design. In May, the university also announced the launch of its Semiconductor Degrees Program, a comprehensive set of innovative, interdisciplinary degrees and credentials in semiconductors and microelectronics. MediaTek has been working with U.S. universities for more than a decade. The project will also include a new MediaTek design team right on campus.

These three projects reflect Taiwan's commitment to work together with the United States across the semiconductor supply chains. If these investments are implemented smoothly, they will bring a new era of Taiwan-U.S. strategic economic partnership stronger than ever for jointly tackling challenges in current global economic context.

It should be noted, though, that Taiwan's success in key manufacturing industries, including semiconductors, is the ability to create an ecosystem with integrated manufacturing activities from upstream (such as materials, equipment, R&D) to middle and downstream (such as components, assembly), making the most of the clustering effects. Therefore, TSMC's success in Arizona will lie in the clustering effects it can bring to support fabrication. One challenge is that TSMC needs strong supports of its key suppliers to provide on-site construction, logistics, components, materials and all critical services. However, as most of the key suppliers are small and medium sized companies in Taiwan, they are not eligible to state subsidies under the CHIPs Act or other related programs. Some of them are already having difficulties setting up U.S. subsidiaries or recruiting local skilled workers. Biden administration should come up with programs to assist these smaller key suppliers if the United States wishes to maximize the clustering effects of TSMC's project.[22]

The Limits of the State Subsidies

The U.S.-led IPEF trade framework highlights the need to establish a resilient supply chain that goes beyond relocation of supply chains and attracting investments to the United States, including having a skilled workforce, improved infrastructure, logistical efficiency, healthy business environment and support from both the public and private sectors.

Supply chain disruptions have been a major challenge to both Trump and Biden administrations. The current disruptions challenge initially referred to the disorders in global supply since President Trump first imposed 301 tariffs on Chinese imports in July 2020. The disruption was further broadened during the COVID-19 pandemic, and came to hit the U.S. economy most when the global shortage of chips started to affect global production and sales of automobiles and other sectors and stressed U.S. imports, exports, and the movement of goods nationwide.

To address the supply chains vulnerability issues, Biden administration had passed legislations include Defense Production Act, the U.S. Innovation and Competition Act (USICA) and the CHIPS for America Act. The Defense Production Act allows the U.S. Department of Defense use authorities to strengthen supply chains for key defense-related semiconductors, while the USICA mandates full funding to catalyze more private-sector investments and continued American technological leadership.

To address the semiconductor supply chains resilience, there are currently various mechanisms in Biden administration, such as the U.S.-EU Trade and Technology Council (TTC), the U.S.- Japan initiative, IPEF, and some other initiatives already proposed or in shaping.

The Trade and Technology Council was launched at the U.S.-EU Summit in June 2021. The United States and EU intend to enhance cooperation on measures to advance transparency and communication in the semiconductor supply chain and identify gaps, shared vulnerabilities, and opportunities to strengthen their domestic semiconductor R&D and manufacturing ecosystems to improve resilience in the supply chain. They also agreed to enhance cooperation on issues related to investment screening and export controls. [23]

Biden administration and Japanese government launched a U.S.-Japan Competitiveness and Resilience (CoRe) Partnership in April 2021. Both agreed to enhanced cooperation on semiconductor manufacturing capacity, diversification, next-generation semiconductor research and development, and responding to supply shortages. Further collaborations were announced after Prime Minister Kishida Fumio of Japan took office, which included joint action to develop, among others, 2 nm advanced chips under bilateral efforts.

Another new mechanism is the U.S. led CHIP 4, or Fab 4 initiative, which is proposed by the United States, reportedly as a working level platform for exchanging market information and handling operational issues. The CHIP 4 initiative will include the United States, Japan, South Korea and Taiwan. However, according to Korean media, South Korea expressed concerns that the group may develop into an anti-China mechanism, which may threaten Samsung's and SK's huge investments in China. The initiative also raises questions such as its overlapping purpose and functions, and how it may fit into the supply chains strategy. South Korea's concerns reflect its difficult situation, so are some other Asian countries, in not supporting economic decoupling and taking sides between the world's two largest economies.

Besides collaboration with Europe and Asia, President Biden also announced the launch of the Americas Partnership for Economic Prosperity in early June, a historic new agreement when Biden hosted the Summit of the Americas on June 8th, where he also prioritized collaboration with the Latin American and the Caribbean nations on making more resilient supply chains.[24]

The aforementioned supply chains mechanisms, large or small, has different membership but similar purpose. However, the fragmented and overlapping mechanisms and varying working agendas with different countries or partners make them confusing and may hinder the U.S.'s efforts to develop a holistic and cross-cutting strategy and develop concrete work programs.

For example, the EU dominates supply of semiconductor equipment and tools for manufacturing, but none of the existing semiconductor initiatives invite both EU and Asian partners. Moreover, though President Biden's Indo Pacific Strategy released in February include Latin America countries such as Mexico, Chile and Peru, but none of them were invited to the IPEF. Instead, President Biden launched the Americas Partnership for Economic Prosperity to address supply chains solely with the Latin American countries.

Last but not least, Taiwan was also not invited to the IPEF or other existing semiconductor supply chains initiatives, except for the CHIP 4. This further sends a confusing message to Taiwan

and the world.[25] Though Biden administration launched a bilateral initiative – the Taiwan-U.S. Initiative on 21st Century Trade - after IPEF was launched, Taiwan is still denied from access to information sharing with other stakeholders in the semiconductor supply chains and engagement with them. Keeping important players or potential new comers away from the semiconductor supply chains initiatives may hinder the efforts to integrate the whole supply chains and handle common concerns and interests, such as investment policy and international standard setting issues.

Risks of State Subsidy Competition

On August 9, President Biden signed into law the CHIPS and Science Act, which will provide $52 billion to catalyze investments in semiconductor industry in the United States The passage of the Act demonstrated bipartisan support for reengaging semiconductor supply chains in the United States to address chip shortage, create good-paying jobs and maintain leadership in technology. Among the $52 billion, $39 billion will be used to fund manufacturing facilities either by foreign or U.S. companies. The Biden administration expects the funding can attract leaders in the supply chains to set up new investment or expand existing ones in the country.

Because costs to manufacture advanced semiconductors are much greater in the United States, Europe and Japan than in Taiwan or other Southeast Asia, governments have to provide subsidies to attract leading companies to build manufacturing facilities in their countries. Huge state subsidies from wealthy countries have already triggered a race for subsidies and competing for potential investors. This may further contribute to inflation.

For example, the EU plays a key role in advanced IP design, key semiconductor equipment and tools and wafer raw materials, but it lacks semiconductor manufacturing, same as the United States, and has little capacity for APT. In December 2020, the EU released a Joint Declaration on Processors and Semiconductor Technologies with an aim to bolster Europe's electronics and embedded systems of value chains. The EU Commission President Ursula von der Leyen also introduced the European Chip Act, with a goal to double its share of global semiconductor production from currently around 9 percent to 20 percent by 2030, and to 25 percent beyond 2030. EU governments and the private sector will invest more than 43 billion euros to develop semiconductor supply chains. More than two-thirds of the budget will be in the form of state grants to encourage manufacturers to build new cutting-edge wafer factories or mega fabrications.

According to a chips survey in EU released in February 2022, chip demand is expected to double between 2022 and 2030, with significant growth in the future for leading-edge semiconductor technologies. It also found companies establishing new chip fabrication facilities consider finding qualified labour and compliance with government regulations key issues when they select manufacturing locations.

In Asia, Japan also announced in mid-2021 that it will provide $8 billion in state funds to supplement its semiconductor industry. In July 2022, Japanese Diet passed the legislation to provide subsidies to private sector investment in semiconductor industry. TSMC became the first foreign investor to be granted with $3.5 billion to subsidize its fabrication factory in Kumamoto which will produce 28 nm chips for its client Sony company. In May 2021, South Korea also announced a policy to support semiconductor industry with

$450 billion in tax credits through 2030 for private domestic companies to invest in R&D and manufacturing.

The United States, Europe, Japan and South Korea, and a number of other countries, all set up their government policy to establish self-sufficient semiconductor supply chains and are ready to provide generous state subsidies to attract investments. According to SEMI, there will be more than 30 wafer fabrications to be built worldwide between 2022 to 2024, which means an extra amount of more than 30 percent of manufacturing capacity will be added to global supply.

However, these programs and state subsidies may create risks of over-capacity, as increasing worries in the global market are already observed for potential market protectionism and geo economic-political conflicts that will add to business operation costs and create unexpected loss.

Very few U.S. chip manufacturing investments are in the assembly, packaging and testing sub-sector. Korea's NAND Flash SK Hynex is one of the few that recently announced its investment plan to build an advanced testing and packaging factory in the United States, scheduled to start building in early next year and start quantity production in 2025-2026. The investment projects, amounting to $22 billion, will include semiconductors, green energy and biotechnology, with around $15 billion in semiconductors. SK plans to apply for subsidy of the CHIPs Act, making it one of the few companies already announced to build testing and packaging capacities in the United States since the CHIPs Act was introduced.

The relatively less skill- and capital-intensive nature of packaging and testing was dominated by East Asia, accounting for more than 80 percent of global supply. China is building dozens of new factories for advanced packaging and testing in the aftermath of the COVID-19 pandemic. The United States needs to think hard how its strategy to encourage relocation of assembly, packaging and testing into the country.

Why packaging and testing industry is more difficult than fabrication to relocate in the United States? The key reason is labor costs and labor issues. For instance, Taiwan currently has 37 manufacturers in assembly, packaging and testing, altogether hiring more than 130,000 workers. Comparatively, wafer fabrication in Taiwan has three times of annual revenues than assembly, packaging and testing, but hire only around 100,000 workers (including engineers and operators). Taiwanese companies had since the 1990s outsourced most of manufacturing to China and other Southeast Asian countries, contributing to relocation of the semiconductor supply chains in these countries. As of today, Taiwan continues to dominate advanced packaging and testing, while has shifted most matured packaging and testing to China and Southeast Asia.

Most APT companies would not consider it commercially viable to move APT facilities in the United States due to difficulty to hire workers and stringent labour laws and practices. For example, the ASE Technology Holding Co (ASEH) in Taiwan, the world's largest packaging and testing company, employs around 80,000 workers in Taiwan, with around 5 percent foreign workers. Furthermore, workers in the packaging and testing factory take two shifts, sometimes three shifts, in the factory. This would be violating labour laws or regulations in many states in the U.S. It is very likely that in the next few years, after new fabrications begin operation in the U.S., companies would still need to outsource packaging and testing to East Asia, and ship the finished products back to the United

States or other destinations for further process. This may appear to hinder the supply chains resilience as a critical part of the manufacturing does not take place in the United States, but this may be a more commercially reasonable outcome.

Promoting International Collaboration

The IPEF and other initiatives highlight the importance to work with like-minded partners to improve the supply chains resilience. The U.S. strategy has prioritized transferring of supply chains back to the United States or closer to home, but when both are not commercially viable, working with like-minded partners through "friend-shoring" can ensure supply chains will be relocated to trusted and friendly countries. Under the concept of "friend-shoring", it is important to identify who are the friends and what kind of roles these friends could play. The often mentioned friends are Vietnam, Malaysia, India, Mexico, Cost Rica and several other Latin American countries. The United States can work with these countries to establish less technology intensive capacities, such as APT. However, to enable these potential new comers participate in the semiconductor industry, some of them are already building small capacity. The United States needs to provide capacity building and promote international collaboration with stakeholders in these countries.

Since the 1980s, Taiwanese companies have established comprehensive business networks and manufacturing facilities in Southeast and South Asia, ranking among the top foreign investors, especially in manufacturing sectors, including textile and garment, footwear, electronics and ICT products.[26] Taiwan companies, as contract manufacturers, U.S. clients or importers, and a Southeast Asian host country, have developed vital triangular cooperation. For example, U.S. clients invite contract manufacturers of Taiwan companies to establish facilities in a Southeast Asian country, Mexico or Honduras, place orders to them to contract manufacturing Polo shirts, Nike sneakers, or iPads for the U.S. market.

In the past decades, this triangular partnership has not only boosted U.S.-oriented supply chains in countries such as Vietnam and Mexico, but also has helped the United States to diversify import sources. For example, since the U.S.-China trade conflicts escalated in 2018, Taiwan electronics companies also significantly expanded manufacturing facilities in Vietnam and Mexico, exporting from these two countries assembled products to the U.S. market to avoid the 301 tariffs imposed on Chinese products and further geopolitical tensions. Taiwan-invested supply chains in Southeast Asia and Latin American countries can further contribute to the "friend-shoring" or relocation of semiconductor supply chains in these areas.[27]

A timely example is Apple requesting its key suppliers, mostly large Taiwanese electronics companies, to set up facilities in Vietnam and India to diversify Apple's import sourcing. Taiwanese companies have expanded footprints in Vietnam and India, bringing these two new comers into the Apple supply chains.[28] Taiwan is already among the largest foreign direct investors in Vietnam and Mexico. Total Taiwan FDI in Vietnam amounts to $50 billion, recent growth focusing in ICT and electronics industries by large Taiwan companies to serve their U.S. clients. Vietnam works closely with Taiwan investors in its strategic industrial plans. Taiwan investment in Mexico also significantly increased in ICT industry. Taiwan has fabrications in Singapore, has packaging and testing facilities in Malaysia and Philippines. The semiconductor industry can be another area for the United States, Taiwan, Vietnam, or Malaysia,

or Mexico trilateral collaboration. Taiwan can bring capacity building in collaboration with the United States to these countries, share experiences in developing semiconductor industry and help design training programs.

Conclusion and Policy Implications

Building manageable, resilient and self-sufficient semiconductor supply chains to reduce over dependence in East Asia is a priority for the United States IPEF and the CHIP 4 Alliance reflect U.S. strategy towards establishing resilient semiconductor supply chains on U.S. soil. The efforts have significantly progressed with the passage of the CHIP Act and announcement of major investments in the United States In particular, the announcement of TSMC to build a fabrication factory on 5 nm in Arizona marks the beginning of reshoring of the supply chains back to the United States

However, the Biden administration's strategy does not address key issues. The emergence of a subsidies race among industrialized countries to build their own supply chains, fragmented mechanisms to integrate stakeholders in the supply chains, difficulties of fabrications to recruit a skilled workforce, the lack of APT facilities in the United States are but a few of challenges that have been neglected by the White House to date. At the same time, there is declining global demand and risks of overcapacity in chip production.

Furthermore, Taiwan's potential role to address the looming supply chain challenges is underrated. Neither is Taiwan's participation in the supply chains could hugely contribute to the U.S. strategy as is expected. The risks of underestimating Taiwan's role is considerable, and there are looming risks to Washington's semiconductor supply chain resilience strategy as it currently stands.

First of all, the over politicization of supply chains issues may hinder construction and operations of the semiconductor supply chains. Certainly, Southeast Asia and other participating countries have concerns that IPEF may have become overly politicized.[29] Some countries also suggest that the IPEF and CHIP 4 initiative should be inclusive and welcome all players in the supply chains. Therefore, inviting Taiwan to join IPEF and other relevant initiatives and alliances can strengthen supply chains. The United States also needs to demonstrate its leadership to integrate Indo Pacific like-minded partners, including Taiwan and Southeast and South Asia, in its supply chains strategy. As the United States has explicitly demonstrated its commitments to security of Taiwan Strait, it should also publicly support Taiwan's economic security by incorporating Taiwan into its major multilateral economic and industrial strategy, including in the semiconductor industry.

Second, it is estimated that 42,000 new jobs will be directly created by CHIPS Act in the future. The United States should develop joint programs with Taiwan for training skilled workforce and talents. It is estimated that more than 5 percent of engineering positions are presently unfilled, and that the need for microelectronics workforce in the United States will double, mostly highly skilled engineer and technician roles, in the next few years. Taiwan has over three decades of experiences of cultivating human resources to meet the need of the semiconductor and electronics industries in Taiwan. The United States and Taiwan should develop joint programs to improve supply of university graduates from the U.S. higher education system. The programs

should also provide preparatory and on-site training to workforce in the semiconductor supply chains located in the United States[30]

Third, the semiconductor supply chains encompass IC design, materials, equipment and tools, fabrication, and APT. The United States is a leader in IC design and equipment and tools, but lags far behind Asian countries in fabrication and APT. The CHIPS Act helps attract investments of TSMC, Samsung, SK, Intel, and other major companies. However, when these fabrications begin operation, the fabricated chips will need to be shipped back to Asia for assembly, packaging and testing, due to little APT capacity and no advanced packaging and testing at all in the United States Taiwan is the world's largest player in APT, particular focusing advanced testing. The United States should work with Taiwan to encourage Taiwan investments of this sub-sector in the United States by providing assistance to address the need of intensive labor force, and access to financial and other supports in the United States The United States should also collaborate with TSMC to solve challenges facing its key suppliers in supporting TSMC operation in Arizona.

Fourth, the United States should work with Taiwan to provide capacity building to Southeast Asia and Latin America countries, including Vietnam, Malaysia, and Mexico. Taiwan has long developed electronics clusters in those countries. A trilateral collaboration has existed in these industries for decades, namely Taiwan contract manufacturers manufacture products in Southeast Asia or Mexico for exports to the U.S. market. The trilateral collaboration model can be duplicated or expanded in the semiconductor supply chains in Vietnam or Mexico through more policy dialogues among three parties, such as through "friend-shoring" initiatives to outsource APT activities in these countries.

Kristy Tsun Tzu Hsu is a Taiwan Scholar at the Woodrow Wilson Center. She is also the Director of the Taiwan ASEAN Studies Center (TASC) at Chung Hua Institution for Economic Research (CIER), Taiwan.

Endnotes

1. The Administration released findings from the comprehensive 100-day supply chain assessments for four critical products (semiconductor manufacturing and advanced packaging; large capacity batteries; critical minerals and materials; and pharmaceuticals and active pharmaceutical ingredients).
2. Boston Consulting Group, SIA. (2021), Strengthening the global semiconductor supply chain in an uncertain era. https://web-assets.bcg.com/9d/64/367c63094411b6e9e1407bec0dcc/bcgxsia-strengthening-the-global-semiconductor-value-chain-april-2021.pdf
3. For example, in 1999, a strong earthquake in the center of Taiwan caused a week long shutdown of the semiconductor companies in Hsinchu Science Park as a result of power outages. The memory-chip prices soon tripled which impacted the global market. Many large companies outsourced manufacturing to Taiwan suffered huge loss.
4. Before the U.S.- China rivalry, in 2019, Japan imposed export controls on semiconductor materials to South Korea, causing huge loss for South Korea. The sanctions on Russia after its invasion in Ukraine in February 2022 also threatens disruption of semiconductor materials. Apart from these, increasing tensions in the Taiwan Strait also raises global concerns on possible disrupted supply.
5. According to SEMI, the semiconductor industry or the supply chains includes integrated device manufacturers; semiconductor foundries (fabrications); fabless chip or IC design firms; assembly, testing, and packaging (ATP) service providers. Sometime it also includes wafer fabrication equipment and metrology tool vendors; semiconductor wafer and chemical suppliers; electronic design methods and automation software providers. In the broader microelectronics ecosystem, it further includes electronics systems companies, researchers, and educators.
6. According to definition of SIA, IDMs are vertically integrated across multiple parts of the value chain, performing design; fabrication; and assembly, packaging and test activities in house. Some IDMs have hybrid "fablite" models where they outsource some of their production and assembly.
7. Semiconductor production also depends to a substantial extent on neon supplied by Ukraine. Ukraine supplies more than 90 per cent of US semiconductor-grade neon, critical for lasers used in chipmaking. Yoon, J. (2022), "The Lex Newsletter: Bright prospects for neon price dim chip outlook" (Financial Times, 2 March 2022)
8. The figures are calculated by semiconductor industry value added by activity and region, 2019, SIA.
9. According to definition of SIA, IDMs are vertically integrated across multiple parts of the value chain, performing design; fabrication; and assembly, packaging and test activities in house. Some IDMs have hybrid "fablite" models where they outsource some of their production and assembly.
10. IEK, ITRI. (2022), 2021 Semiconductor Industry Yearbook of Taiwan.
11. Taiwan government lifted restrictions of 200 mm wafer fabrication in China in 2006, and in 2016 approved TSMC's investment of a 300 mm wafer fabrication in Nanjing, China.
12. FACT SHEET: Biden-Harris Administration Bringing Semiconductor Manufacturing Back to America | The White House, JANUARY 21, 2022
13. Semiconductor Market - Global Industry Analysis, Size, Share, Growth, Trends, Regional Outlook, and Forecast 2021 - 2030, Precedence Research, 2022. precedenceresearch.com/semiconductor-market
14. FACT SHEET: Biden-Harris Administration Bringing Semiconductor Manufacturing Back to America - The White House.
15. In the 1980s, the U.S. had more than 200 IDM (as distinguished from Fab-lite and fabless) semiconductor manufacturers, but many of them were sold, merged dissolved, or liquidated over the past decades. There were also nearly 180 U.S. universities and colleges which offered semiconductor programs.
16. Testimony of Dr. Tsu-Jae King Liu, Hearing on "Strengthening the U.S. Microelectronics Workforce," House Committee on Science, Space, and Technology, Subcommittee on Research and Technology, February 15, 2022. https://science. house.gov/hearings/strengthening-the-us-microelectronics-workforce

17. Taiwan Ministry of Economic Affairs (MOEA) adopted the "Tai-shang (臺商) Return to Taiwan" Program since 2018 by providing tax breaks, financial subsidies and assistance in locating lands and recruiting workforce in Taiwan. As of end of 2021, it was reported that around 1,100 companies were approved under the Program, together attracting $ 1.5 trillion NT dollars and creating 120,000 jobs.

18. President Tsai Ing Wen adopted the New Southbound Policy (NSP) in 2016 and further released the 'Invest Taiwan", or "Taiwan Business Returning Home", program in 2018, targeting Taiwancompanies in China to remove their operations back home. Details of the Invest Taiwan program can be found at: https:://investtaiwan.nat.gov.tw/showPage?lang=eng&search=serviceCenter_07. Also see Glaser, B. S., Kennedy, S., Mitchell, D., Funaiole, M. P., Center for Strategic and International Studies (Washington, D.C.). (2018). The new southbound policy: Deepening Taiwan's regional integration: a report of the China Power Project. https://southbound.csis.org/ (last visited April 4, 2022)

19. Some of the benchmark projects are Foxconn's investment in Wisconsin State in 2017 and TSMC's project in Arizona State.

20. In December 2021, TSMC announced a decision to establish a subsidiary in Kumamoto, Japan in joint venture with Japanese partners. The plan is to build a 12-inch wafer fabrication with production targeted to begin by the end of 2024.

21. GlobalWafers, based in Hsinchu Science and Industrial Park, Taiwan, specializes in 3" to 12" silicon wafer manufacturing. Its product applications have extended through power management, automotive, IT and MEMS.

22. TSMC has more than 3,000 suppliers from the world. It identifies key suppliers to provide direct on-site support. These suppliers are not eligible to subsidies from CHIPs Act, but may be eligible to tax credits from Federal or State government of Arizona.

23. FACT SHEET: U.S.-EU Establish Common Principles to Update the Rules for the 21st Century Economy at Inaugural Trade and Technology Council Meeting, SEPTEMBER 29, 2021https: //www.whitehouse.gov/briefing-room/statements-releases/2021/09/29/fact-sheet-u-s-eu-establish-common-principles-to-update-the-rules-for-the-21st-century-economy-at-inaugural-trade-and-technology-council-meeting/

24. FACT SHEET: President Biden Announces the Americas Partnership for Economic Prosperity JUNE 08, 2022, https: //www.whitehouse.gov/briefing-room/statements-releases/2022/06/08/fact-sheet-president-biden-announces-the-americas-partnership-for-economic-prosperity/

25. Goodman, Matthew., Reinsch, William. CSIS. (2022). Filling in the Indo-Pacific Economic Framework. https://www.csis.org/analysis/filling-indo-pacific-economic-framework?msclkid=c41570d4c62011ec9c4756938a5e21ce (last visited April 4, 2022)

26. Taiwan investments in Southeast Asia highly concentrate in manufacturing sectors, ranging from labour intensive industries, such as textile and apparel and footwear, to more technology-intensive industries, mainly Information and Communication Technology (ICT) and electronics industry.

27. Hsu, Kristy T.T. (2022). Taiwan Investment in Southeast Asia: The Choice of Taishang and Their Response in the Changing Asia. To be published in end of 2022.

28. Vietnam has become the fastest growing supplier of ICT and electronics products since 2018, owing to increasing investments from Taiwan into North Vietnam to avoid the 301 tariffs if they export products directly from China to the U.S. India has also benefitted from relocation of supply chains of electronics products to the country. Wistron, a Taiwanese company, was the first foreign manufacturer to assemble iPhone in India, followed by Foxconn and Pegatron, both Taiwanese companies. Taiwan's Pegatron follows Foxconn and Wistron to make iPhones in India, Taiwan News, July 17, 2020. https: //www.taiwannews.com.tw/en/news/3968775

29. Suzuki, Hiroyuki. (2021). Building Resilient Global Supply Chains in the Geopolitics of the Indo-Pacific Region. https://csis-website-prod.s3.amazonaws.com/s3fs-public/publication/210219_Suzuki_Global_Supply.pdf?DJzRt8ACjVJAKaikeMd8mToyxoByQ6B8 (last visited April 12, 2022)

30. SEMI, American Semiconductor Academy. (2022). Fuel American Innovation and Growth, A national Networks for Microelectronics Education and Workforce.