MP-IDSA Occasional Paper No. 61

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MANOHAR PARRIKAR INSTITUTE FOR
DEFENCE STUDIES AND ANALYSES
मनोहर पर्रिकर रक्षा अध्ययन एवं विश्लेषण संस्थान

ISBN: 978-81-953957-9-8

First Published: February 2023

Price: Rs. 200/-

Published by: Manohar Parrikar Institute for Defence Studies and Analyses
No.1, Development Enclave, Rao Tula Ram Marg,
Delhi Cantt., New Delhi - 110 010
Tel. (91-11) 2671-7983
Fax.(91-11) 2615 4191
Website: http://www.idsa.in

Cover &
Layout by: Geeta Kumari

Printed at: Pentagon Press LLP
206, Peacock Lane, Shahpur Jat
New Delhi-110049
Tel. (91-11) 26491568, 26490600
Fax: (91-11) 26490600
email: rajanaryaa@gmail.com
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website: http://www.pentagonpress.in

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Introduction

India's assumption of the G20 Presidency on 1 December 2022 could not come at a more opportune time. It confronts a world embroiled in numerous crises, including the ongoing conflict between Russia and Ukraine, intensifying US-China competition over technology, unstable supply chains, the Taiwan Strait crisis, rising inflation, and climate change. Economist Adam Tooze has referred to this confluence of events as a 'poly-crisis,' wherein the combined impact of multiple shocks is more overwhelming than the sum of their individual effects. As a result, the concept of national security is undergoing change. India intends to use its G20 Presidency to promote 'human-centric globalisation', and serve as a bridge between the North and South. In this context, the current crises imply a broadened notion of national security which is rooted in technology, self-reliance, and partnerships.

As a country with two nuclear-armed revisionist powers on its western and northern borders, India must also consider the military threat posed by both — sub-conventional in the former and technological in the latter case. Climate change, pandemics, domestic terrorism, cyber-attacks, and disinformation are among the many challenges India faces, and technology — particularly digital technology — plays a role in both exacerbating and addressing these threats. Semiconductors, the physical substrate undergirding these technologies, therefore, form a crucial part of India's national security as all aspects of India's security have a link to technology, and hence to semiconductors.

In this essay, the importance of semiconductors for India will be examined in the contexts of the US-China strategic competition; China's rapid modernisation of the People's Liberation Army (PLA); attempts at the re-localisation of offshore manufacturing by developed countries; Climate change; and India's ambitious data-usage policies. It will also examine Atmanirbhar Bharat from a national security perspective in the context of semiconductors and digital technologies.

Thus, this Occasional Paper looks at the ways semiconductors impact national security. The initial part is focused on the broad technical details of the semiconductor ecosystem. The paper then delves into the geopolitics of semiconductors, and how technology transfer, export controls, and similar means of skewing access to technology to certain parts of the world have led to an emerging strategic competition over the technology itself. Finally, the increasing requirements of the Indian military for low power consumption systems, wireless sensors, rugged displays, and absorption of niche technologies due to evolving warfighting doctrines and, in addition, the expanding definitions of security are also discussed.

Changing Notions of National Security

Today, national security as a public good comprises seemingly unconnected concepts, such as food security, human security, environmental security, and information security, in addition to the conventional concept of territorial or armed security. At its broadest, national security is the ability of the government to protect its citizens, economy, and other institutions that define the particular State. In each of these aspects, the role of semiconductors is critical. However, the concept of national security — and even the definition itself — have never remained static. In fact, security and its definition have conformed to the prevailing zeitgeist. Though this section briefly explores the history and context of national security as a whole, it is instructive to see what the set of national security has included and excluded since the late 1940s, when the topic began to be taken seriously on a policy level.

When Walter Lippmann declared in the late 1940s that 'a nation is secure to the extent to which it is not in danger of having to sacrifice core values, if it wishes to avoid war, and is able, if challenged, to maintain them by victory in such a war', the context was the ongoing conflict between the two ideological systems of capitalism and communism, and the likelihood of a major conflict breaking out between the two powers in the near future. Till the late 1960s, military security was conflated with national security, with force build-up and alliances being major factors. Security at that time was understood as military protection against threats from the armed forces of other States. The 'billiard ball' model of international relations also affected the conception of security which looked at threats to States rather than to individuals. Aspects of nuclear disarmament and arms control treaties were the major focus areas. Another strand focused on the (then) recently independent countries of the Third World which were viewed as ideological battlegrounds for the First and the Second world rather than sovereign States. As a result, limited war and counter-insurgency entered the security lexicon wherein the West sought ways to combat communism without being dragged into an escalating conflict with the Soviet Union.

It was only in the post-Cold War period, and the period just preceding the end of the Cold War, that security was expanded to other fields. Barry Buzan defined security as 'freedom from threats', implying that the threat did not have to be military in nature, yet concerned the society and the State, and hinged on the ability of the State to maintain its independent identity and functional integrity. Though the concept of national security had expanded, many critics have called it too broad to not amount to anything at all.

However, this is what security is. It is generally defined by how a particular State or entity defines its threat. To be clear, security is still State-bound. Security challenges can change — expand or contract — but the recipient remains the State since holistic security is only attendant on the State. Only a nation-state with the relevant institutions and resources can be affected by security challenges outside the ambit of military security. Challenges of Climate Change, unstable supply chains, trade wars, conflicts, and other crises have affected how States view threats today. There is an increasing trend toward self-sufficiency and relative autarky due to a realisation that the interconnectedness of the world while spelling benefits for many, has also created its own issues. The example of the current Russia-Ukraine crisis impacting the forex reserves of countries, such as Sri Lanka and Pakistan, and the food-related needs of several African nations are some examples.[1]

[1] Sacko, J., & Mayaki, I., 'How the Russia-Ukraine conflict impacts Africa', *African Renewal,* April 21 2022, at https://www.un.org/africarenewal/magazine/may-2022/how-russia-ukraine-conflict%C2%A0impacts-africa accessed 21 September 2022.

India's conception of national security is based on a number of pillars, such as strategic, social, political, financial, and environmental security. Categorising the different notions of national security does not mean that they are insulated from each other. All are affected by digital technologies which, today, encompass domains as varied as bioengineering, energy storage solutions, artificial intelligence (AI), and 5G communications, among others. Strategic security concerns military matters, both for modernisation and self-reliance. The call for Atmanirbharta, therefore, is not only to strengthen indigenisation but also to form partnerships that will enable India to be a leading power in the region.[2] The India stack, a unique initiative which has enabled peer-to-peer financial transactions between citizens and vendors and within citizens themselves, is ready to be exported to the rest of the developing world. This will also entail stringent data and cyber security measures. India's security, given that it is poised to act as an anchor of Third World hopes and ambitions, rests on the foundation of semiconductors, and ways to indigenise parts of the highly clustered supply chain.

The ongoing strategic competition between the USA and China is another factor that has affected India's national security calculus. The competition has its most visible and militant manifestation in the realm of technology, especially US sanctions and export controls targeting China's intention to modernise its economy and military. The most visible form of these restrictions is the specialised chips. This interaction has important lessons for India as it grows in stature and power amongst the world community. India's geographical position and natural endowments enable it to project power, and to create socio-politico-cultural and military ties with a host of nations. There may come a time when India's national interests may not be in convergence with the powers that control access to the latest technology of the time. It is essential that India starts looking at semiconductors from a national security perspective since technological solutions to India's Climate change challenges will also require a level of indigenisation to ensure innovations and self-sufficiency. India's security

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2 Jaishankar, S., *The India Way: Strategies for an Uncertain World*, New Delhi: HarperCollins India, 2021.

architecture today depends, to a great extent, on mitigating the effects of climate change. A turn to electric vehicles (EVs) and alternate sources of energy implies leaning towards semiconductors within these vehicles. Similarly, in terms of economic security, India's plans to provide employment opportunities to its massive numbers of youth, access to poverty alleviation programs, and service the needs of an influential middle class which will require scaling up its digital infrastructure, and provisioning the latest electronics consumer goods.

Even for India's economic growth, semiconductors play a huge role. The forecast for India's growing consumer electronics market is that the requirement for semiconductors will grow five times the current US $24 billion to around US $110 billion by around 2030.[3] This will be so unless a proactive plan is put in place to make them within the country, steps for which are already underway with the announcement of the India Semiconductor Mission (ISM).[4] India has also been insistent on applying quite strict data localisation and sovereignty standards, especially for foreign firms dealing with the private data of Indian citizens. These will be included in the upcoming Digital India Act.[5] Storing this data inside the country will require access to non-volatile (NV) memory assets based on specialised semiconductors. Finally, the issues of backdoors in processors imported from abroad, and the requirements of a networked force using sophisticated identification, reconnaissance, surveillance, and intelligent devices and algorithms will need to be catered for.

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3 'India's semiconductor consumption will be highest in the world, worth $110 billion by 2030: MoS IT', ET Government.com, 2022, at https://government.economictimes.indiatimes.com/news/technology/indias-semiconductor-consumption-will-be-highest-in-the-world-worth-110-billion-by-2030-mos-it/91170308, accessed 22 September 2022.

4 'India Semiconductor Mission', Ministry of Electronics and IT, 2022, at https://pib.gov.in/PressReleasePage.aspx?PRID=1808676

5 Barik, S., 'For better compliance, tech transfer, Govt to ease data localisation norms', *The Indian Express*, online, 2022, at <https://indianexpress.com/article/india/for-better-compliance-tech-transfer-govt-to-ease-data-localisation-norms-8088627/>, accessed 22 September 2022.

When it comes to strategic security, a changing notion of warfighting that privileges digitisation, networking, faster communications, and data processing for shortening the observe-orient-decide-act (OODA) cycle, will require faster and stronger processors, and customised chips — all with the caveat that they are 'Made in India'. If the Indian Armed Forces intend to fight a modern war, they will have to look at the continued availability of indigenous processors as the first step of the battle. The conventional notions of warfighting dependent on conventional platforms will have to be ditched in favour of a non-contact mode of warfighting, which will prioritise a competitive mode of thinking, and the use of cyber, information warfare, electromagnetic spectrum warfare, and long-range missiles. All of these will require the heavy use of semiconductors.

A confluence of factors — the Covid-19 lockdown, the crisis in the Taiwan Strait, climate change, the excessive dependence on certain countries, the Russia-Ukraine conflict, and the weaponisation of interdependence[6] — have all reinforced the notion that for India to grow securely in the future, self-reliance on semiconductors — to the extent possible — has now become a critical security issue. In order to understand why the issue of supply chains in semiconductors features so prominently in a majority of statements and publications, there is a need to examine some details.

Semiconductors: Important Terms and Definitions

In this essay , the terms 'semiconductor', 'semiconductor chips' or 'chips' will be used interchangeably. Some definitions that may be useful in understanding the technical nuances in this essay are given below.

- **Semiconductor**: A semiconductor is a material with electrical properties between a conductor and an insulator. It can occur as a

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6 Farrell, H., & Newman, A. L., 'Weaponized Interdependence: How Global Economic Networks Shape State Coercion', *International Security*, *44*(1), 2019, pp. 42–79.

pure element, like silicon or germanium, or a combination, like gallium arsenide. However, silicon is the most widely used in the industry.[7]

- **Integrated Circuits (ICs)**: A combination of circuits composed of transistors, diodes, resistors, and capacitors directly embedded on the surface of a silicon wafer is known as an integrated circuit (IC).[8] ICs come in many varieties. They can be classified into memory, logic, and analog devices.[9]

- **Memory Devices**: Memory devices store information. They come in two forms: volatile for random access memory (RAM), or NV for permanent storage. The difference between the two depends on the device's ability to retain data after the removal of voltage.[10]

- **Logic Devices**: Logic devices carry out calculations based on provided inputs. Examples include microprocessors, and the central processing units (CPU) of computers and mobile phones.

- **Analog Devices**: Analog devices convert analog signals into digital ones, enabling calculations and the processing of sound, motion, and other non-digital forms of data.

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7 'What are semiconductors?: Hitachi High-Tech GLOBAL', Hitachi-hightech.com, at https://www.hitachi-hightech.com/global/products/device/semiconductor/about.html, accessed 22 September 2022.

8 Awati, R., 'What is an integrated circuit (IC)? A vital component of modern electronics', WhatIs.com. at https://www.techtarget.com/whatis/definition/integrated-circuit-IC, accessed 22 September 2022.

9 Nathan Associates, 'Beyond Borders: The Global Semiconductor Supply Chain', Semiconductor Industry Association, 2016, at https://www.semiconductors.org/wp-content/uploads/2018/06/SIA-Beyond-Borders-Report-FINAL-June-7.pdf

10 Trick, C., 'Volatile Memory vs. Nonvolatile Memory: What's the Difference?' Trentonsystems.com, at 2022, https://www.trentonsystems.com/blog/volatile-vs-nonvolatile-memory, accessed 22 September 2022.

Other types of semiconductor devices include the following.

- **Discrete semiconductors**: These are individual devices used to control electric currents and optoelectronic devices to either generate or sense light.
- **Application-specific ICs (ASICs):**[11] ASICs are customised chips for specific uses instead of general-purpose use. A typical use of ASIC is in AI applications where custom chips are used to handle the vast amounts of data required for training models for AI.
- **Radio-frequency ICs (RFICs)**: RFICs are chips designed specifically for wireless communication in a defined frequency range.
- **Micro-electromechanical systems (MEMS):** These combine mechanical and electric components on a chip.[12]
- **System-on-a-chip (SoC) Ics**:[13] An SoC is an IC that integrates most or all components of a computer, or any electronic system within a single IC.

The Semiconductor Supply Chain

The process of converting silicon into sophisticated chips is dispersed across the globe. It is dominated by certain countries clumped into specific geographies. Also, the smooth flow of the product to different parts of

11 Author, L., 'ASIC: Diving into Industrial Applications', Linear Microsystems (LMI), 2022, at https://linearmicrosystems.com/asic-diving-into-industrial-applications/, accessed 22 September 2022.

12 Prime Technology Watch, *An Introduction to MEMS* (*Micro Electro Mechanical Systems*) [Ebook], 2002, (1st ed., pp. 7-9), at https://www.lboro.ac.uk/microsites/mechman/research/ipm-ktn/pdf/Technology_review/an-introduction-to-mems.pdf, accessed 22 September 2022.

13 Dejno, J., 'What's in a chip? Breaking down the Semiconductor Industry', [Blog], 2020, at https://techonomics.substack.com/p/-whats-in-a-chip-breaking-down-the, accessed 10 September 2022.

the world is a very delicate operation that relies on more than 16,000 moving parts[14] or specialised companies — which is also why the entire semiconductor supply chain is vulnerable to even minor disruptions. The Covid-19 crisis, tensions over Taiwan — a hub of advanced chip manufacturing in the world — strategic competition between the USA and China, the Russia-Ukraine war, and natural disasters have all played a major part in the securitisation of the entire supply chain . This is so to such an extent that, today, some countries are conceptualising plans on how to achieve near autarky — or at the very least self-sufficiency — in this field.

Semiconductor manufacturing is extremely complex, and divided into three broad stages: design; fabrication; assembly, and testing and packaging (ATP) — which is conducted by companies called outsourced semiconductor assembly and test (OSAT) vendors. While the design phase is known as the upstream segment, the consumer electronics companies are part of the downstream segment, with the second and third stages falling in the middle segment. The ATP or OSAT is the last stage where chips are assembled into different packages of varying shapes and sizes for use in different industries. Each of the three stages is dominated by different specialised companies and countries, supplemented by several specialised service providers such as electronic design automation (EDA) tool makers, semiconductor manufacturing equipment (SME), materials and core intellectual property (IP).

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[14] Nathan Associates, *Beyond Borders: The Global Semiconductor Supply Chain*, Semiconductor Industry Association, 2016, at https://www.semiconductors.org/wp-content/uploads/2018/06/SIA-Beyond-Borders-Report-FINAL-June-7.pdf

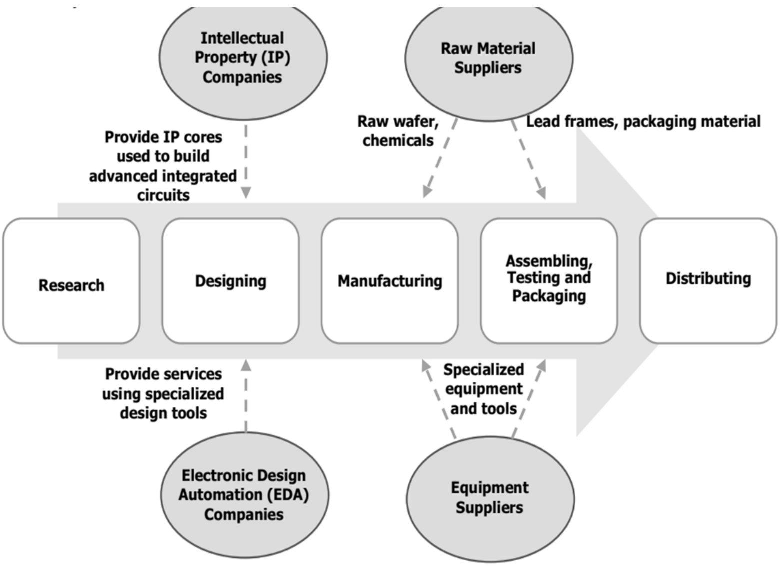

Figure 1: Semiconductor Supply Chains: Stages involved.[15]

Before naming the countries and companies involved in the various phases of manufacturing, there is a need to look at the three broad models of production viz. integrated device manufacturers (IDM) or companies in which all three 'verticals' of R&D and design, and the fabrication and OSAT are within the same firm; and fabless-foundry where design and fabrication are split into specialised companies. In this model — which is the dominant one in the industry today — the fabless firms focus on designing sophisticated chips for specialised purposes, such as graphics rendering in movies and video games, lossless communication, and others. The foundries, on the other hand, harness their R&D in order to make the physical chips based on the designs of the fabless firms. The main purpose

15 Nathan Associates, 'Beyond Borders: The Global Semiconductor Supply Chain', Semiconductor Industry Association, 2016, at https://www.semiconductors.org/wp-content/uploads/2018/06/SIA-Beyond-Borders-Report-FINAL-June-7.pdf

of a foundry is to create economies of scale, and create chips with ever-decreasing gate sizes. Gate size is measured in nanometres (nm), and is the same metric used by chip companies when advertising the sophistication of their products. Gate size is the distance between the two gates of a transistor or, very broadly, the distance that electrons have to travel in order to represent electric current. The smaller the gate size, the less distance electrons have to travel and, subsequently, the faster is the switching speed of the current. The switching on and off of current by semiconductors forms the basis of processing speed or the number of calculations a processor can make.

The structure of the chip is shared by the fabless firms, and the foundry executes the design in physical form, using very highly specialised machinery and processes.[16] Companies specialising only in the fabrication of chips are also known as pure-play fabs. Fab-lite is a situation where some fabless companies may have a small foundry (or fabrication unit) that they use for low-cost higher technology nodes for use in specific cases, such as in automotives and defence. Companies in the shipping, defence, and automotive sector may either acquire older fabs, or create small in-house ones for lower-technology nodes that do not require very high specialised knowledge but are more than adequate for their products. Most automotives use legacy chips; but since the services of limited foundries are in competition with cloud computing providers (like Amazon and Microsoft) and mobile companies (such as Apple), these take a lower priority. The recent shortage in cars across the world was a result of chip supply chain issues.

In terms of the geographical concentration of the semiconductor supply chain, firms headquartered in six countries control the chain in its entirety.[17]

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[16] Hung, H., Chiu, Y., & Wu, M., 'Analysis of Competition Between IDM and Fabless–Foundry Business Models in the Semiconductor Industry', *IEEE Transactions on Semiconductor Manufacturing*, *30*(3), 2017254-260, at https://doi.org/10.1109/tsm.2017.2699739

[17] Saif M. Khan, Alexander Mann, and Dahlia Peterson, 'The Semiconductor Supply Chain: Assessing National Competitiveness', Center for Security and Emerging Technology, January 2021.

Supply chain segment	Critical technology	Country	Country's market share
Fabs	Leading-edge logic chips (<10nm)	Taiwan	92%
	Memory chips	South Korea	41%
Water manufacturing and handling tools	Crystal growing furnances	Germany	100%
	Wafer bonders and aligners	Austria	83%
	Crystal machining tools	Japan	95%
	Wafer handlings		88%
Deposition tools	Spin coating tools		100%
	Tube difffusion and deposition tools		84%
Assembly and packaging tools	Dicing tools		85%
Lithography tools	Resist processing tools		96%
	EUV resists		>90%
	EUV photolithography tools	Netherlands	100%
	EUV laser amplifiers and mirrors	Germany	100%

Figure 2: Various stages of semiconductor manufacturing and the countries dominating the processes[18]

[18] Saif M. Khan, Alexander Mann, and Dahlia Peterson, 'The Semiconductor Supply Chain: Assessing National Competitiveness', Center for Security and Emerging Technology, January 2021.

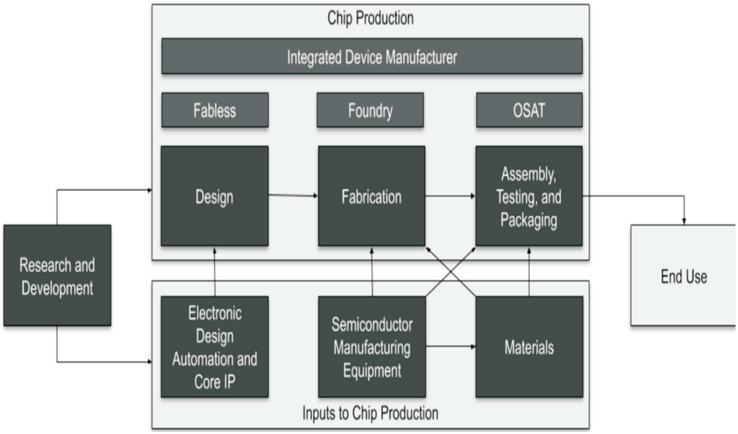

Figure 3: Dominance of various stages of chip manufacturing by companies[19]

Five firms account for 90% of the world's silicon wafer production, of which two Japanese firms control three-fifths.[20] IDMs include Intel, Samsung, SK Hynix, Micron, Texas Instruments, Toshiba, Sony, NXP, and Infineon, among others. Broadcom, Qualcomm, and Nvidia are all fabless design firms;[21] but companies such as Microsoft, Google, and Amazon have also entered the fray due to their need for specialised chips for providing cloud services, and investment in AI applications.[22] Additionally, automotive manufacturers have also joined in — contracting foundries directly for specialised chips for their automobiles, especially for electric and hybrid electric vehicles. The trend now converges to offering mobility as a service (MaaS).[23]

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19 Khan, S. M., Peterson, D., & Mann, A., (rep.), 'The Semiconductor Supply Chain Assessing National Competitiveness', (Ser. CSET Analysis), CSET, 2021.

20 'Semiconductors: U.S. Industry, Global Competition, and Federal Policy', Congressional Research Service (CRS), 2020), Washington DC: CRS.

21 Ibid.

22 Ranade, P., 'Chip Wars: A New Semiconductor World Order', [Blog], 2021, at https://semiconductor.substack.com/p/chip-wars, accessed 2 September 2022.

23 Moody, J., 'Mobility-as-a-Service (MaaS) can help developing cities make the most of complex urban transport systems—if they implement it right', [Blog], 2022, at https://blogs.worldbank.org/transport/mobility-as-a-service-can-help-developing-cities-make-most-complex-urban-transport-systems-if-they-implement-it-right, accessed 22 September 2022.

Three companies in the world — Cadence and Synopsys in the USA, and Mentor Graphics in Germany — provide the majority of EDA tools to the entire industry. EDA tools are specialised software used for designing all semiconductor devices. These tools have facilitated the entry of start ups in this sector, which had long been dominated by big firms in the West, making the playing field comparatively level for talented firms in the Global South to compete. Arms Holdings provides the IP cores, or reusable modular design logic interface, to the entire chip industry.[24] Arm Holdings is wholly owned by Japan-based Softbank, and Nvidia was in talks to acquire the company; but after a pushback from both USA and UK-based regulators, and a strange episode with its Chinese branch — the CEO of the China branch, Arm China, refused to vacate his position despite being instructed to step down — the deal has been scrapped.[25] Chip foundries or fabs are capital-intensive operations, and only three fabs in the world today produce the most advanced chips in the world. These are Taiwan Semiconductor Manufacturing Corporation (TSMC), Samsung, and Intel.[26] Ironically, Intel has also started contracting TSMC for manufacturing their advanced 7nm chips,[27] while Samsung also contracts out its foundry to other designers for manufacturing. Other lesser-known foundries are GlobalFoundries — a US-based but foreign-owned

24 'Worldwide Semiconductor Intellectual Property to 2027 - Featuring Arm Holdings, CEVA and Intel Among Others' , ResearchAndMarkets.com, Businesswire.com, 2021, at https://www.businesswire.com/news/home/20210702005233/en/Worldwide-Semiconductor-Intellectual-Property-to-2027—Featuring-Arm-Holdings-CEVA-and-Intel-Among-Others, ResearchAndMarkets.com. accessed 22 September 2022.

25 Knight, W., 'The Collapse of the Nvidia Deal Leaves Arm Exposed', WIRED, 2022, https://www.wired.com/story/collapse-nvidia-deal-leaves-arm-exposed/ , accessed 10 September 2022.

26 'Semiconductors: U.S. Industry, Global Competition, and Federal Policy', Congressional Research Service (CRS), 2020, Washington DC.

27 'Intel to tap TSMC to make new chip using enhanced 7-nanometer process: Reuters, citing sources', CNBC, 2021, at https://www.cnbc.com/2021/01/12/intel-to-tap-tsmc-to-make-new-chip-using-enhanced-7-nm-process-reuters.html, accessed 7 September 2022.

company[28]— China's Semiconductor Manufacturing International Corporation (SMIC), and United Microelectronics Corporation (UMC), among others.

Finally, certain companies provide SMEs, with a host of equipment used for photographic, lithographic, and chemical processing steps. Five companies — Applied Material, KLA Corporation, and the Lam Research Corporation (US), ASML (Netherlands), and Tokyo Electronics (Japan) — cover more than 75% of the global production.[29] ASML has the sole IP over Extreme Ultra Violet (EUV) lithography equipment which is used for making advanced chips.[30] Similarly, the entire global supply of photoresists — chemicals critical to the production of semiconductors — is controlled by a small cluster of companies based in the USA, Germany, Japan, and South Korea.[31] In 2018, SMIC purchased ASML's EUV lithography equipment. However, due to backlog, the product was not shipped, and the export license for the same expired. US pressure on the Dutch government led to the non-renewal of the export license, and the machine finally did not get delivered to China.[32] OSAT companies — such as Amkor and ChipMOS — offer third-party IC packaging and test

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28 Levy, A., 'Abu Dhabi-controlled GlobalFoundries files for U.S. IPO amid worldwide chip shortage', CNBC, 2021, https://www.cnbc.com/2021/10/04/abu-dhabi-controlled-globalfoundries-files-for-ipo-amid-chip-shortage.html, accessed 8 September 2022.

29 Ibid.

30 Thompson, C., 'Inside the machine that saved Moore's Law', MIT Technology Review, 2021, at https://www.technologyreview.com/2021/10/27/1037118/moores-law-computer-chips/#:~:text=The%20Dutch%20firm%20ASML%20spent,keep%20making%20denser%20computer%20chips.&text=Patrick%20Whelan%20peers%20through%20the,see%20how%20things%20are%20going. accessed 13 September 2022.

31 Saif M. Khan, Alexander Mann, and Dahlia Peterson, 'The Semiconductor Supply Chain: Assessing National Competitiveness', Center for Security and Emerging Technology, January 2021.

32 Morra, J., 'ASML Warns Against U.S. Push to Block Equipment Sales to China', Electronicdesign.com, 2022, at https://www.electronicdesign.com/technologies/analog/article/21247036/electronic-design-asml-warns-against-us-push-to-block-equipment-sales-to-china, accessed 10 September 2022.

services in the context of the device's space constraints.[33] OSAT was initially considered to be labour-intensive and low tech-wise; but the industry is also moving into super-specialisations. The current market is still concentrated in Thailand, Malaysia, and China where the cost of labour is low.[34]

Advanced Packaging Technology	Notable Sub-segment(s)	Advanced Packaging Wafer Split, 2020	Wafer Split Compound Annual Growth Rate, 2019–25	Leading Firms
Flip-Chip	Chip Scale Package (FC-CSP)	43%	8%	ASE, Amkor, TSMC, JCET
	Ball Grid Array (FC-BGA)			OSATs: ASE, Amkor, JCET IDMs: Micron, SK Hynix, Samsung
2D, 2.5D, 3D Stacking	N/A	5%	15%	Intel, TSMC, Samsung, SK Hynix, Sony
Fan-Out	Wafer-Level Packaging (FO-WLP)	4%	15%	TSMC, ASE, JCET
	Panel-Level Packaging (FO-PLP)		12%	Samsung, PTI, ASE
Fan-In	Wafer-Level Packaging (FI-WLP)	48%	5%	ASE, Amkor, TSMC, JCET
Embedded Die/System in Package (SiP)	N/A	<1%	23%	ASE, SEMCO

Figure 4: Semiconductor Supply Chains: Types of Production Models[35]

[33] 'Global Outsourced Semiconductor Assembly & Test Market (OSAT) Market with Focus on IC Packaging (2018-2022) - ResearchAndMarkets.com', Businesswire.com, 2022, at https://www.businesswire.com/news/home/20180830005723/en/Global-Outsourced-Semiconductor-Assembly-Test-Market-OSAT-Market-with-Focus-on-IC-Packaging-2018-2022—ResearchAndMarkets.com, accessed 15 September 2022.

[34] 'Rise of the 'Big 4': The semiconductor industry in Asia Pacific', Deloitte, 2022, at https://www2.deloitte.com/content/dam/Deloitte/cn/Documents/technology-media-telecommunications/cn-tmt-rise-of-the-big-4-en-082820.pdf.

[35] Khan, S. M., Peterson, D., & Mann, A. (2021). (rep.). The Semiconductor Supply Chain Assessing National Competitiveness (Ser. CSET Analysis). CSET.

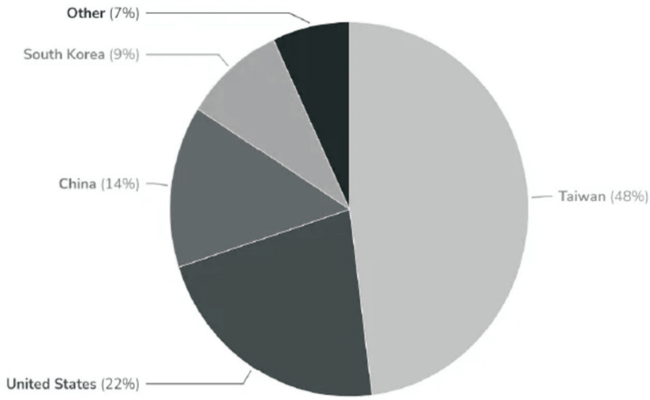

Figure 5: Share of different companies in the OSAT stage. Note that of these, only JCET is a Chinese company. The rest are headquartered either in Taiwan or South Korea.[36]

As seen from the above distribution, the supply chain is paradoxically highly concentrated and dispersed, with companies based in a handful of countries responsible for the entire process — from start to finish. It is notoriously fragile, and vulnerable to conflicts, crises and climate-related disasters.

Criticality of Semiconductor Supply Chains to Countries Today

One may question the logic of focusing excessively on the supply chain of a single element for the purpose of national security when theoretically it can be argued that there are several commodities — like oil and grains — which are produced by select countries, and whose absence may also create national security issues. This brings us to the point of replaceable goods. An oil shortage today from, hypothetically West Asia, due to a conflict may be offset by oil from Russia, Venezuela, or any of the other Organisation of Petroleum Exporting Countries (OPEC) members.

[36] Santosh Kumar, Stefan Chitoraga, and Favier Shoo, 'Status of the Advanced Packaging Industry 2021', Yole Développement, September 2021, p. 36.

Similarly, wheat exports from Ukraine were curtailed due to the Russian blockage of Ukrainian ports, and the alternative was India stepping up to supply grains to a number of countries.

In the case of semiconductors, the critical component is not the chips but the combination of industrial processes, R&D, management techniques, and other forms of know-how which are only present in either the particular company or with the technical manpower which cannot be easily exported or transferred across countries. It is also not a question of exporting technologies. The right conjunction of knowledge, technology, R&D, and processes has been responsible for the semiconductor industry. Missing even a single component may lead to inefficient or unscalable processes in different countries. The turn towards semiconductors, or more broadly technological nationalism, has created a situation which will create cleavages between two techno-political systems in the future — that is, China and the USA. How will the rest of the world cope with this? Since digitisation is increasingly becoming the norm for every activity in the world, countries are scrambling to secure and on-shore a number of domains within the semiconductor supply chain.

As an example, in 2011, the Great East Japan earthquake and the accompanying tsunami led to the disruption of 75% of the world's supply of hydrogen peroxide, a key element used in maintaining the exacting cleanliness standards of the rooms where chips are fabricated. A shortage of almost 200,000 wafers for 2-3 months led to the closure of Japanese plants which had a domino effect on US-based GM truck plants, which also closed temporarily.[37] There is currently a global chip shortage in which COVID-19 has been the catalyst for a pre-existing critical situation. One of the major reasons has been competition for limited chip manufacturing slots between automotive manufacturers, cloud service providers (CSPs),

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[37] Bunkley, N., 'Piecing together a supply chain', *The New York Times*, 12 May 2011, at https://www.nytimes.com/2011/05/13/business/global/13auto.html, accessed 14 September 2022.

AI-based start ups, and chip design firms.[38] Despite the fact that there are still several firms that look at the upstream and downstream end of semiconductor manufacturing, the most crucial part is the one played by foundries or companies which convert silicon from sand into the world's most sophisticated product.

There are only three companies in the world which manufacture the world's most advanced chips namely, Intel, TSMC, and Samsung. Of these, Intel generally lags behind the other two by almost one or two generations. It is TSMC, currently headquartered on an island that China claims in its entirety, which is the world's leading and most prolific producer of sophisticated chips. The importance of TSMC to not only the commerce of the entire world but to the very existence of Taiwan is so crucial that the company has been termed Taiwan's 'Silicon Shield'.[39] The USA has pledged to save the island from Chinese invasion and, if it fails, follow a 'scorched-earth' policy to ensure that the company and its technological know-how do not fall into Chinese hands.[40]

The Importance of TSMC

Being one of the world's most advanced chipmakers, the role of TSMC in Taiwan's national security calculus cannot be overemphasised. Its very existence on Taiwanese soil, and the dependence of US companies on its fabrication potential provides it with an adequate security umbrella. TSMC currently occupies the lion's share of the semiconductor manufacturing

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38 Hille, K., 'TSMC signals global chip crunch may be easing', 15 July 2021, at https://arstechnica.com/information-technology/2021/07/tsmc-signals-global-chip-crunch-may-be-easing/?comments=1, accessed 22 August 2022.

39 Cronin, R., 'Semiconductors and Taiwan's 'Silicon Shield'', Stimson Center, 2022, at https://www.stimson.org/2022/semiconductors-and-taiwans-silicon-shield/, accessed 10 December 2022.

40 Honrada, G., 'US mulls scorched earth strategy for Taiwan', *Asia Times,* 2022, at https://asiatimes.com/2022/12/us-mulls-scorched-earth-strategy-for-taiwan, accessed 10 December 2022.

market, with a 53% piece of the pie, with Samsung at 16.3% coming a distant second[41]. A majority of US-based AI firms depend on TSMC for their advanced chips.[42]

This has played a huge part in framing Taiwan's centrality in USA's 'strategic competition' with China. The US Department of Defence (DoD)'s vaunted Third Offset strategy has focused on autonomy and AI as the foundation for military effectiveness against China.[43] The very focus on autonomy, AI, smart systems, and the internet of military things (IoMT) has brought the semiconductor to the centre of their strategic rivalry. China understands that it lags behind the USA in chip design expertise, and is dependent on it for SMEs. As a result, it has given a big push to its indigenous chip manufacturing industry. Today, only 16% of the semiconductors used in China are produced in the country, and only half of these — that is, 8% — are made by Chinese firms.[44] The modernisation of the Chinese People's Liberation Army (PLA),[45] the actualisation of Chinese President Xi Jinping's 'Chinese Dream' or 'great rejuvenation of the Chinese nation',[46] the

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41 'TSMC 2Q 2022 profit up by 76 per cent, revenue by 36 per cent compared to 2Q 2021', Swarajya Magazine, 14 July 2022 at https://swarajyamag.com/business/tsmc-2q-2022-profit-up-by-76-per-cent-revenue-by-36-per-cent-compared-to-2q-2021, accessed August 12, 2022.

42 Crawford, A., Dillard, J., Fouquet, H., & Reynolds, I., 'The world is dangerously dependent on Taiwan for semiconductors', Bloomberg News, 25 January 2021, at https://www.bloomberg.com/news/features/2021-01-25/the-world-is-dangerously-dependent-on-taiwan-for-semiconductors, accessed 22 August 2022.

43 'Deputy secretary: Third offset strategy bolsters America's military deterrence', U.S. Department of Defense (n.d.), at https://www.defense.gov/News/News-Stories/Article/Article/991434/deputy-secretary-third-offset-strategy-bolsters-americas-military-deterrence/, accessed 22 September 2022.

44 Lewis, J., (rep.), 'Learning the Superior Techniques of the Barbarians', Ser. China Innovation Policy Series, 2019.

45 Fedasiuk, R., Melot, J., & Murphy, B., (rep.), 'Harnessed Lightning: How the Chinese Military is adopting Artificial Intelligence', CSET, 2021.

46 *Xi Jinping: The Governance of China*, at http://www.npc.gov.cn/englishnpc/xjptgoc/xjptgoc.shtml, accessed 22 September 2022.

mitigation of climate change, and the maintenance of the compact between the people and the Chinese Communist Party (CCP) post-1989,[47] are all dependent on the continuous deliverance of progress and economic development to Chinese citizens in exchange for their silence and acquiescence in the Party's sole hold on political power. This development model is premised on the continued availability of advanced semiconductors for China, aiding its march towards progress. Tightening US export controls, Covid-19 lockdowns, and decoupling attempts by other countries and regions have put a big question mark on the CCP's ability to deliver on the promises made to the Chinese people.

Technical and Geopolitical Convergence

There is a need to descend to certain granular details, and understand the geopolitical underpinnings the USA vis-à-vis China. Intel forms a major part of this narrative since it is the biggest IDM in the USA, with the capacity to manufacture advanced chips. Intel introduced the first single-chip CPU in the early 1980s called the 80286.[48] Keeping the basic instructions set architecture (ISA) the same — itself devised by Intel called x86 — the company kept on increasing the number of transistors in the chip, and focused on performance as the quantifiable parameter.[49] An ISA, very broadly, is an abstract model of how a computer functions, or is supposed to function. In layman's terms, these are standards for how a particular computing machine should be built. Any company or industry with a first-mover advantage over an ISA can define, to a large extent — at least

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47 Feigenbaum, E. A., 'The big bet at the heart of Xi Jinping's 'new deal'', Carnegie Endowment for International Peace, 27 November 2017, at https://carnegieendowment.org/2017/11/27/big-bet-at-heart-of-xi-jinping-s-new-deal-pub-74847, accessed 20 September 2022.

48 Y, R., 'What is 80286 microprocessor? Modes of operation and architecture of 80286 microprocessor', Electronics Desk, 9 January 2021, at https://electronicsdesk.com/80286-microprocessor.html accessed 25 August 2022,

49 Ranade, P., 'Bits and Bytes', 16 October 2015, at https://semiconductor.substack.com/p/history-and-future-of-computing-in-one-chart-eadb25ce61fc, accessed 28 August 2022.

theoretically — the kind of computers to be manufactured and, hence, can scale rapidly, which is what happened in the case of Intel.

With Microsoft holding the monopoly on personal computer (PC) operating systems (OS), the Intel and Microsoft combine dominated the computing market since other companies were forced to adopt the x86 chip architecture.[50] The CPU-focused hardware complemented the Microsoft Disk Operating System (MS-DOS) and, later, the Windows software ecosystem. For a long time, Intel also defined how Moore's law will progress, including the number of transistors, their packaging, and the performance parameters to be prioritised. This advantage diminished over time due to physical limitations[51] and, during the mobile era, disappeared almost completely.

The famous Moore's law — which was more of an observation by Gordon Moore in 1965 — postulated that the development of better methods of miniaturisation and packing had led to the doubling of the chip processing speed every 18-24 months, and that this trend should continue. The 'law' was never predictive; it was only descriptive. However, it was treated as a self-fulfilling prophecy by the chip industry.[52] As a result, this trend of miniaturisation and speeding up continued as designers and manufacturers were able to double the number of transistors every two years, doubling the processor speed of the computer, and enabling it to perform massive calculations, and birthing the current era of social media, smartphones, IoT, virtual reality (VR), and AI, among others.

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[50] Ranade, P., '*Bits and Bytes*' 16 November 2015, at https://semiconductor.substack.com/p/how-the-soc-is-displacing-the-cpu-49bc7503edab, accessed 28 August 2022.

[51] Vellante, D., & Floyer, D., 'A New Era of Innovation: Moore's law is not dead and AI is ready to explode', SiliconANGLE, 17 April 2021, at https://siliconangle.com/2021/04/10/new-era-innovation-moores-law-not-dead-ai-ready-explode/, accessed 22 August 2022.

[52] Azhar, A., 'The Harbinger', in *Exponential: How Accelerating Technology is Leaving Us Behind and What to Do About It*, (1st ed.), Random House Business, 2021, Ch. 1, pp. 15–37.

Till the early 2000s — strictly sticking to a conventional definition of Moore's law — which meant packing in more and more transistors into a silicon chip — was giving exponential results with each reduction in node size (the length of the gate size of a transistor in nanometres; however, current usage of node sizes indicates the technology used in the manufacturing of a particular transisto*r*)[53] leading to phenomenal performance due to increased processing power. Intel's total domination of the global PC market enabled it to reap immense profits, most of which was ploughed back into R&D for future chips. As a result, the direction and pace of Moore's law were set by Intel. All this changed in 2007. Apple kickstarted the era of smartphones by designing an ultra-low power yet high computing SoC, which was manufactured by the Samsung foundry after Intel rejected the offer.[54] The success of the iPhone enabled the rise of smartphones, after which the SoC model proliferated as it enabled the integration of multiple functionalities within a single chipset. The architecture also changed to the advanced reduced instructions set computer (Advanced RISC or ARM) architecture, which became the predominant method by which chips started to be manufactured.[55]

In 2014, Samsung's contract for manufacturing Apple's chips was discontinued due to Samsung's series of smartphones competing with Apple, and the manufacturing shifted solely to TSMC which has been Apple's sole manufacturer since then.[56] From 2007 to 2014, Samsung being

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53 Kumawat, K., '7NM VS 10nm VS 14NM: Fabrication Process', Tech Centurion, 26 November 2019, at https://www.techcenturion.com/7nm-10nm-14nm-fabrication, accessed 18 September 2022.

54 Lee, T. B., 'Intel made a huge mistake 10 years ago. now 12,000 workers are paying the price', Vox, 20 April 2016, at https://www.vox.com/2016/4/20/11463818/intel-iphone-mobile-revolution, accessed 11 September 2022.

55 Banerjee, P., 'It's official, Apple is moving to ARM based processors for Mac', *Mint*, 24 June 2020, at https://www.livemint.com/technology/tech-news/it-s-official-apple-is-moving-to-arm-based-processors-for-mac-11592853386445.html, accessed 23 August 2022.

56 Bishop, B., 'Apple signs chip manufacturing deal with TSMC in effort to distance itself from Samsung', The Verge, 29 June 2013, at https://www.theverge.com/2013/6/28/4476182/apple-signs-chip-manufacturing-deal-with-tsmc-in-effort-to-distance-itself-from-samsung, accessed 11 August 2022.

Apple's sole supplier of advanced chips enabled it to produce advanced chips at scale, and also start its series of smartphones. As a result, Samsung progressed to five consecutive node sizes (90, 65, 40, 32, and 28 nm) within these seven years.[57]

Post-2014, Apple's use of TSMC enabled the foundry to take the lead in leading-edge chip manufacturing, and is considered to be the sole advanced chip manufacturer in the world. Today, the limited manufacturing capacities of foundries are being used to make chips for IoT wearables, such as smartwatches and smart glasses; cloud service providers (CSPs), such as Amazon, Microsoft and Google; and AI applications, such as computer vision and deep learning. Resultantly, the predominant products out of TSMC are logic chips, with shorter and shorter nodes based on the ARM ISA. It is reiterated here that ARM is Japan-owned, and attempts by US-based Nvidia to take over the company have failed.

Also, Intel's x86 ISA is in serious competition with ARM's ISA, which is based on the open-source RISC-V protocol, itself based in neutral Switzerland. China has also shifted to manufacturing chips under RISC-V.[58] Apple has also moved away from Intel's x86 ISA starting from their 2020 series Mac laptops (a 15-year-old partnership), and shifted to the ARM ISA.[59] As per the latest reports, China has enlisted Alibaba and Tencent to design RISC-V chips in order to insulate itself from the spate of sanctions by the USA which is based on the x86 chipset ISA.[60] Though technically,

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57 Khan, S. M., & Mann, A., (rep.), 'AI Chips: What They Are and Why They Matter', CSET, 2020.

58 Larguier, J. Y., 'China's semiconductor industry: The promises of RISC-V Open Source Architecture', Institut Montaigne, 9 September 2022, at https://www.institutmontaigne.org/en/analysis/chinas-semiconductor-industry-promises-risc-v-open-source-architecture, accessed 16 September 2022.

59 Banerjee, P., 'It's official, Apple is moving to ARM based processors for Mac', *Mint*, 24 June 2020, at https://www.livemint.com/technology/tech-news/it-s-official-apple-is-moving-to-arm-based-processors-for-mac-11592853386445.html, accessed 23 August 2022.

60 Martin, D., 'Alibaba, Tencent enlisted to help sanction-weary China build RISC-V chips', The Register; 'Biting the hand that feeds IT', The Register, 2022, at https://www.theregister.com/2022/12/01/alibaba_tencent_china_riscv/, accessed 10 December 2022.

the alternative is the Arm ISA; since the company is British with Japanese stakes, there are chances that the British may be persuaded to comply with, or partake in, the US sanctions against China in the future. Similarly, Japan's increasing uneasiness with Chinese military modernisation may nudge it to use its big stake in the Arm group to push through its own set of export controls against China.

This short technical analysis is necessary since it links the technical with the geopolitical, and forms the basic link behind the US narrative of losing the 'competitive edge' in its geopolitical tussle with China. A case study of Chinese dependence on semiconductors for its modernisation, and the challenges that it faces is important to put Indian efforts in context.

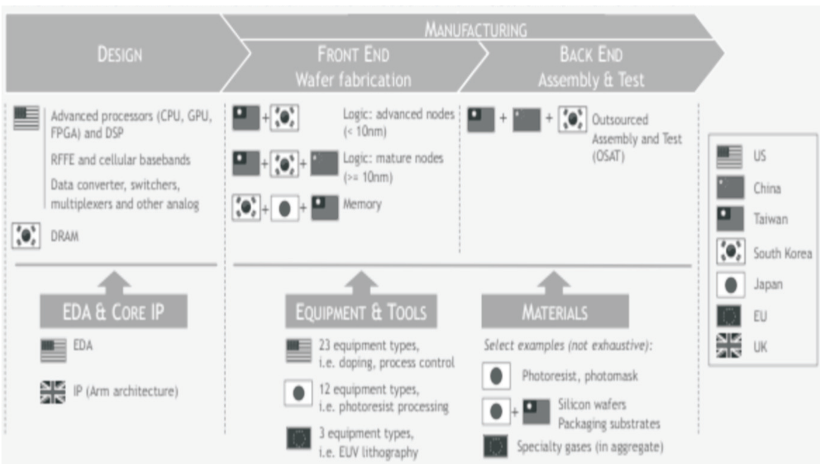

Figure 6: Value chain activities where one single region accounts for ~65% or more of global share

China's Semiconductor Dependence

In 2014, China's State Council set the goal of becoming a global leader in all segments of the semiconductor industry by 2030.[61] 'Made in China

61 Lewis, J., (rep.), 'China's Pursuit of Semiconductor Independence', 2019, at https://www.csis.org/analysis/chinas-pursuit-semiconductor-independence, accessed 11 September 2022.

2025' reiterated this. However, chip manufacturing is not an easy market to break into and, since most SMEs are dominated by the West, this continues to be the country's Achilles heel so far.

Figure 6: China's share in the entire supply chain based on value. In the critical phases of design, EDA, core IP, and SMEs, China is nowhere. It is only in the back end (amounting to 10% of the supply chain value), and the fabrication of relatively lower technology nodes that China figures — and that too in combination with Taiwan, Japan, and South Korea.[62]

The initial ambitious plan to produce 40% of semiconductors by 2020, and 70% by 2025, has had to be revised since the country has reached just a minimal fraction of this target.[63] The chief difficulty for Chinese firms is not only access to equipment but also the lack of experience and know-how. China's pursuit of indigenous industries also runs counter to the trend towards globally integrated supply chains, where firms have focused on their sole area of expertise to take part in a free market system. This is in line with the directions of President Xi Jinping who, in November 2018 in the first known Politburo study session on AI, called for China to 'ensure that critical and core AI technologies are firmly grasped in our own hands'.[64] Similarly, the New Generation AI Development Plan (AIDP) issued in July 2017, noted that China was 'lacking major results in … high-end

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62 Varas, A., Varadarajan, R., Goodrich, J., & Yinug, F., 'Strengthening the Global Semiconductor Supply Chain in An Uncertain Era', Semiconductor Industry Association (SIA), 2021, at https://www.semiconductors.org/strengthening-the-global-semiconductor-supply-chain-in-an-uncertain-era/ accessed 23 August 2022.

63 Tabeta, S., 'Made in China' chip drive falls far short of 70% self-sufficiency', *Nikkei Asia*, 12 October 2021, at https://asia.nikkei.com/Business/Tech/Semiconductors/Made-in-China-chip-drive-falls-far-short-of-70-self-sufficiency, accessed 11 September 2022.

64 Hart, B., *The CCP's Shifting Priorities: An Analysis of Politburo Group Study Sessions*. The Jamestown Foundation: Global Research and Analysis. 12 July 2021, at https://jamestown.org/program/the-ccps-shifting-priorities-an-analysis-of-politburo-group-study-sessions/, accessed 22 September 2022.

chips'.[65] The AIDP called for breakthroughs in 'intelligent computing chips and systems', 'reconfigurable, brain-inspired computing chips', and 'new-model perception chips'.[66]

The Chinese View of Semiconductors

China's view of semiconductors has several manifestations. A majority of the chips imported by China are used in the consumer electronics segment, wherein finished electronics goods are re-exported to growing markets in Asia,[67] Africa,[68] and Latin America.[69] China also wishes to transition to green energy-based platforms and, for this, electric vehicles (EVs) form an important component. China has been hit by floods and drought for the last few years, affecting people's livelihoods, economic growth, and productivity.[70] As a result, being one of the highest carbon dioxide emitters

[65] 'Full translation: China's 'new generation artificial intelligence development plan, 2017', DigiChina, Stanford University, 1 October 2021, at https://digichina.stanford.edu/work/full-translation-chinas-new-generation-artificial-intelligence-development-plan-2017/#:~:text=By%202025%2C%20a%20new%20generation,global%20high%2Dend%20value%20chain, accessed 11 September 2022.

[66] Ibid.

[67] Jamrisko, M., & Zheng, S., 'China slowdown means contrasting fortunes for Asia's exporters', *The Economic Times*, 31 August 2022, at https://economictimes.indiatimes.com/small-biz/trade/exports/insights/china-slowdown-means-contrasting-fortunes-for-asias-exporters/articleshow/93893911.cms?from=mdr, accessed 2 September 2022.

[68] Regissahui, M. H. J., 'Overview on the China-Africa trade relationship', *Open Journal of Social Sciences*, 9 July 2019, at https://www.scirp.org/journal/paperinformation.aspx?paperid=94000, accessed 14 September 2022.

[69] Blazquez-Lidoy, J., Rodriguez, J., & Santiso, J., (rep.), 'Angel or Devil? Chinese Trade Impact on Latin American Emerging Markets', Ser. OECD Paper, OECD, 2004.

[70] Maizland, L., 'China's fight against climate change and environmental degradation', Council on Foreign Relations, 19 May 2021, at https://www.cfr.org/backgrounder/china-climate-change-policies-environmental-degradation, accessed 23 August 2022.

in the world, it has had to turn to EVs, and other advancements, to mitigate the effects of climate change.[71] That the Chinese do not have fabs of their own, or an indigenous capacity to produce the desired chips, merely adds to the challenge. Paradoxically, manufacturing semiconductors consumes vast amounts of electricity and water, worsening the very climate condition sought to be mitigated.[72] As per some estimates, Intel uses nine billion gallons of water annually in California for its fab.[73] The wastewater produced is also toxic, and high in metallic content. Thus, it has to be treated before releasing it into the ground. The current news about TSMC setting up a plant in the US's desert state of Arizona[74] is, therefore, puzzling. As per one figure, TSMC requires close to 63 million tons of water per year and, even in Taiwan, which faces one of its worst droughts in the last 50 years, the government has rerouted water supply from 20% of irrigated farmland. It has even limited water access to three cities to two days per week to help TSMC reach its manufacturing capacity goals.[75]

The Importance of Semiconductors in Modernisation of the People's Liberation Army (PLA)

Semiconductors also play an important part in China's growing ambitions in the military domain. President Xi was very contemptuous about the

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71 Lee, H., & Qiao, Q., (rep.), 'The Role of Electric Vehicles in Decarbonizing China's Transportation Sector', Belfer Center for Science and International Affairs. 2019, at https://www.belfercenter.org/sites/default/files/files/publication/RoleEVsDecarbonizingChina.pdf, accessed 20 September 2022.

72 Wishnick, E., 'Water with your chips? Semiconductors and Water Scarcity in China', *The Diplomat*, 13 August 2021, at https://thediplomat.com/2021/08/water-with-your-chips-semiconductors-and-water-scarcity-in-china/, accessed 23 August 2022.

73 'Intel wastewater story', Business for Water Stewardship (n.d.), at https://businessforwater.org/stories/story-005, accessed 23 September 2022.

74 'Secretive Giant Tsmc's $100 Billion Plan To Fix The Chip Shortage', YouTube. 2021, at https://www.youtube.com/watch?v=GU87SH5e0eI, accessed 1 September 2022.

75 Ibid.

functioning of the PLA before he took over as the Chairman of the Chinese Communist Party (CCP)[76] and, after 2012, has tried to transform the leadership, structure, and capabilities of the force — from a guerrilla-based antiquated army guarding the borders to a high-tech force, capable of projecting power abroad. Mechanisation was made a priority in the 1980s, when the PLA sought to equip its units with modern platforms, such as electronic warfare (EW) systems, armoured personnel vehicles (APCs), and Infantry Fighting Vehicles (IFVs).[77] These were based on the concept of fixed boundaries, and were meant for troops stationed at China's borders. Naval and air operations were relegated to supporting or secondary roles. By 2020, the PLA had achieved mechanisation. As per the 2014 guidelines issued by Xi, and published in the open domain as 'China's Military Strategy' in 2015,[78] informatization — that is, information dominance by one's own side, and information denial to the enemy to disrupt his forces cognitively[79] — forms one of the four major pillars of the new PLA. The other three are joint integrated operations, the centrality of the maritime domain in China's overall strategy, and a new definition of China's maritime domain extending beyond China's 'near seas'.[80]

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76 Rudd, K., 'The Avoidable War: The Dangers of a Catastrophic Conflict Between the Us and Xi Jinping's China', (1st ed.), *PublicAffairs*, 2022.

77 Fedasiuk, R., Melot, J., & Murphy, B., (rep.). 'Harnessed Lightning: How the Chinese Military is adopting Artificial Intelligence', CSET, 2021.

78 'China's Military Strategy', (full text), The Government of the People's Republic of China, 27 May 2015, at http://english.www.gov.cn/archive/white_paper/2015/05/27/content_281475115610833.htm#:~:text=China%20will%20unswervingly%20follow%20the,never%20seek%20hegemony%20or%20expansion, accessed 10 September 2022.

79 Sawhney, P., *The Last War: How AI will Shape India's Final Showdown with China* (1st ed.), Aleph, 2022.

80 Rudd, K., 'The Avoidable War: The Dangers of a Catastrophic Conflict Between the Us and Xi Jinping's China', (1st ed.), *PublicAffairs*, 2022.

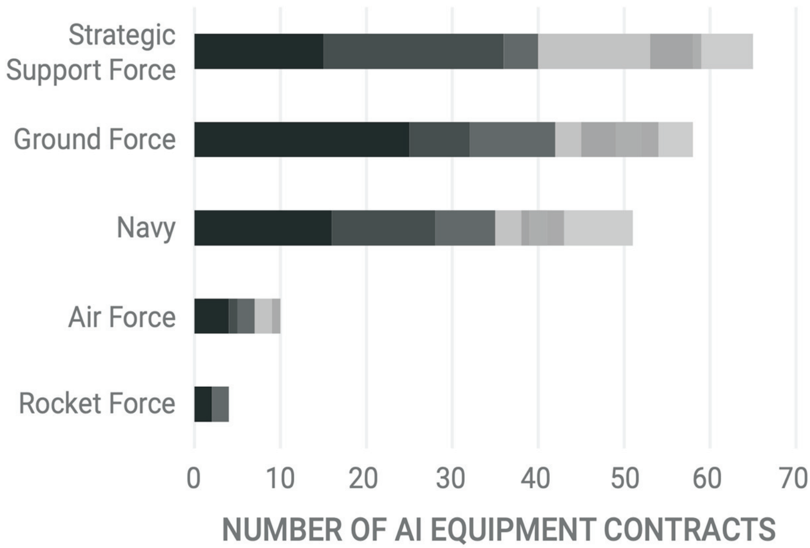

Figure 7: A screenshot of the priority given to AI-based applications by the different branches of the PLA.[81]

Naturally, with its emphasis on the integration of space, cyber, and electromagnetic spectrum, the PLASSF takes the lion's share. The PLA Ground Force, or PLA GF, comes a close second, with its focus on intelligent logistics, 3D mapping of boundaries, and manned-unmanned teaming in the form of robot-soldier teams.

Informatisation has been in the play since the 1990s. The PLA aims to win local wars by using cyber and space domains, unmanned systems, and long-range precision missiles. In 2020, the PLA announced that it would complete informatisation by 2027.[82] Informatisation depends heavily on smart weapons which are, in turn, dependent on data processing power

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[81] Fedasiuk, R., Melot, J., & Murphy, B., (rep.), 'Harnessed Lightning: How the Chinese Military is adopting Artificial Intelligence', CSET, 2021.

[82] Hart, B., Glaser, B. S., & Funaiole, M. P., 'China's 2027 Goal Marks the PLA's Centennial, Not an Expedited Military Modernization, The Jamestown Foundation, 26 March 2021, at https://jamestown.org/program/chinas-2027-goal-marks-the-plas-centennial-not-an-expedited-military-modernization/ accessed 11 September 2022.

and edge computing, based on the availability of customised heavy-duty AI chips. The next step in China's warfighting strategy is intelligentization.

Figure 8: The number of times the words 'mechanisation', 'informatisation', and 'intelligentisation' have been mentioned officially in China's Defence White Papers since 2000.[83]

In his latest book, Pravin Sawhney quotes a 2018 monograph written by Senior Colonel Zhang Yongchao titled 'Next-Generation Warfare: Intelligent Warfare?' which details the stages involved in the intelligentisation of warfare, which will occur in three distinct phases.[84] The initial stage will be distributed intelligent warfare in which an intelligent brain will command and control less intelligent combat units. The intermediate stage will involve the creation of a node-based structure wherein several intelligent brain-like nodes will control a number of intelligent combat unit clusters. This will involve extensive use of big data, cloud computing, and AI algorithms.

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[83] Fedasiuk, R., Melot, J., & Murphy, B., (rep.), 'Harnessed Lightning: How the Chinese Military is adopting Artificial Intelligence', CSET, 2021.

[84] Sawhney, P., *The Last War: How AI will Shape India's Final Showdown with China*, (1st ed.), Aleph, 2022.

The most advanced stage is planned to be achieved by 2035, and will feature independent military operations by high-intelligence terminal and combat units working independently to achieve war aims. China has no other option but to go for the indigenisation of its chip industry. China's focus has been mechanisation, informatisation, and intelligentisation — sought sequentially, but occurring in overlapping periods. These have generally followed US advances in warfighting tactics, doctrines, and platforms.[85]

Though there have been several technological demonstrations by the PLA where they have sought to showcase AI-based drone swarms[86] and other applications, it is not clear whether or not these have been scaled or deployed operationally. Even the Strategic Support Force (SSF), an entity created in the 2015 reforms — which theoretically combines the tenets of space, cyber and electronic warfare[87] — is still in the works, and not fully operationalised. As a result, the technological innovations trumpeted by the PLA are mainly for strategic communication, and not actually usable during the conflict — at least not yet. As of date, PLA is dependent on AI chips designed by US companies, and produced in Taiwan and South Korea. Certain indigenous chips made by Alibaba's chip design arm T-Head (Pinguote) such as the Yitian 710, or by Phytium, are not being ordered by the PLA, and are under severe US export controls.[88] The Yitian 710 was fabricated by TSMC in the 5nm node.[89] However, the

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85 Fedasiuk, R., Melot, J., & Murphy, B., (rep.), 'Harnessed Lightning: How the Chinese Military is adopting Artificial Intelligence', CSET, 2021.

86 Johnson, J., 'Artificial Intelligence, drone swarming and escalation risks in future warfare', *The RUSI Journal*, *165*(2), 2020, pp. 26–36, at https://doi.org/10.1080/03071847.2020.1752026

87 Kania, E. B., & Costello, J., 'Seizing the Commanding Heights: The PLA Strategic Support Force in Chinese Military Power', *Journal of Strategic Studies*, *44*(2), 2020, pp. 218–264, at https://doi.org/10.1080/01402390.2020.1747444.

88 Fedasiuk, R., Lu, E., & Elmgren, K., (rep.), 'Silicon Twist: Managing the Chinese Military's Access to AI Chips' (Ser. CSET Issue Brief), Washington DC: CSET, 2022.

89 Khalili, J., 'A new arm-based CPU with 128 cores will send a shiver down spines at Intel and AMD', TechRadar 14 April 2022, at https://www.techradar.com/news/a-new-arm-based-cpu-with-128-cores-will-send-a-shiver-down-spines-at-intel-and-amd, accessed 29 August 2022.

company stopped manufacturing the chip after the Chinese firm was placed on the Entity List in April 2020. As per a paper by China's Ministry of Industry and Information Technology, more than 90% of China's high-end chips rely on imports.[90] PLA units and defence SOEs continue to procure systems that use advanced chips from companies such as Xilinx and Nvidia and, as an indicator of desperate times, sometimes procure them through intermediaries.

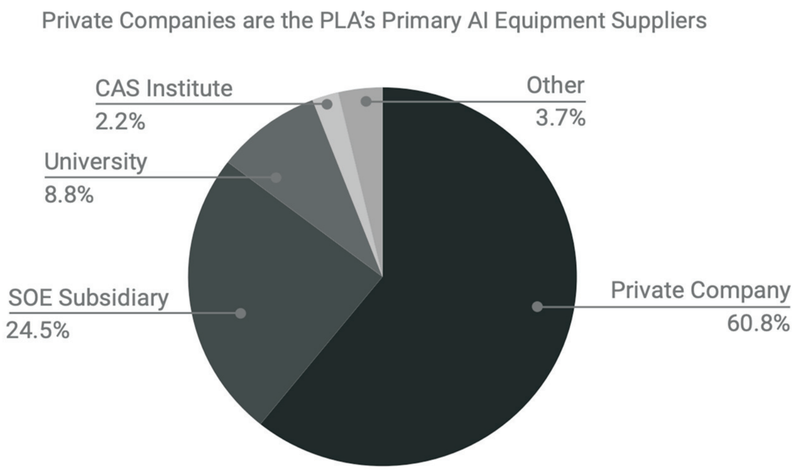

Figure 9: The percentage of entities supplying AI equipment to the PLA. More than 60% are private, while state-owned enterprises (SOE) come second, with close to 25%.[91]

The USA has applied a string of measures restricting the transfer of sensitive technologies, materials, and research to China, both directly and indirectly, through allies and multilateral export controls. It is necessary here to look

[90] Fedasiuk, R., Lu, E., & Elmgren, K., (rep.), 'Silicon Twist: Managing the Chinese Military's Access to AI Chips', (Ser. CSET Issue Brief), Washington DC: CSET, 2022.

[91] Fedasiuk, R., Melot, J., & Murphy, B., (rep.), 'Harnessed Lightning: How the Chinese Military is adopting Artificial Intelligence', CSET, 2021.

at the brief intellectual history of technology transfer (ToT) to China in the past, and how attitudes have changed since. The Chinese example continues to be a great case study of a country which had excellent relations with the West as well as the Soviets — though not at the same time as India — and benefited from ToT a great deal. India needs to harness lessons of self-reliance from China's interactions with these countries starting in the 1970s.

Transfer of Technology: A Brief History

The concept of ToT gained prominence in the late 1950s and early 1960s, when it was assumed that the superior technologies of the West, especially in agriculture, healthcare, education, and transportation, could be transferred to the least developing countries (LDCs).[92] The assumption was also that elites within the recipient country could overcome the resistance to the change of the 'locals' who were not aware of the transformational nature of Western technology.[93] This phase was followed by another phase focusing on planning criteria. Factors that aided the creation and proliferation of these technologies included comparatively cheap capital and foreign exchange, readily available skilled technical personnel, and excellent transport and input supply conditions, among others.[94]

The 'small is beautiful' movement concerning appropriate technologies came to the fore.[95] The focus shifted to 'feasible production techniques' and, within that subset, available production processes. It was thought that these country-specific conditions will enable the creation of specific expertise

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92 Tuma, E., 'Technology Transfer and Economic Development: Lessons of History', JSTOR, 21 July 1987, at https://www.jstor.org/stable/4191592, accessed 18 September 2022.

93 Feinstein, C. and C. Howe (eds.), *Chinese Technology Transfer in the 1990s: Current Experience, Historical Problems, and International Perspectives*, (1st ed.), Edward Elgar, 1997.

94 Ibid.

95 Sukumar, A. M., *Midnight's Machines: A Political History of Technology in India* (1st ed.), Penguin Viking, 2020.

and literature that will enable a much more contextualised transfer, and the absorption of Western technology into the recipient country. Understanding technological knowledge required the assimilation of two components: codified (explicit) knowledge which was easily diffusible, and tacit (contextual) knowledge which is difficult to gain, and can be accessed through either informal interactions, or experientially absorbed, or culturally propagated. The greater the difference in analogous experiences between the two firms' domains of production, the more difficult it was for one firm to elicit from the other the list of subjects for further information. The common training of skilled personnel, the easy mobilisation of this personnel, the transfer of codified technology from one unit of a multinational corporation (MNC) to an overseas subsidiary, and the standardised infrastructure technology programs have all served to lower the cost of obtaining tacit information.[96]

During the 1970s, in the West — and especially in the USA — there was a focus on the commercial spin-offs attributed to technological developments within federally-funded research and development (R&D) projects, as a means to justify the primary missions. This was especially true in the case of military and non-military R&D in the USA's National Aeronautics and Space Administration (NASA), and the Department of Defence (DoD). The Linear Model of Innovation came to be used extensively

> Fundamental Scientific Discovery -> Applied Science -> Invention -> Improvement and Development of Invention for Economic Exploitation -> Innovation by Business Firm of Introducing the Technology commercially in the Market -> Adoption and Acceptance by the Market.[97]

This model gave the government agencies the option of segregating the last step of the commercial viability of the product from the initial R&D phases, and the 'task' of ensuring that scaling became the responsibility of

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[96] Feinstein, C. and C. Howe (eds.), *Chinese Technology Transfer in the 1990s: Current Experience, Historical Problems, and International Perspectives*, (1st ed.), Edward Elgar, 1997.

[97] Ibid.

the business firm. It was a top-down approach which did not take into account feedback from the firm(s) vis-à-vis the viability of the technology itself, especially when it came to adaptation to field conditions, as well as technical design refinements.

Securitisation of Technology Transfers

On a parallel track, while the focus of the West in terms of technology turned inwards, reflecting the background of the Cold War, there was a concern that there were likely to be unintended spill overs, or leakage of technology, in case of international ToT, such as patents, patent licensing, exports of instruments, and production machinery. This fear became more pronounced in the case of 'hi-tech' industries as information leakage could lead to US rivals gaining an edge over it in the military domain. In the 1980s, the USA felt that the diffusion of technology, whether as an intended or unintended consequence of private sector activities, was leading to international convergence in technical capabilities.[98] This was eroding the USA's technological and economic primacy in the immediate post-World War II period. A concern for 'technological leadership' for securing 'competitiveness' began to be voiced.[99]

The national security concerns of the 1970s, which focused on the leakage of defence-sensitive technologies from the West to the East, were replaced with concerns over the ToT of civilian technologies, which was initially considered one of the desiderata of international economic integration. This shift in technological leadership — which is again being repeated in the context of the US-China relationship — is due to a wider trend which has seen a change between defence and civilian technologies. From spearheading major technological advances with peripheral and attendant

[98] Schwartz, P., & Leyden, P., 'The Long Boom: A History of the Future, 1980–2020', Wired, 1 July 1997, at https://www.wired.com/1997/07/longboom/, accessed 8 August 2022.

[99] Nelson, R. R., & Wright, G., 'The Rise and Fall of American Technological Leadership: The Postwar Era in Historical Perspective', JSTOR, December 1992, at https://www.jstor.org/stable/2727970, accessed 23 August 2022.

spinoffs in the civilian sector, the defence sector is now trailing civilian technologies, such as AI, quantum computing, and unmanned systems.[100] Also, the pace of change within these data-dominant technologies is exponential, and defence forces have been unable to harness these changes in the same manner for operational uses. As a result, these technologies themselves have become national security goods,[101] and the abstract notion of competitiveness that the USA used against Japan in the 1980s in the semiconductors and electronics sector, has finally found a firm footing. Mathematical models that tried to explain the difference recognised that ToT from the West to other countries was neither automatic nor instantaneous.[102] The role of IPR in preventing or facilitating access to certain technologies to producers in the Global South was also acknowledged.

ToT in the Case of China

As Manoj Joshi mentions in his latest book, *Understanding the India-China Border* (2022), in 1999 the USA came out with a three-volume report (chaired by Christopher Cox) that detailed commercial and military espionage by China in the USA in the 1990s.[103] The charges included theft of US thermonuclear weapons design, US missile technology, etc. As per the report, the role of technology control regimes, and their alleged loosening in the wake of the Soviet breakup, were responsible for China getting access to sensitive technologies like these.[104] Therefore, export

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[100] Horowitz, M. C., 'Artificial Intelligence, International Competition, and the Balance of Power', *Texas National Security Review*, *1*(3), 2018, pp. 36–57, at https://doi.org/https://doi.org/10.15781/T2639KP49

[101] Noah, *Noahopinion*, 15 July 2022, at https://noahpinion.substack.com/p/the-war-economy, accessed 16 September 2022.

[102] Feinstein, C. and C. Howe (eds.), *Chinese Technology Transfer in the 1990s: Current Experience, Historical Problems, and International Perspectives*, (1st ed.), Edward Elgar, 1997.

[103] Joshi, M., *Understanding the India-China Border* (1st ed.), C Hurst & Co Publishers Ltd., 2022.

[104] Ibid.

controls have played a major part in keeping the playing field deliberately uneven. In China's case, it seems that the country went through several phases of ToT before being singled out for export control by the USA.

From 1953–60, the Soviet Union was China's dominant partner for ToT, and defence industries were prioritised in this phase.[105] One has to remember that this phase had come just at the end of the armistice agreement signed between the two Koreas, and the USA had even contemplated dropping nuclear weapons on China.[106] There was an urgent recognition that the USA as an adversary needed to be thwarted through better defence technology, and that opportunities for future human-wave style attacks against the Americans may not arise. ToT from the Soviets included not only the import of hardware — like whole plants and capital goods — but also blueprints, tech literature, personnel exchanges, and training programs, which were all required for the full transmission of know-how and tacit information.

The Soviets also upgraded Chinese higher education institutions, and established R&D centres apart from formulating long-term science and technology plans.[107] This phase was comparatively successful; but by the late 1950s, problems associated with the Soviet system of production — lack of innovation and continuous productivity growth — started cropping up. Since the system was biased in favour of completing pre-set physical productivity norms, there was no requirement on the part of managers to take any risk. Even Mao felt that the system was too prone to centralisation, bureaucratisation, and coercion.

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[105] Luke, T., 'Technology and Soviet Foreign Trade: On the Political Economy of an Underdeveloped Superpower', JSTOR, September 1985, at https://www.jstor.org/stable/2600488, accessed 20 August 2022

[106] George, J. P., 'When US used Nehru to 'warn' China of nuclear attack over Korean War', *The Week*, 1 July 2021, at https://www.theweek.in/news/world/2021/07/01/when-us-used-nehru-to-warn-china-of-nuclear-attack-over-korean-war.html, accessed 23 September 2022.

[107] Feinstein, C. and C. Howe (eds.), *Chinese Technology Transfer in the 1990s: Current Experience, Historical Problems, and International Perspectives*, (1st ed.), Edward Elgar, 1997.

The period between 1960 and 1978 was marked by three different phases, which were also differentiated by the destruction of Chinese educational and research institutions during Mao's Cultural Revolution between 1965–70.[108] The aim during this phase was self-sufficiency, rejection of foreign investment, and decentralised management. Minimal contact with foreign industries, apart from the bare minimum required for the large-scale sector, was ensured with no respect for foreign IP. From 1972–78, the pace of ToT was greater than the pace of absorption, and only hardware was the focus, without sufficient increment in Chinese know-how capacity. Since 1992, technology firms were given increased autonomy in a system heavily dominated by SOEs.[109] The focus was on importing technology rather than government-mandated imports of the 1980s. Unfortunately, despite the technology firms being given autonomy, more than 50% of the imports were still being carried out by SoEs, which were more interested in the hardware rather than in the software part. Absorption was not thought of much.

In 2000, the recently-deceased, then CCP Chairman Jiang Zemin, started the Golden Shield project which sought to censor internet content from the outside world, and prevent companies such as Amazon, Netflix and Google, to gain access to the massive internet-savvy population in mainland China.[110] This allowed home-grown companies such as Baidu, Alibaba, and Tencent to gain market access to a captive market, without any competition from the outside world. As a result, over the last two decades, Chinese software giants became huge. Since the very beginning, China has

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108 Chang, P. H., 'China's Scientists in the Cultural Revolution', *Bulletin of the Atomic Scientists*, *25*(5), 1969, pp. 19–40, at https://doi.org/10.1080/00963402.1969.11455213.

109 Feinstein, C., C. Howe (eds.), *Chinese Technology Transfer in the 1990s: Current Experience, Historical Problems, and International Perspectives*, (1st ed.), Edward Elgar, 1997.

110 E. R. Roberts, 'The Great Firewall of China: Background', Torfox, Stanford University, 1 June 2011, at https://cs.stanford.edu/people/eroberts/cs181/projects/2010-11/FreedomOfInformationChina/the-great-firewall-of-china-background/index.html, accessed 11 September 2022.

been very specific regarding its engagement with the West, importing or pilfering technologies it feels critical to serving its national interests and, at the same time, blocking attempts from Western companies to access its market and society beyond a minimal level.

Theoretically, the different aspects of technology do not advance evenly in all dimensions in the recipient country. These are reflective of the influence of past science, the evolution of knowledge, the complex adaption of tacit knowledge to factor in the availability and scale of markets, consumer demands, etc. The persistence of past choices and path dependence also play a role. In China's case, there was a tendency to look at the relatively open state-backed market system which allowed China to hold foreign companies hostage concerning the parting with their IPs, to gain access to the Chinese market. Despite the lack of know-how for manufacturing semiconductors at the leading edge, there was never any immediate security concern concerning the availability of customised chips for its various requirements. The US-China strategic competition was also a few years away, and had not taken the militant form that it does today. Chinese innovation blossomed in a period of relative political openness. Now that this openness is shrinking under Xi Jinping, and has been accompanied by greater state economic direction, the trend of increasing Chinese innovation may slow down or reverse.

Weaponisation of Export Controls by the USA

The USA has long used export controls as a method to prevent the proliferation of sensitive and strategic technologies to target countries such as Russia and China today, and even Japan and India in the past. The Export Administration Act (EAA) was passed in 1979, but expired in August 1994. The EAA regulated the export of dual-use items and technologies. Since then, the control of exports of dual-use items has been carried out through a combination of emergency statutory authority —the International Emergency Economic Powers Act (IEEPA) — executive orders, and regulations.[111] As a part of the US's Export

[111] Balachandran, G., 'India, US and The Entity List', Issue Brief, Institute of Defence Studies and Analyses (IDSA), 2010, at https://idsa.in/system/files/IB_IndiaUSandTheEntityList.pdf., accessed 23 September 2022.

Administration Regulations (EAR), the Entity List is a trade restriction list published by the US Department of Commerce's Bureau of Industry and Security (BIS), which consists of certain foreign persons, entities, or governments.[112] Those on the list may be required to apply for licenses from the Commerce Department for the export or transfer of specified items, especially technologies that the US considers sensitive or critical to its national security. On the other hand, revealing a very Cold War-style way of functioning, US citizens, or companies, do not seem to be prohibited from purchasing items from a company on the Entity List.

There are multiple layers of US export controls over China when it comes to semiconductors. Broadly, SMEs, chips, material, software, and technical data are controlled and, even within these categories, specific items are again controlled, such as lithography, deposition, ion implanting, testing, and wafer handling tools. In high-end semiconductors, export controls include field programmable gate arrays (FPGAs), and certain types of CPUs.

China's Technological Access Problem

The main challenge for China is that the IP used for fabrication is from the USA, the UK, and a handful of other countries. Since 2019, the USA has placed Huawei and its subsidiaries on the Entity List, making it almost impossible for China to use US-based IP and manufacturing tools for its chip production. To offset this, China has increased its commitment to the open-source RISC-V infrastructure, as a counter to the x86 and ARM-dominated ISA for microprocessors.[113] Chinese chip-design AI start ups

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112 *Entity List*, 2020, Bureau of Industry and Security: Where Industry and Security Intersect, US Department of Commerce, at https://www.bis.doc.gov/index.php/policy-guidance/lists-of-parties-of-concern/entity- list#:~:text=The%20Entity%20List%20specifies%20the,imposed%20elsewhere%20in%20the%20EAR, accessed 17 September 2022.

113 Larguier, J. Y., 'China's semiconductor industry: The promises of RISC-V Open Source Architecture', 9 September 2022, Institut Montaigne, at https://www.institutmontaigne.org/en/analysis/chinas-semiconductor-industry-promises-risc-v-open-source-architecture, accessed 16 September 2022.

and established companies, such as Cambricon, Horizon Robotics, Novumind, Yitu, and Intellifusion, are going to TSMC, with RISC-V-based designs for fabrication without US interference, though it is difficult to predict how fast this architecture will catch up, both within China, and outside.[114] With a total planned investment of US$ 150 billion in the next ten years, China is pushing very hard for the indigenisation of its chip-making industry.[115] Another reason for this push is that, as of now, Chinese fabless manufacturers can contract the services of US foundries at the current node size. With the implementation of the Creating Helpful Incentives to Produce Semiconductors (CHIPS) Act of 2022, any company accepting a subsidy from the US government will have to undertake that it will not manufacture advanced chips for countries like China.[116] Once the appropriations for the Act are passed, then it will become very unlikely for China to access the latest chip fabrication facilities even from TSMC, since it is likely that TSMC has already opted for a heavily subsidised plant in Arizona in the USA. [117] Chinese firms have captured close to 16% of the fabless manufacturing market with the production of lower-end logic chips, analog chips, and discrete semiconductors, but adjusting for value — that is, giving greater weight to the production of more advanced chips. Thus, China's share reduces to 3%.[118] Chinese foundries still lag by generations in state-of-the-art production at volume.

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114 Fedasiuk, R., Melot, J., & Murphy, B., (rep.), 'Harnessed Lightning: How the Chinese Military is Adopting Artificial Intelligence', CSET, 2021.

115 Webb, A., 'China's $150 Billion Chip Push Has Hit a Dutch Snag', Bloomberg.com, 20 January 2021, at https://www.bloomberg.com/opinion/articles/2021-01-20/asml-china-s-150-billion-chip-push-has-hit-a-dutch-snag, accessed 23 September 2022.

116 'FACT SHEET: CHIPS and Science Act Will Lower Costs, Create Jobs, Strengthen Supply Chains, and Counter China', The White House, 9 August 2022, at https://www.whitehouse.gov/briefing-room/statements-releases/2022/08/09/fact-sheet-chips-and-science-act-will-lower-costs-create-jobs-strengthen-supply-chains-and-counter-china/, accessed 10 August 2022.

117 'Secretive Giant Tsmc's $100 Billion Plan to Fix The Chip Shortage', YouTube, 2021, at https://www.youtube.com/watch?v=GU87SH5e0eI, accessed 1 September 2022.

118 Khan, S. M., Peterson, D., & Mann, A., (rep.), 'The Semiconductor Supply Chain Assessing National Competitiveness', (Ser. CSET Analysis), CSET, 2021.

A semiconductor firm TechInsights has also noted that SMIC has been able to fabricate a 7nm ASIC chip without the help of ASML's EUV lithography equipment.[119] Though the chip is supposedly meant for crypto-mining, it is equally likely that it may end up being used in military applications due to China's military-civil fusion doctrine. The fact that EUV equipment has not been used implies that the company has used older processes, like Deep Ultra Violet lithography (DUV) to fabricate the chip. As of now, the chip is more of a technology demonstrator given the excessive time taken for fabrication; but SMIC plans to invest US$ 11 billion into DUV, and ramp up 7nm fabrication capacity by 2023. [120] If successful, this will break China's dependence on TSMC for manufacturing advanced chips in the long run. SMIC was put on the US Entity List in December 2020, with plans to limit the export of any item that would assist SMIC in manufacturing chips below 10nm.[121] This restriction follows a letter written by two US Senators to Treasury Secretary, Gina Raimondo, calling for the foreign direct produce rule (FDPR) to be extended to all Chinese companies involved in semiconductor design.[122] FDPR expands the jurisdictional reach of EAR by mandating that foreign-produced items can be regulated even if they do not incorporate US-origin content, as long as they are produced from covered US-regulated technology or

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[119] 'SMIC 7nm technology found in MinerVa Bitcoin Miner', TechInsights, (n.d.), at https://www.techinsights.com/blog/disruptive-technology-7nm-smic-minerva-bitcoin-miner, accessed 23 September 2022.

[120] Martin, D., 'China figured out how to make 7NM chips despite US sanctions', The Register: Biting the hand that feeds IT, 22 July 2022, at https://www.theregister.com/2022/07/22/china_smic_7nm_chips/, accessed 15 September 2022.

[121] Wang, C. J., 'China's Semiconductor Breakthrough', *The Diplomat*, 20 August 2022, at https://thediplomat.com/2022/08/chinas-semiconductor-breakthrough/, accessed 28 August 2022.

[122] 'Senators Urge Commerce Department to Prevent Unlawful Shipments to Huawei, Other Entity List Companies', US Senate Committee on Commerce, Science and Transportation, 15 November 2021, at https://www.commerce.senate.gov/2021/11/senators-urge-commerce-department-to-prevent-unlawful-shipments-to-huawei-other-entity-list-companies, accessed 11 September 2022.

software.[123] The USA has also intensified efforts to block Chinese Big Tech from accessing any of the leading edge chip design, R&D, and manufacturing options, initially through export controls and review under the Committee on Foreign Investment in the United States (CFIUS), and now the CHIPS Act. In the latest salvo, the USA will ban exports of SMEs from three US-based companies: Applied Materials, KLA Corps, and Lam Research Corps, as well as AI chips designed by AMD and Nvidia Corps to China. The letters from the US Commerce Department addressed specific companies restricting the export of any SME to Chinese factories producing chips at sub-14nm size.[124] US export controls also restrict the re-export of certain items from one foreign country (Japan, Germany, South Korea) to China.[125]

Additionally, for the so-called AI stack, hardware is one of the main elements along with data, algorithms, and talent. The US National Security Commission on AI (NSCAI) report says that the USA needs to stay at least two generations ahead of China in state-of-the-art microelectronics, and have multiple access routes to indigenous chips. There is also an emphasis on increasing R&D in microelectronics. Interestingly, the report benchmarks the 16nm node as the limit for using chips below this node size for AI applications.[126] The report also recommends that the USA target the EUV lithography equipment, and the Argon Fluoride immersion lithography tools for export controls, which are completely dominated by the USA, the Netherlands, and Japan to prevent China from developing

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[123] Froehlich, A., 'Foreign direct product rule: Is Russia the next Huawei', Atlantic Council, 3 February 2022, at https://www.atlanticcouncil.org/blogs/econographics/foreign-direct-product-rule-is-russia-the-next-huawei/, accessed 11 September 2022.

[124] Freifeld, K., & Alper, A., 'Exclusive: Biden to hit China with broader curbs on U.S. chip and tool exports -sources', Reuters, 16 September 2022, at https://www.reuters.com/business/exclusive-biden-hit-china-with-broader-curbs-us-chip-tool-exports-sources-2022-09-11/, accessed 23 September 2022.

[125] Khan, S. M., Peterson, D., & Mann, A., (rep.), 'The Semiconductor Supply Chain Assessing National Competitiveness', (Ser. CSET Analysis), CSET, 2021.

[126] Ibid.

any node below 16nm through a two-pronged attack: Chinese firms will not be able to replace or repair any chip brought previously, and won't be able to make leading-edge chips at 7 or 5nm at scale.[127] Again, SMIC's ability to fabricate a chip at 10nm through slightly outdated equipment should raise concerns about whether the sanctions are working as intended. As reiterated in this essay, the physical limits of Moore's laws are about to be breached. This has provided the chip industry incentives to increase the efficiency of their chips in other ways, such as using algorithms and parallel processing. These are areas where China can compete.

The NSCAI also recommended setting up a National Technology Foundation (NTF) to focus efforts around a set of technologies deemed critical to U.S. national competitiveness:

- Artificial Intelligence
- Biotechnology
- Quantum Computing
- Semiconductors and Advanced Hardware
- Robotics and Autonomy
- 5G and Advanced Networking
- Advanced Manufacturing
- Energy Technology[128]

The USA has long faced the challenge of not being able to attract adequate venture capital (VC) funding for patent-intensive companies involved in critical technologies, such as computer hardware, semiconductors, medical devices and supplies, pharmaceuticals, and biotechnology, as compared

127 Schmidt, E., & Work, R., (rep.), 'Final Report: National Security Commission on Artificial Intelligence', 2021.

128 Ibid.

to start up-based non-patent intensive companies specialising in software-based applications. This trend seems to have reverted since 2021.[129] The US government has also pitched in. US President Joe Biden signed the CHIPS and Science Act of 2022 on 25 Aug 2022. It combines the best features of the US Innovation and Competition Act (the USICA, passed in June 2021), and the America Creating Opportunities to Meaningfully Promote Excellence in Technology, Education, and Science Act (the America COMPETES Act, passed in January 2022).[130]

The Act has multiple aims, the primary amongst them being: to attain self-sufficiency in semiconductor manufacturing amidst supply chain disruptions due to either conflict (Taiwan) or crisis (Covid-19); to promote indigenous advanced semiconductor manufacturing on US shores by giving subsidies to the tune of US$ 54.2 billion; prevent China from gaining an edge over the USA in terms of AI-based applications which, in turn, are based on advanced chips (in the field of national defence). Most equipment based on electronics and future military exploitable technologies are all based on the hardware layer of semiconductors, and that too, advanced ones. These are quantum computing, and 5G communication, both enabling next-generation network-centric warfare NCW); facilitating US R&D into advanced chip design and manufacturing; strengthening supply chain resilience through the operationalisation of the CHIPS for America International Technology and Security Fund and, finally, maintaining USA's competitive edge over its competitors.[131] In the economic competition

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[129] Lee, J. L., 'U.S. chip startups, long shunned in favor of internet bets, stir excitement again', Reuters, 5 May 2021, at https://www.reuters.com/article/venture-capital-semiconductors-funding-idINKBN2CM10S, accessed 21 September 2022.

[130] 'FACT SHEET: CHIPS and Science Act Will Lower Costs, Create Jobs, Strengthen Supply Chains, and Counter China', The White House, 9 August 2022, at https://www.whitehouse.gov/briefing-room/statements-releases/2022/08/09/fact-sheet-chips-and-science-act-will-lower-costs-create-jobs-strengthen-supply-chains-and-counter-china/, accessed 10 August 2022.

[131] Kersten, A., Arcuri, G., & Athanasia, G., 9 August 2022, 'A Look at the CHIPS-Related Portions of CHIPS+', Center for Strategic and International Studies, at https://www.csis.org/analysis/look-chips-related-portions-chips, accessed 19 September 2022.

between the USA and China, indigenising semiconductor manufacturing will play a major part since the future of work is tech-based. CHIPS will enable the US private industry to gain leverage over Chinese ones based on this. There are two Division summaries — A & B — for the Act.[132]

Main Features of CHIPS Act

The interesting part about the wording of the Act is on the first page itself: the first page of Summary A mentions restricting Chinese technology companies with links to the CCP, and even mentions Huawei by name.[133] The Act promotes the Open Radio Access Network (OpenRAN or ORAN) to allow US vendors to bid for, and enter the global market based on their modular expertise in specific systems rather than as whole firms. ORAN is a shift in mobile network architecture which allows networks to be built using subcomponents from a variety of vendors.[134] Three Departments of the US government — the Department of Commerce (DOC), State Department (DOS), and DOD — have been authorised under the Act to develop indigenous/ onshore semiconductor manufacturing expertise to advance US competitiveness and national security.[135] In fact, in several US official documents as well as in studies of

132 'FACT SHEET: CHIPS and Science Act Will Lower Costs, Create Jobs, Strengthen Supply Chains, and Counter China', The White House, 9 August 2022, at https://www.whitehouse.gov/briefing-room/statements-releases/2022/08/09/fact-sheet-chips-and-science-act-will-lower-costs-create-jobs-strengthen-supply-chains-and-counter-china/, accessed 10 August 2022.

133 Chris Van Hollen (US Senator for Maryland), 'CHIPS and Science Act of 2022 Division A Summary — CHIPS and ORAN Investment', 9 August 2022, at https://www.vanhollen.senate.gov/imo/media/doc/CHIPS%20and%20Science%20Act%20of%202022%20Summary.pdf, accessed 1 September 2022.

134 'What is Open RAN (ORAN)?' Cisco, 23 November 2021, at https://www.cisco.com/c/en/us/solutions/what-is-open-ran.html, accessed 11 September 2022.

135 Chris Van Hollen (US Senator for Maryland), 'CHIPS and Science Act of 2022 Division A Summary —CHIPS and ORAN Investment', 9 August 2022, at from https://www.vanhollen.senate.gov/imo/media/doc/CHIPS%20and%20Science%20Act%20of%202022%20Summary.pdf, accessed 1 September 2022.

the Cold War period, terms such as 'competitive edge' and 'conventional overmatch' figure heavily. This kind of mindset does not cater for countries like India which are in the game not for any overmatch but are diffusing technologies for their defence. It is equally important to understand that any tech/ application with commercial potential which can be utilised for gaining profits (dual-use) has a much better chance of being successful as compared to state-facing. The USA is very clear that any company benefiting from the funds of the CHIPS Act will not set up shop, nor share leading-edge technology, with China. US$ 2 billion were kept aside in FY22 for the creation of the National Semiconductor Technology Centre (NSTC), which will be a consortium of private and public firms, NSF, and the Department of Energy. US$ 2.5 billion are for the establishment of the Advance Packaging Manufacturing Program (APMP) under NIST in the field of ATP (Assembly, Test and Packaging).[136]

Legacy chips were allotted US$ 2 billion in the FY 2022, but nothing after that.[137] However, it is these 'legacy' chips which form the backbone of the majority of the automotive and defence industry requirements. These need to be carefully maintained, and even subsidised for the defence industry. The Indian government recently announced that it will provide incentives of 50% to all semiconductor manufacturing setups across node sizes.[138] Initially, the incentives were graded — more for smaller node sizes. However, there has been a realisation that the so-called legacy chips, — that is, chips with bigger node sizes — are critical for the defence and automotive industry. Hence the modifications. The USA also needs to take a leaf out of India's playbook. The Investment Tax Credit (ITC) is similar to the Performance linked incentives (PLI) being given by the Indian

136 Ibid.

137 Ibid.

138 'Cabinet approves 50% incentive to manufacture semiconductors', The Hindu BusinessLine, 21 September 2022, at https://www.thehindubusinessline.com/economy/cabinet-approves-50-incentive-to-manufacture-semiconductors/article65918640.ece#:~:text=The%20Cabinet%2C%20on%20Wednesday%2C%20approved,setting%20up%20of%20display%20fabs, accessed 21 September 2022.

government for several industries, such as unmanned systems and semiconductor manufacturing.[139] However, the ITC's aim is not only to subsidise its manufacturers but also to attract foreign manufacturers, such as Samsung and TSMC, to set up shops in the USA, and level up or destroy the advantage enjoyed by East Asian countries whose chip manufacturing is heavily subsidised by their home governments. Currently, the TSMC based in Taiwan makes up 90% of the semiconductor fabrication requirements of US-based tech giants, such as Apple, Google, and Amazon.[140] The US share in global semiconductor fabrication capacity has declined from 40% to 12% (1990 to 2020), and most US firms have gone 'fabless'.[141] In advanced chip manufacturing, US capabilities are close to zero. East Asia, especially Taiwan, South Korea, and Japan now cater to 80% of global demand, creating several vulnerabilities.[142] This move may prove to be detrimental in the longer term, especially in the context of coordination within the Quad, ASEAN, and other bilateral and multilateral forums. The same issue brings back memories of agricultural subsidies and other issues during the WTO debates where the USA and EU were on one side, and China and India on the other. This needs to be clarified diplomatically, and maybe the Ministry of External Affairs (MEA)'s New and Emerging Strategic Technologies (NEST) division may like to have a look at it.

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139 The Central Government is providing an incentive of Rs 120 crore under the PLI scheme. A Provisional list of 23 PLI beneficiaries has been released, including 12 drone manufacturers and 11 drone component manufacturers, Press Information Bureau, 25 July 2022, at https://pib.gov.in/PressReleasePage.aspx?PRID=1844623, accessed 14 August 2022.

140 Chaudhary, S. R., 'Tough road ahead for U.S. firms trying to cut reliance on Taiwan Chipmakers', CNBC, 13 April 2021, at https://www.cnbc.com/2021/04/13/semiconductor-shortage-us-tech-companies-and-their-reliance-on-taiwan.html, accessed September 16, 2022.

141 Platzer, M. D., Sargent, J. F., & Sutter, K. M., 'Semiconductors: U.S. Industry, Global Competition, and Federal Policy', Congressional Research Service, 26 October 2020, at https://crsreports.congress.gov/product/pdf/R/R46581, accessed 24 August 2022.

142 Ibid.

The Division B summary focuses on R&D, and includes departments such as the National Science Foundation (NSF), National Institute of Standards and Technology (NIST), DOC, NASA, and the Department of Energy (DOE).[143] The US edge in tech has been due to a tie-in between the US Federal government and private companies. This research has been divided into two parts: curiosity-driven and use-inspired/translational.[144] The USA has been concerned about the theft of IPR data by China, reducing supply chain vulnerabilities in advanced manufacturing, next-gen tech, computer hardware, and pharma. New tech hubs are also planned to be built in the USA, with a lab-to-fab mentality for teaching students from an early age. A new Tech, Innovation and Partnerships (TIP) directorate has been created within NSF, with a seeding of US$ 20 billion for the domestic development of economic and national-security critical tech, such as 6G comms, AI, quantum computing, advanced manufacturing, energy, and material science.[145] A whole nation approach towards national security has been taken in which basic research has been encouraged in the food-energy-water system, sustainable chemistry, risk and resilience, clean water systems, tech and behavioural health, critical minerals, and precision agriculture. Also, a 4-year National Science and Tech strategy, in line with the NDS and NSS, and focusing on economic security, needs to be submitted. The USA is also getting into the race for designing and creating standards for advanced and emerging technologies such as AI, cyber security, and semiconductors. Small and Medium-sized Enterprises are being strengthened, and the entire government and private firm strength are being leveraged to 'promote competitiveness' in international standards. In view of preventing the leeching of US researchers and sensitive research by China under the guise of collaboration, the USA has created a Research

143 Shivakumar, S., & Arcuri, G., 'A Look at the Science-Related Portions of CHIPS+ |', Center for Strategic and International Studies, 11 August 2022, at https://www.csis.org/analysis/look-science-related-portions-chips, accessed 11 September 2022.

144 Cooper, V., 'Explainer: The CHIPS and Science Act 2022', United States Studies Centre, 11 August 2022, at https://www.ussc.edu.au/analysis/explainer-the-chips-and-science-act-2022, accessed 15 September 2022.

145 Ibid.

Security and Policy Office within NSF that looks at these issues. There are options to suspend or terminate the research funding of the researcher if found guilty.[146]

The CHIPS Defence Fund will get US$ 2 billion in FY22-27 (US$ 400 million per year) for defence priorities in semiconductor manufacturing. The DoD will establish a consortium of private companies to facilitate the production of secure semiconductors.[147] This is in addition to the Trusted Foundries program, which has had a lukewarm reception to the DoD's requirements, mostly because the percentage of DoD's demands from the semiconductor industry form less than 1% of the industry's output — and that too in the legacy chip segment. The CHIPS for America International Security and Innovation Fund will get US$ 500 million to coordinate with international partners.[148] Here India needs to attract these funds as incubators for future military tech, as the aim is to focus on semiconductors, telecommunications, and other emerging technologies.

Till the 1970s, the USA used an abstract methodology called 'shielded' innovation to facilitate/ force private firms to make exclusive platforms for the military. These technologies or equipment could not be utilised by these firms later for commercial purposes, unless a specific time had elapsed.[149] However, the situation has undergone a major change in the past decade. With the focus of the military shifting slowly towards AI and

146 Ibid.

147 Chris Van Holle (US Senator for Maryland), 'CHIPS and Science Act of 2022 Division A Summary - CHIPS and ORAN Investment', 9 August 2022, at https://www.vanhollen.senate.gov/imo/media/doc/CHIPS%20and%20Science%20Act%20of%202022%20Summary.pdf, accessed 1 September 2022.

148 Chris Van Hollen (US Senator for Maryland), 'CHIPS and Science Act of 2022 Division A Summary - CHIPS and ORAN Investment', 9 August 2022, at https://www.vanhollen.senate.gov/imo/media/doc/CHIPS%20and%20Science%20Act%20of%202022%20Summary.pdf, accessed 1 September 2022.

149 Stowsky, J., 'Secrets to shield or share? New dilemmas for military R&D policy in the digital age', *Research policy*, *33*(2), 2004, pp. 257–269.

autonomy — especially with the announcement of the Third Offset strategy by the DoD — the military has had to look at Silicon Valley-based firms for their operational needs.[150] Unfortunately, the US military as a customer forms less than 1% of the tech industry's output, and has had to woo the industry on several instances to get specialised chips and software made for them.[151] Two recent controversies — protest by Google employees over the company's involvement in the US military's Project Maven,[152] and the tussle over Project Joint Enterprise Defence Infrastructure (JEDI) between Amazon and Oracle, and the subsequent cancelling of the same[153] — have created quite a rift between the tech industry and the military, especially in terms of the viability of future projects.

DoD's Trusted Foundry Program: Ensuring Safe Supply Chains

The DoD's Trusted Foundry Program was a means to ensure that the USA retained the critical edge in microelectronics.[154] This was meant to be

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150 Pavluk, J., & Cole, A., 'From Strategy to Execution: Accelerating the Third Offset', War on the Rocks, 8 June 2016, at https://warontherocks.com/2016/06/from-strategy-to-execution-accelerating-the-third-offset/, accessed 11 September 2022.

151 Platzer, M. D., Sargent, J. F., & Sutter, K. M., 'Semiconductors: U.S. Industry, Global Competition, and Federal Policy', Congressional Research Service, 26 October 2020, at https://crsreports.congress.gov/product/pdf/R/R46581, accessed 24 August 2022.

152 Shane, S., & Wakabayashi, D., 'The Business of War': Google Employees Protest Work for the Pentagon', *The New York Times*, 4 April 2018, at https://www.nytimes.com/2018/04/04/technology/google-letter-ceo-pentagon-project.html, accessed 11 September 2022.

153 Feiner, L., & Macias, A., 'Pentagon cancels $10 billion Jedi Cloud contract that Amazon and Microsoft were fighting over', CNBC, 6 July 2021, at https://www.cnbc.com/2021/07/06/pentagon-cancels-10-billion-jedi-cloud-contract.html#:~:text=Tech,Pentagon%20cancels%20%2410%20billion%20JEDI%20cloud%20contract,and%20Microsoft%20were%20fighting%20over&text=The%20Department%20of%20Defense%20said,new%20multivendor%20cloud%20computing%20contract, accessed 10 September 2022.

154 Platzer, M. D., Sargent, J. F., & Sutter, K. M., 'Semiconductors: U.S. Industry, Global Competition, and Federal Policy', Congressional Research Service, 26 October 2020, at https://crsreports.congress.gov/product/pdf/R/R46581, accessed 24 August 2022.

accomplished by designating certain chip manufacturing companies as Trusted Foundries which had the implicit backing of the US government. It was initially implemented with IBM, but later expanded to other vendors. However, that was at the 90nm edge. Currently, with DoD forming less than 1% of the industry's demands,[155] there are hardly any takers for the military's requirements since companies are focusing on leading- edge ICs while the military remains dependent on legacy chips. IBM remains one of the trusted suppliers, but it currently manufactures only non-leading-edge chips. The changing needs of modern warfare to cater to more AI-based applications require that the foundries are also able to fabricate leading-edge chips for the military. The DoD has, therefore, turned to a different way of ensuring the resilience and safety of its supply chains.

Under the State-of-the-Art Heterogeneous Integrated Packaging (SHIP) program, the DoD has integrated its IP with the commercial IPs of other leading-edge chip companies. However, SHIP is designed to be at the end of the supply chain for ICs, and is focused on the integration of chips into assemblies. An October 2020 press release by Intel states that the DoD has awarded the second phase of SHIP to Intel, which facilitates the access of the DoD to cutting-edge R&D and manufacturing efforts of Intel. The project is executed by the Naval Surface Warfare Centre, Crane Division, and is administered by the National Security Technology Accelerator.[156] SHIP is funded by the Trusted and Assured Microelectronics Program (TAMP) of the Office of the Undersecretary of Defence for Research and Engineering. The second phase of the program will develop prototypes of multi-chip packages, and accelerate the advancement of interface standards, protocols and security for heterogeneous systems. The Rapid Assured Microelectronics Prototype Commercial (RAMP-C) program envisages the creation and establishment of a sustainable, leading-edge, domestic foundry solution for the USA. As per the planning

155 Ibid.

156 'Intel wins US Government Advanced Packaging Project', Intel, 2 October 2020, at https://www.intel.com/content/www/us/en/newsroom/news/us-government-advanced-packaging-project.html#gs.crytxw, accessed 11 September 2022.

documents, the first phase has been sponsored for US$ 309 million, and will have two additional phases, with the requirement being the creation of a US-located foundry which is capable of a complex SoC chip fabrication, using 7/5 nm Silicon CMOS technology.[157] RAMP will provide the design centre for custom chips; SHIP will provide the packaging and testing for the end product; and RAMP-C will provide the leading-edge foundries for both custom and commercial, over-the-shelf (COTS) products.[158]

Electronic Resurgence Initiative (ERI)

Not only this, DoD has established the Electronic Resurgence Initiative (ERI) announced by the Defence Advanced Research Projects Agency (DARPA) in Jun 2017. This initiative plans to leverage the unique position of the DoD in ushering in technological innovations within the electronics industry and academia.[159] This is based on historical precedents wherein DoD-led academic research and commercial investments led to advances in electronics. These are ambitious long-term projects, which aim to look at altering chip ISAs, and to look at materials other than silicon to offset the critical dependence on silicon. Some of the programs currently underway include Data Protection in Virtual Environments (DPRIVE) (Fully Homomorphic Encryption (FHE) which is mainly used for the computation of data in clouds without the need for decryption);[160]

157 Odell, L., DiLorenzo, C. D., Dawson, C. A., & Kowalyk, M. D., 'Supply Chain Risk in leading-edge integrated circuits', Institute for Defence Analyses, March 2021, at https://www.ida.org/-/media/feature/publications/s/su/supply-chain-risk-in-leading-edge-integrated-circuits/d-21590.ashx, accessed 24 September 2022.

158 Williams, B. D., 'DOD forms New Task Force to Shore up supply chain', Breaking Defense, 7 September 2021, at from https://breakingdefense.com/2021/09/dod-forms-new-task-force-to-shore-up-supply-chain/, accessed 24 August 2022.

159 'DARPA Electronics Resurgence Initiative', DARPA, 8 August 2022, at https://www.darpa.mil/work-with-us/electronics-resurgence-initiative, accessed 10 September.

160 Jacobs, B. (n.d.), 'Data Protection in Virtual Environments (DPRIVE)', DARPA, at https://www.darpa.mil/program/data-protection-in-virtual-environments, accessed 11 September 2022.

Foundations Required for Novel Compute (FRANC) (develop innovative approaches as alternatives to traditional von Neumann architecture by leveraging advances in materials, devices, and integration technology);[161] Hierarchical Identity Verify Exploit (HIVE) (advances in graph analytics used in the field of cyber security, social media analysis, and infrastructure monitoring);[162] Software-defined Hardware (SDH) (program aims to create hardware/software systems that allow data-intensive algorithms to run at near ASIC efficiency without the cost, development time,[163] and similar programs. These programs are mostly in the conceptual stage; but any practical utilisation will have to contend with attempts by China to either disrupt the process through innovation, or by grey zone warfare.

Grey Zone Warfare by China

In order to offset its disadvantage in chip manufacturing, China has pursued grey zone warfare with increased ferocity, and has progressed on quite a few fronts simultaneously. Grey zone warfare can be defined as a series of offensive actions undertaken by a state against its adversary which are below the threshold of armed conflict, and places the onus of retaliation on the adversary.[164] China has poached talent from TSMC,[165] and

[161] Joshi, Y., (n.d.), 'Foundations Required for Novel Compute', DARPA, at https://www.darpa.mil/program/foundations-required-for-novel-compute, accessed 11 September 2022.

[162] Jacobs, B., (n.d.), 'Hierarchical Identify Verify Exploit (HIVE)', DARPA, at from https://www.darpa.mil/program/hierarchical-identify-verify-exploit, accessed 11 September 2022.

[163] Shrobe, H., (n.d.), 'Software Defined Hardware (SDH)', DARPA, at https://www.darpa.mil/program/software-defined-hardware, accessed 11 September 2022.

[164] 'Today's wars are fought in the 'gray zone.' here's everything you need to know about it', Atlantic Council, 23 February 2022, at https://www.atlanticcouncil.org/blogs/new-atlanticist/todays-wars-are-fought-in-the-gray-zone-heres-everything-you-need-to-know-about-it/, accessed 23 September 2022.

[165] Hale, E., 'Taiwan cracks down on China Poaching Tech Talent', Technology, Al Jazeera, 4 May 2022, at https://www.aljazeera.com/economy/2022/5/4/taiwan-is-trying-to-thwart-chinas-efforts-to-poach-tech-talent, accessed 23 September 2022.

committed massive cyber espionage against the top semiconductor companies in the world.[166] A cybersecurity firm based in Taiwan, Cycraft, detailed the actions of a Chinese state-sponsored hacking campaign which compromised at least seven Taiwanese firms between 2018 and 2020. The attack was aimed at stealing chip designs, source codes, and software development codes.

There are also fears that China may be waging grey zone warfare through a very unlikely ally: Russia. Two leading US firms — Intel and Nvidia — were targeted by the Solarwinds attack allegedly by Russia.[167] The level of compromise is still not clear. In the Ukrainian context, there are fears that the Chinese may be supplying much-needed semiconductors to the Russians. Russia is facing a major shortage of microchips for its missile systems and other weapon platforms, since most of the missile inventory has already been expended in the invasion of Ukraine.[168] Now, the Russians have had to depend on legacy equipment, and are looking at refurbishing their supplies of semiconductors.

Russian Dependence on Semiconductors

Russia is apparently down to the last four dozen of its hypersonic missiles. A report from *Politico* lists 25 Priority 1 items that are being sought to be purchased from abroad, including microchips manufactured by US firms Marvell, Intel, Holt, ISSI, Microchip, Micron, Broadcom and Texas

166 Greenberg, A., 'Chinese Hackers Have Pillaged Taiwan's Semiconductor Industry', Wired, 6 August 2020, at https://www.wired.com/story/chinese-hackers-taiwan-semiconductor-industry-skeleton-key/, accessed 20 September 2022.

167 Clark, M., 'Big Tech companies including Intel, Nvidia, and Cisco were all infected during the Solarwinds hack', The Verge, 21 December 2020, at https://www.theverge.com/2020/12/21/22194183/intel-nvidia-cisco-government-infected-solarwinds-hack accessed 21, September 2022.

168 Gauthier-Villars, D., Stecklow, S., Tamman, M., Grey, S., & MacAskill, A., 'Special report-as Russian missiles struck Ukraine, Western Tech still flowed', Reuters, 8 August 2022, at from https://www.reuters.com/article/ukraine-crisis-russia-missiles-chips-idUSL8N2ZJ087, accessed 1 September 2022.

Instruments.[169] They have also placed a demand for chips from Japan's Renesas, and Germany's Infineon; as also microcircuits from the US firm Vicor; and connectors by US firm AirBorn.[170] Russians have various ways to acquire these items, such as buying them on unregulated online marketplaces, and using third-party front shops and post-box companies to smuggle high-tech kits into the country. As per a statement by US Treasury Secretary, Gina Raimondo, Russia has become so desperate for sophisticated semiconductors for its weapons that it has been stripping microchips from dishwashers and fridges to use in its military gear.[171] However, since this intelligence was attributed to Ukrainian officials, it needs to be taken with a pinch of salt.

Russians have indeed smuggled high-grade military parts from the West since the days of the Cold War. Since the 1970s, the USA has used export controls as a way to ensure a technological edge over the then-Soviet Union. The USA felt that Soviet superiority in conventional weaponry and manpower in any military campaign in West Germany (like the Fulda Gap), could only be offset through sophisticated technology and, for that, a distinct gap always needs to be maintained.[172]

Another foundational assumption for applying strict export control regimes was that two opposing systems (capitalism and communism, in this case) with nothing in common, could be insular to each other. However, the interconnected supply chains of today have made it impossible for the

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169 Sheftalovich, Z., & Cerulus, L., 'The chips are down: Putin scrambles for high-tech parts as his arsenal goes up in Smoke', POLITICO, 6 September 2022, at from https://www.politico.eu/article/the-chips-are-down-russia-hunts-western-parts-to-run-its-war-machines/, accessed 11 September 2022

170 Ibid.

171 Humphries, M., 'Russia Is Using Chips from Dishwashers to Fix Its Tanks', PC Mag, 13 May 2022, at from https://www.pcmag.com/news/russia-is-using-chips-from-dishwashers-to-fix-its-tanks, accessed 10 September 2022.

172 Hammerich, L. C. H. R., 'Defense at the Forward Edge of the Battle or rather in the Depth? Different approaches to implement NATO's operation plans by the alliance partners, 1955–1988', *Journal of Military and Strategic Studies*, 15(3), 2014.

Cold War-era sanctions to work. These sanctions restricted entire components and fields. However, currently, Chinese companies are involved in some stages of chip fabrication, such as providing rare earth metals,[173] and targeting countries based on components may backfire on the sanctioning country. After the Ukrainian invasion, the USA and other countries banned high-tech exports to Russia in an attempt to disrupt and destroy Russia's industry. Many tech companies announced that they had halted all exports to Russia. However, a joint report by Reuters and the Royal United Services Institution (RUSI) found that the flow of Western brand-name computer parts to Russia had not stopped, and thousands of shipments have been supplied to Russia since the Ukrainian invasion. The shippers were mainly unauthorized suppliers; but they also included some manufacturers.[174] Several missiles and guided rockets used by Russian forces against targets in Ukraine (3650 as per Reuters) used microcontrollers, programmable chips, and signal processors made by USA and Germany, including TI, Altera (owned by Intel), Xilinx (owned by AMD), Maxim Integrated Products Inc (acquired by Analog Devices Inc), and Cypress Semiconductor (owned by German Infineon AG).[175]

There is concern amongst Western governments that they have little ability to stop countries like China from transferring microchips to Russia.[176] Additionally, Russia's Ministry of Industry and Trade has prepared proposals that seek to further incentivize local companies to produce the

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173 'Does China Pose a Threat to Global Rare Earth Supply Chains?' ChinaPower Project, 12 May 2021, at https://chinapower.csis.org/china-rare-earths/, accessed 11 September 2022.

174 Gauthier-Villars, D., Stecklow, S., Tamman, M., Grey, S., & MacAskill, A., 'Special report-as Russian missiles struck Ukraine, Western Tech still flowed', Reuters, 8 August 2022, at https://www.reuters.com/article/ukraine-crisis-russia-missiles-chips-idUSL8N2ZJ087, accessed 1 September 2022.

175 Ibid.

176 Albanese, C., 'EU suspects China may send chips, Tech to soften Russian sanctions', Bloomberg.com, at https://www.bloomberg.com/news/articles/2022-03-25/eu-analysis-suggests-china-may-send-tech-hardware-to-help-putin, accessed 24 August 2022.

high-tech components needed by the military-industrial complex,[177] such as slashing taxes, reducing insurance premiums, providing preferential loans, and guaranteeing purchases. Beijing has already provided Russia with off-road vehicle exports for command personnel, as well as drone components and naval engines[178] — though this enthusiasm seems to be slowing down, as was evident from the proceedings of the latest Shanghai Cooperation Organisation (SCO) summit held in Samarkand. China's intent and capacity to provide Russia with advanced chips for its weapons programs has hit a brick wall with a host of sanctions applied by the USA. The war in Ukraine as well as the wheat shortage has led countries to believe that a similar scenario may obtain in case China intends to attack Taiwan, and resilience may need to be introduced in the supply chain so that capabilities for chip production may remain, or be created in certain countries in case the main pipeline for advanced chips is disrupted.

Another tenet of China's grey zone warfare — which has still not been proven yet — is the possible use of hardware trojans (HTs) for introducing counterfeits and malicious insertions in the target countries' supply chains of chips. In the US military, a Senate Armed Forces Committee report found 1800 incidents of counterfeit electronic parts in defence equipment.[179] A 14 September 2022 report by *Air Force Times* has found that there was likely use of counterfeit electronic parts in the ejection seat of an F-16 Fighting Falcon, flown by First Lt David Schmitz on 30 Jun 2020, who died post ejection when his parachute failed to deploy. An internal investigation by the US Air Force (USAF) confirmed that the 'electronics

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[177] Gauthier-Villars, D., Stecklow, S., Tamman, M., Grey, S., & MacAskill, A., 'Special report-as Russian missiles struck Ukraine, Western Tech still flowed', Reuters, 8 August 2022, at https://www.reuters.com/article/ukraine-crisis-russia-missiles-chips-idUSL8N2ZJ087, accessed 1 September 2022.

[178] Hille, K., 29 March 2022, 'China reverses roles in Arms Trade with Russia', *Financial Times*, at https://www.ft.com/content/dc4bc03c-3d9d-43bd-91db-1ede084e0798, accessed 14 September 2022.

[179] Tripathi, A., 'The economics of hardware trojans: An expert's opinion', *Journal of Information Technology Case and Application Research*, *22*(3), 2020, pp.159–174, at https://doi.org/10.1080/15228053.2020.1824878

inside the seat were scratched, unevenly sanded, and showed otherwise shoddy craftsmanship'.[180] However, there are doubts that some of the pieces may have been fraudulent, and an Air Force Research Lab report suspects that several transistors and microchips may have been fake. Suppliers such as Atmel, Analog Devices, and Siliconix provided the potentially fake transistors, memory, and accelerometer chips.[181]

The US DoD considers access, buffer during shortages, or supply chain shocks, ban on foreign ICs, and lack of trusted alternatives as critical vulnerabilities,[182] especially since no other company, apart from Intel, has any interest in leading-edge IC manufacturing. Most US companies have either gone fabless, or are specialising in the manufacture of analog chips and memory ICs — none of which requires leading-edge technologies. Counterfeits and malicious insertions are always a risk when manufacturing units are not within the country. HTs play a big part in the latter of the two.[183]

HTs and Cyber Attacks in the Upstream Phase of Chip Manufacturing

The tightening of export controls by the USA has led to a two-pronged response by the Chinese: indigenisation, and grey zone warfare, which are closely linked. The blockade by China of Taiwan post-Nancy Pelosi's visit to the island can be viewed as part of Gray Zone warfare by China to see how the world reacts to a shortage of chips from TSMC. It may be a

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180 Cohen, R., 'An F-16 pilot died when his ejection seat failed. Was it counterfeit?' *Air Force Times*, 14 September 2022, at https://www.airforcetimes.com/news/your-air-force/2022/09/13/an-f-16-pilot-died-when-his-ejection-seat-failed-was-it-counterfeit/ accessed 19 September 2022.

181 Ibid.

182 'Securing Defense-Critical Supply Chains: An action plan developed in response to President Biden's Executive Order 14017', 2022, (rep.).

183 Tripathi, A., 'The economics of hardware trojans: An expert's opinion', *Journal of Information Technology Case and Application Research*, *22*(3), 2020, pp. 159–174, at https://doi.org/10.1080/15228053.2020.1824878.

part of a long-term calculation to make the West pay for the tight export controls and bans. Gray zone warfare, and its manifestation in the form of hardware trojans (HTs) and partnership with Russia will be looked at in detail in the succeeding paragraphs. An interesting counter argument from James Andrew Lewis, the Director of the CSIS's Strategic Technologies Program, posits that broad-based export controls on China may end up hurting US companies in the long term as compared to the Chinese. This is based on experience when, in response to US export controls on satellite equipment to China, the foreign companies just designed US components out of their products, and built alternate sources of supply[184] — although in such a tightly integrated supply chain, the likelihood of this happening is pretty low. Also, the fear of an aggressively rising China which has no qualms in using its economic and geopolitical heft against several countries, may force these companies to be cautious. The Chinese are currently three generations behind in leading-edge chip fabrication,[185] and with exponential advantages accruing to companies due to Moore's law slowing, the chances are that the catch-up will be faster. China's efforts at indigenous chip design and manufacturing are 30 years in the making, although progress has not been commensurate with the investment of time and money involved. The succeeding paragraphs look at the likely ways HTs and cyberattacks may affect the semiconductor manufacturing process, as part of China's grey-zone operations.

Traditional norms of cyber security focus on software and software-impacted hardware and physical systems. But it is understood that the hardware remains sacrosanct, or the 'Root of Trust'. A hardware root of trust is the foundation on which all secure operations of a computing system depend. It contains the keys used for cryptographic functions, and

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184 Lewis, J. A., 5 May 2020, 'Managing Semiconductor Exports to China', Center for Strategic and International Studies (CSIS), at https://www.csis.org/analysis/managing-semiconductor-exports-china, accessed 3 September 2022.

185 'China 3-4 generations away from 'cutting-edge' chip capabilities: Report', Moneycontrol, 21 January 2022, at https://www.moneycontrol.com/news/business/china-3-4-generations-away-from-cutting-edge-chip-capabilities-report-7966361.html, accessed 31 August 2022.

enables a secure boot process. It is inherently trusted, and therefore must be secure by design. The most secure implementation of a root of trust is in hardware — making it, in theory, immune from malware attacks.[186] As such, it can be a stand-alone security module, or implemented as a security module within a processor or system-on-chip (SoC).[187] A silicon-based hardware root of trust falls into two categories: fixed function, and programmable. A fixed-function root of trust is typically compact, and designed to perform a specific set of functions, like data encryption, certificate validation, and key management. A programmable root of trust is versatile and upgradable, enabling it to run entirely new cryptographic algorithms and secure applications to meet evolving attack vectors. It can be continuously updated to contend with an ever-increasing range of threats.[188]

Trust in a hardware system — due to global supply chains — requires a linear or graded certification process, based on modules and components. It is an exhaustive, time-consuming process, but seems to be the only defence against counterfeits. An HT is a functionality modification which makes the system behave unexpectedly or abnormally.[189] It is a form of a firmware attack since pure HTs are hard to find in public literature. R-SIM, the trojan that enables US Apple iPhones to respond to any carrier in another country (by blanking out the phone's IC Card Identification Device

[186] Landry, J., 'What Is Hardware Root of Trust? Dell Technologies, 19 April 2021, at https://www.dell.com/en-us/blog/hardware-root-trust/, accessed 9 September 2022.

[187] Zimmer, V., & Krau, M., 'Establishing the root of trust', UEFI. org document, August 2016.

[188] Coughlin, A., Cusack, G., Wampler, J., Keller, E., & Wustrow, E., 'Breaking the trust dependence on third party processes for reconfigurable secure hardware', in *Proceedings of the 2019 ACM/SIGDA International Symposium on Field-Programmable Gate Arrays*, February 2019, pp. 282–291.

[189] Tripathi, A., 'The economics of hardware trojans: An expert's opinion', *Journal of Information Technology Case and Application Research*, 22(3), 2020, pp. 159–174, at https://doi.org/10.1080/15228053.2020.1824878.

(ICCID) signals to the server), is the closest to an HT.[190] There is a trade off between the size and location of the HT deployment since HTs require certain physical access to a system intended to be infected. If the size of the HT is too big or conspicuous, there is a challenge of it being outed earlier in the testing or vetting phase. Also, the size of the HT may lead to fingers being pointed at a certain nation-state since only advanced nations like China have the capability and wherewithal to inject HTs. The best option that countries deploy is a hybrid trojan — part software and part hardware. Four surfaces are exploited by HT — SoC, incomplete functionality/ backdoor, boards and systems (including counterfeit chips), and side-channel attacks (SCAs).[191]

The threat to the EDA industry from China is in the form of talent loss, EDA IP theft, and EDA tool sabotage. The Chinese EDA industry does use pirated US EDA software to service its exclusive semiconductor manufacturing industry. ASICs made for mass markets are called Application Specific Standard Products (ASSPs), such as Qualcomm's SnapDragon. ASSPs also reverse engineer their competitors' products to get a detailed understanding of their chips' node size, power consumption, and a number of transistors. Even if a trojan is inserted, then it is most likely that it will be discerned before likely deployment. Thus, if an HT is inserted, it is either through the knowledge of the firm, or very improbable.[192] Focused ion beam (FIB) insertion in the post-production phase of chips may be possible in ASICs. Since FIB is potent enough for the alteration of circuits on a board, and is the best vessel for inserting small ASIC modifications if there is access to the original design.[193] Multiple flaws in AMD's Ryzen and Epyc processors were reported by an Israeli

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190 Ibid.

191 Lerman, L., Bontempi, G., & Markowitch, O., 'Side channel attack: an approach based on machine learning', Center for Advanced Security Research Darmstadt, 29, 2011.

192 Tripathi, A., 'The economics of hardware trojans: An expert's opinion', *Journal of Information Technology Case and Application Research*, 22(3), 2020, pp. 159–174.

193 Ibid.

cybersecurity firm in March 2018; it enabled hackers to access secure portions of the processors themselves.[194]

Within foundries, the only way to insert a trojan is to recreate or re-engineer the placement of components, ASIC design, or access the original design database. Cyber violations may lead to the latter.[195] Sometimes backdoors are used by the firms themselves to access the chips for post-release improvements, or modifications, or as part of security diktats.[196] Incomplete functionalities in the form of design bugs, or vulnerabilities, are left in the chip as a trade off for a faster release schedule, ahead of a firm's competitor. This is the so-called tech debt. Here, minimum hardware is used for targeting the system, and the main target is the firmware. Spurious and counterfeit chips are also equally responsible for attacks. System-level trojans do not sit on the systems, but are generally between boards or systems. The main issue that the attacker focuses on is a reduction in the level of trust between two systems. Side channel attacks (SCAs) are used for accessing information, especially in labs. They can either use passive observation of side channels or active fault injection.[197]

The use of HTs for inserting counterfeits into the supply chain of target countries is well documented. Though improbable, their utility and sophistication of deployment can only be done through a state actor. If done correctly, the reduction in trust levels between the suppliers and users

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194 Giles, M., 'Researchers say they've found serious security flaws in some AMD Chips', *MIT Technology Review*, 29 June 2022, at https://www.technologyreview.com/2018/03/13/241053/researchers-say-theyve-found-serious-security-flaws-in-some-amd-chips/, accessed 19 September 2022.

195 Tripathi, A., 'The economics of hardware trojans: An expert's opinion', *Journal of Information Technology Case and Application Research*, *22*(3), 2020, pp. 159–174.

196 Linder, C., 'The NSA Wants Big Tech to Build Software 'Back Doors.' Should We Be Worried?' *Popular Mechanics*, 2 November 2021, at https://www.popularmechanics.com/technology/security/a34533340/nsa-tech-back-doors-software/, accessed 24 September 2022.

197 Tripathi, A., 'The economics of hardware trojans: An expert's opinion', *Journal of Information Technology Case and Application Research*, 22(3), 2020, pp. 159–174.

may be so steep that it may lead to slower deployments of new products, due to longer verification and testing times. This creates challenges for the competitive edge of the USA, and use cases for new AI, 5G, and IoT-based lab experiments. Such is the dependence of the USA on advanced chips from abroad that as much as 90% of the advanced chips meant for the USA are now sourced from East Asia.[198]

Cyber attacks during the design or upstream phase are also one of the major challenges that have been under-documented. Malicious or false codes can enter the design process when using unauthorised or unknown EDA tools. This happens during one of two cases: countries or companies under export controls try to circumvent the restrictions through the use of counterfeit software, or in the hope of profits, as well as purchasing and downloading pirated software. Some attempt to resort to using virtual private networks (VPN) to bypass controls which may provide hackers with more attack options. Cadence — one of the three firms in the entire world to provide EDA tools to fabless firms — suffered from an infamous vulnerability known as 'Log4j', which surfaced in 2021,[199] providing opportunities for hackers to exploit the software of the company. Other ways of using cyber attacks to adversely impact the design of the chips in the inception stage itself include hijacking remote access (occasionally used by equipment manufacturers to troubleshoot SMEs); advanced persistent threats used as a form of insider attacks; and taking advantage of weak security controls during bilateral international contracts between fabless firms and their foundries. These are some of the ways in which even chip designing is at risk of being derailed at the initial stage.

This essay now looks at the situation in India, and starts with a brief discussion of India's chip manufacturing history, its hits and misses, and

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[198] Barnes, J. E., 'How the Computer Chip Shortage Could Incite a U.S. Conflict with China', *The New York Times*, 26 January 2022, at https://www.nytimes.com/2022/01/26/us/politics/computer-chip-shortage-taiwan.html, accessed 10 September 2022.

[199] McLellan, P., 'Log4J: 2021 Ends the Same Way It Began, Breakfast Bytes - Cadence Blogs', Cadence Community', 2021, at https://community.cadence.com/cadence_blogs_8/b/breakfast-bytes/posts/log4j, accessed 10 December 2022.

the current attempts at creating an indigenous semiconductor ecosystem in India.

History of Semiconductor Design and Manufacturing in India

The history of semiconductor manufacturing in India started when Texas Instruments (TI) set up an R&D centre in Bengaluru, India in 1985.[200] India has remained a design-focused actor in the semiconductor supply chain. A small number of companies, mostly based in Bengaluru, are now attempting to create their own chips as well as retain IP rights over their creation.[201] Though close to 20% of engineers worldwide working in this industry are Indians, the value-addition done by them is for multinational companies (MNCs), and not Indian firms. The government-owned Semiconductor Complex Limited (SCL) was started in 1983; but a fire in 1989 forced it to close till 1997.[202] Starting with a 5000 nm process in 1984, SCL rapidly advanced to the 800 nm technology, which was the cutting edge only a year or two before. At that time, China and Taiwan had not even entered the fab space. ISRO revived SCL, and used it for the low-volume manufacture of chips for its programs; but it is only a shadow of what it could have been. Currently, it functions as a laboratory. However, the government intends to upgrade it. In the 1960s, at the beginning of the silicon revolution, Fairchild Semiconductor considered

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200 'Texas 'instrumental' in getting Tech Mncs here', *The Times of India*, 11 September 2010, at https://timesofindia.indiatimes.com/business/international-business/texas-instrumental-in-getting-tech-mncs-here/articleshow/6533555.cms, accessed 11 September 2022.

201 Mihindukulasuriya, R., 'How India is trying to win the semiconductor race, fighting decades of challenges & setbacks', *The Print*, 18 July 2022, at https://theprint.in/tech/how-india-is-trying-to-win-the-semiconductor-race-fighting-decades-of-challenges-setbacks/1037063/, accessed 10 August 2022.

202 Singh, S., 'Why a made-in-India chip remains chimeric', LiveMint, 17 March 2010, at https://www.livemint.com/Home-Page/P8hJk0uMYmajN0tFph692K/Why-a-madeinIndia-chip-remains-chimeric.html, accessed 10 September 2022.

building a fab here, but bureaucratic lethargy chased them away to Malaysia.[203]

After the 1962 war, Bharat Electronics Ltd (BEL) set up a fab to manufacture silicon and germanium transistors. When cheaper ICs from China, Taiwan, and South Korea entered the market, BEL could not match global quality and price standards, and many of the fab units had to be shut down.[204] The current government has made efforts to pursue self-reliance in chip manufacturing through rejuvenating SCL. Multiple options are being thought of — such as commercialising SCL through a joint venture (JV) with a business house; handing over SCL to ISM from its current ownership with the Indian Space Research Organisation (ISRO), asking SCL to enhance the production capacity of its 180nm node chips; adding compound semiconductor manufacturing capacity; or converting SCL to an 'Intermediate Research Organisation (IRO)'.[205]

Before these crucial decisions are made regarding the future of SCL, it is important to look in detail at India's national security challenges from the perspective of indigenous semiconductors, and why the government has insisted on accelerating the process of indigenising the manufacturing of semiconductors.

India's National Security Challenges from a Wider Perspective

Environmental Security

An alternate way of looking at security — and one which was briefly discussed at the start of the essay — is to encompass non-traditional

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203 Mihindukulasuriya, R., 'How India is trying to win the semiconductor race, fighting decades of challenges & setbacks', *ThePrint,* 18 July 2022, at https://theprint.in/tech/how-india-is-trying-to-win-the-semiconductor-race-fighting-decades-of-challenges-setbacks/1037063/, accessed August 10, 2022.

204 Ibid.

205 'SCL commercialisation under India Semiconductor Mission: Meity invites proposal for Asset Valuation of Fab Facilities', Swarajyamag, 2022, at https://swarajyamag.com/news-brief/scl-commercialisation-under-india-semiconductor-mission-meity-invites-proposal-for-asset-valuation-of-fab-facilities, accessed 10 July 2022.

methods of thinking. The climate change threat and its responses have evoked several pathways: reducing the carbon footprint; reducing emissions; switching to alternative methods of energy consumption; aggressive afforestation initiatives; and diplomacy, among others. India has taken the lead in several climate change mitigation policies. At the COP-26 global summit on climate change in Glasgow held last year, Indian Prime Minister (PM) Narendra Modi pledged five goals of the Indian government, also known as Panchamrit.[206] These included taking India's fossil-related energy consumption to below 500 GW by 2030, and achieving 'Net Zero' by 2070.[207]

One of the major initiatives of the Indian government toward this goal is a proactive move toward electric vehicles (EVs) which currently run on lithium batteries,[208]but may change over to a more efficient mode of power generation and consumption shortly.[209] However, one of the main challenges for this transition — and where the security factor comes into play — is the availability of chips for the EVs, whose continued availability will be critical if India intends to honour its aim. India's quest for greenification is based on transitioning to EVs as soon as possible, along with the attendant infrastructure, especially charging batteries. There are a number of cross-cutting factors that impact India's climate security initiatives. While the move to EVs is a logical move in the current scenario, in the long term it may prove to be unsustainable from an environmental point

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206 National Statement by Prime Minister Shri Narendra Modi at COP26 Summit in Glasgow, 1 November 2021, Press Information Bureau, at https://pib.gov.in/PressReleseDetail.aspx?PRID=1768712, accessed 19 August 2022.

207 Ibid.

208 Chaudhary, A., 'India, World Bank looking to spur lending for electric vehicles', *The Economic Times*, 21 September 2022, at https://economictimes.indiatimes.com/industry/renewables/india-world-bank-looking-to-spur-lending-for-electric-vehicles/articleshow/94343959.cms, accessed 24 September 2022.

209 'Low-cost, sustainable alternative to lithium-ion batteries found', *The Economic Times*, 3 August 2022, at https://economictimes.indiatimes.com/industry/renewables/low-cost-sustainable-alternative-to-lithium-ion-batteries-found/articleshow/93325123.cms, accessed 24 September 2022.

of view. An EV requires close to six times the number of integrated circuits (ICs) than a conventional fossil-fuel-based car. Similarly, an EV uses 10,000 times as much lithium as a single smartphone. Already, this points to a brewing competition between automotive and smartphone manufacturers, which may lead to the construction of more fabs, aggravating water availability issues, and thereby affect social security issues. Now, fossil fuels contain stored energy within themselves which has to be burned to be released. For EVs, this takes the form of lithium-ion-based batteries. As per one estimate, '80% of battery storage in 2040 would be used in light-duty EVs. This will require a 40-fold increase in the production of lithium and nickel, and more than 20 times as much as copper, graphite, and cobalt as compared with 2020 levels'.[210] As a result, forms of pollution will no doubt be transformed, but they will not be mitigated. Mobility will continue to be imperative, and unless a radical rethought of the societal layout is envisaged, this will continue forming a challenge. The exponential increase in chips required for ICs, and the transformation of vehicles from a means of conveyance to a service — the emerging field of mobility-as-a-service (MaaS) — will involve a continued dependence on chips, whose production, if not indigenised, will create major bottlenecks for automotive manufacturers in the medium to long term. The dependence of the entire world on a handful of fabs is unsustainable for all industries, and not just for defence or smartphones.

The chip manufacturing sector is very water intensive and India, which is already dealing with intermittent dry spells in a number of its states, may see a further share of available water go down. Also, even in fossil fuel-based vehicles, increased informatisation has increased demands for more chips. If India aims to fulfil its UN climate change goals in line with preserving its economic security, and ensuring better connectivity due to 5G's potential, it needs to participate in multilateral efforts to stabilise the

[210] 'Sustainable and responsible development of minerals: the role of critical minerals in Clean Energy Transitions – analysis', IEA, 2021, at https://www.iea.org/reports/the-role-of-critical-minerals-in-clean-energy-transitions/sustainable-and-responsible-development-of-minerals, accessed 10 December 2022.

semiconductor supply chain, and even create redundancies. In the short term, the automotive producers have focused on luxury cars which use more electronics per car, and now, the oil-price spike is driving the demand for EVs and hybrids — again using a lavish portion of automotive electronics. Demand has been built up which, while being satiated in the short term, may lead to overcapacity — one of the fears of the semiconductor industry — since the long-term intention is to focus on lading up the automotive with several connectivity and autonomous features, apart from the climate-change mandated turn towards EVs and hybrids.[211]

The potential for the automotive semiconductor industry has been estimated to jump to US$ 250 billion by 2040, excluding semiconductors required for charging EVs and V2X infrastructure.[212] The best part is that this segment does not require leading-edge chips with single-digit nm. So-called legacy chips between 28-40 nm are the backbone of this industry. The car-to-cloud system — which requires the onboarding of several 'smart' features of the car directly to a cloud — will enable the 'supercomputerification' of cars. Features in the future which are likely to be added to cars include LiDAR sensors, image recognition systems, and 5G communications systems. Apart from this, the transition to green technology (including hybrid and EVs) will require an exponential use of semiconductors — in fact, almost doubling it. The kind of chips used will also change. Autonomous and connected vehicles will require logic IC and memory chips, while electric powertrains will require analog ICs and discrete semiconductors.[213]

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211 Vancamp, F., 'Automotive Semiconductors: The New Ice Age', KPMG, 2022, at https://home.kpmg/be/en/home/insights/2022/02/aut-automotive-semiconductors-the-new-ice-age.html, accessed 24 September 2022.

212 Vancamp, F., 'Automotive Semiconductors: The New Ice Age', KPMG, 2022, at https://home.kpmg/be/en/home/insights/2022/02/aut-automotive-semiconductors-the-new-ice-age.html, accessed 24 September.

213 Ibid.

Strategic Security

In terms of strategic security, the way a military envisages the future of warfare will also change the way the semiconductor industry is incentivised. The current thought process is to be indigenous and, in the medium term, stabilise the supply chain to the extent possible. However, the long-term requirement is innovation, which is no doubt one of the reasons why the USA competes with China. If the Indian military decides that a non-contact mode of warfighting — emphasising cyber, EW warfare, and non-contact warfare — is the way ahead, the demand for such capabilities will likely be more. In effect, what this essay also argues is that instead of a territorial and platform-based approach, a capabilities-oriented approach is much more pragmatic. The focus is on augmenting specific capabilities in the form of mini-offsets rather than going for all-out modernisation. Non-contact warfare, which has increasingly involved the use of unmanned systems, medium and short-range missiles, information warfare and cyber attacks — all depend, to a large extent, on innovation and indigenisation, supported by robust partnerships with like-minded nations.

Again, in this reasoning, the possibility of a conflict is not being denied; only the prospect of an all-out war — a variant of which we are currently witnessing in Russia’s invasion of Ukraine — is being discounted. Instead of looking at set periods of war and peace as precedents, it is important to view relations between States as part of a larger competition continuum. India’s growing interests necessitate a higher paradigm of thinking about its security interests. For example, the scope and ambit of the Defence Space Agency (DSA) will likely increase in the near future, with a focus on intelligence, surveillance and reconnaissance (ISR), and communications. When that happens, there will be a requirement for specialised microcontrollers on board our indigenous satellites, apart from radiation-hardened ICs and monolithic microwave ICs.

So far, the needs of defence are one of the lowest priority areas for the processor and semiconductor industry. If the military wants to make its presence, importance, and consumption pattern felt, there needs to be a proactive, almost aggressive stance towards the indigenous semiconductor industry, and demand for specific chips for the military. This also means going into much greater granularity in the General Staff Qualitative

Requirements (GSQR) than before, especially in areas such as electro-optical (EO) devices, precision munitions, autonomous systems, and servers for Big Data applications. Future procurement contracts must insist on Indian-designed and manufactured chips.

Another issue is how innovation needs to be stirred within the military. Most of the current requirements of the military are image sensors, communication chips, amplifiers, FPGAs, and microcontrollers. The node sizes vary between 40 and 180nm.[214] This is a market which also coincides with that of the automotive sector, which has been facing a slump for the past many months due to the major customers of the foundries being CSPs and mobile manufacturers, whose requirement for advanced chips far outweighs the demand of the legacy-oriented automotive sector. The Indian Armed Forces have pivoted towards AI and 5G,[215] and even floated a request for information (RFI) for an internet-of-military-things (IoMT) system[216] — all of which require increasingly advanced chips. However, the operational and systemic thinking within the military organisation still treats AI, EW, and other data-dominant methods as part of an experimental schema.

There is a dawning recognition that these technologies are important for future warfare. However, the main challenge is to understand the utilisation, and how and if they can provide a quantum jump in the military's effectiveness in the battlefield. Statements by various service Chiefs extolling the virtues of AI and other emerging technologies — such as drone swarms, 5G, IoMT, and quantum computing — underline the fact that the intentions are present.[217]

The need for military modernisation in India has generally been hamstrung by several debates: dilemma over investing in the economy versus investing in national security; revenue versus capital expenditure; big-ticket platforms versus capabilities; service centric versus a joint approach. The main question, however, is how to view national security: either as a necessary evil or a public good. It is the view of this author that investment into upgrading the capabilities of the Armed Forces should be viewed through the latter lens. National defence is a public good. Since defence requires a huge technological and industrial supply chain in this day and age, the public good of defence-oriented planning will positively impact many sectors of the economy. Modern Russia's technological weakness provides a blueprint of what happens when the economic and technological foundations of military strength are neglected. Semiconductor manufacturing and design capacity are modern-day infrastructures for technology and software, with the similar requirement that these kinds of infrastructure projects require government incentives and regulatory support to thrive. The Indian government's plans to jump-start the semiconductor start up industry by offering PLIs and design-linked incentives (DLIs) through the Indian Semiconductor Mission (ISM)[218] are applause-worthy.

However, the needs of the defence sector need to be catered for in the initial plan. There is a need within the plan to create space for chip design start ups by offering incentives, and favourably prioritising the defence industry. A much deeper collaboration between the Armed Forces and chip design start ups as well as established players needs to be set up, with specific quotas for legacy chips being set aside. The expertise of the Defence

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[214] Kapoor, V., 'Indian military can't be a silent spectator to global semiconductor boom. see US, China', ThePrint, 7 September 2022, at https://theprint.in/opinion/indian-military-cant-be-a-silent-spectator-to-global-semiconductor-boom-see-us-china/1115864/, accessed 19 September 2022.

[215] Upadhyay, A., 'Indian Armed Forces push for integrating niche technologies', *The Financial Express Stories*, 15 August 2022, at https://www.financialexpress.com/defence/indian-armed-forces-push-for-integrating-niche-technologies/2630428/, accessed 15 August 2022.

[216] 'Request for Information from vendor for proof of concept (POC) for IOMT, Indian Army', (n.d.), at https://indianarmy.nic.in/writereaddata/RFI/789/RFI%20on%20IoMT%2021%20SG%20110521.pdf, accessed 10 September 2022.

[217] 'Indian Army chief general Manoj Pande bats for domestic defence technology', Firstpost, 15 September 2022, https://www.firstpost.com/india/indian-army-chief-general-manoj-pande-bats-for-domestic-defence-technology-11261941.html, accessed 24 September 2022.

[218] 'India Semiconductor Mission', Press Information Bureau, 23 March 2022, athttps://pib.gov.in/PressReleasePage.aspx?PRID=1808676, accessed 10 August 2022.

Research and Development Organisation (DRDO) will also have a major impact. A great incentive for India will be to target the 45-65nm category when looking at jumpstarting semiconductor manufacturing within India. Once a foothold is attained and production starts at scale, then we can aim for single-digit nm chips, and that too in collaboration with Japan, South Korea, and the USA. The CHIPS Act provides for a US$ 500 million fund called the CHIPS for America International Technology Security and Innovation Fund. This fund leverages relationships with international partners in chips, telecoms, and other emerging technologies, and can be harnessed through effective diplomacy.

The American perspective on dual-use technologies prioritises investments in the commercial sector first, checking viability and scale, and then transposing it onto the national security sector. In this case, national security always takes second place.[219] Additionally, in this setup, defence start ups are the ones that lose since they have to first prove that their tech is commercially viable before approaching the DoD. Due to faster tech cycles, the technology is already 5-6 years old before it reaches the military. Also, since defence start ups cannot look into national security solutions at the get-go, they end up ceding space to the already established handful of companies in the defence sector, further consolidating their hold. The defence start ups end up selling to these defence contractors. 'A system that seamlessly moved from capability development to capability adoption would enable founders to build for defence customers first without fear of being swallowed up by the "valley of death".'[220] But this is easier said than done.

In the Indian sector, defence start ups are being incentivised through a variety of means: competitions like Innovation for Defence Excellence (iDEX), PLI and DLI schemes, tax breaks under the Startup India scheme,

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219 Chapman, J., 'Reliance on dual-use technology is a trap', War on the Rocks, 8 September 2022, at https://warontherocks.com/2022/09/reliance-on-dual-use-technology-is-a-trap/, accessed 12 September 2022.

220 Ibid.

handholding of selected start ups by the Indian Armed Forces, etc. All these intend to facilitate the traversing of the Valley of Death. However, how these challenges will be resolved in the semiconductor setup is difficult to estimate now, due to the huge initial setting-up costs of fabs, and the attendant permissions required for land use as well as electricity and water consumption. Even small fabs require substantial capital which the start ups might not be able to conjure. The government may need to look at handholding certain fabs, in conjunction with the state governments.

Conceiving Military Procurement: A New Concept

Another factor to be kept in mind is the fast-changing pace of digital technology which is at variance with the procurement cycle of any military organisation. By the time the checks and balances, negotiations over price, and the final product is acquired and scaled to reach the soldier, the technology has already leapfrogged by at least two or three generations. There is, therefore, a need to look at digital technologies separately from the conventional platform-based ones, and their induction or absorption needs to be faster. In this, two processes need to be expedited, besides creating a new vision of how procurement needs to take place. Firstly, technology adoption needs to be thought of as undergoing five stages from inception to action. These are Inception-Conception-Validation-Scaling-Action (ICVSA).[221] This needs to be accomplished in an expedited time frame. Secondly, and most importantly, there is a need for companies to innovate as well as fail fast. The erstwhile method of pumping money into white elephants needs to be discarded as quickly as possible. When it comes to conceptualising defence procurement, the most grievous handicap that the Indian Armed Forces face is a mindset that looks at military challenges from the perspective of already available technological and

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[221] Upadhyay, A., 'Engagement or Estrangement: Gauging Indian Army's Relationship with the Emerging Technologies, Centre for Land Warfare Studies', CLAWS, 2021, at https://www.claws.in/static/IB-272_Engagement-or-Estrangement.pdf, accessed 12 August 2022.

platform-based solutions that can be commercially procured. Though there has been an evolution in the mindset with the entry of defence start ups, and manufacturing companies for specific geographic and regional requirements, the general solution is adaptation and customisation on an already built platform. Instead, what is required is a new conceptualisation of requirements.

Let's take a hypothetical example. If it is assumed that, for the theatre of counterinsurgency operations in Kashmir, there are requirements for software-defined radio (SDR) sets with particular encryption standards and operations within a certain frequency band. This specific set may not exist for the time being. So, the Army can look for chip design start ups through the Army Design Bureau (ADB) which can design the specialised chip, get a 'tape-out' (the physical design) constructed from either SCL or one of the new fabs within a month, get the design tested in the field, and then the formation may decide whether the set meets their requirement, or whether a major change is required. The most important part is that both the design and manufacture of the communications chip are indigenous. This will obviously involve other manufacturers such as plastics for the overall body but the example is hypothetical and focuses merely on the technical requirements. Similarly, the customised requirements of the three Services in terms of ISR, communications, encryption, IW, and precision computing — all these can and should be addressed indigenously.

Centre for Armed Forces Innovativeness (CAFI)

One cannot assume that the entire technological parameters will be known to the Armed Forces personnel, and this is where the need for translators, or an additional layer of personnel adept in defence technologies, arises. One can place DRDO in this role, or a new organisation comprising members of the defence manufacturing industry, along with DRDO scientists, can be created. The role of this organisation would be to convert the requirements of the Armed Forces into technical parameters for the defence industry so that convergence is achieved in product design and development. Along with serving members of the Armed Forces — technically inclined junior and mid-level officers — this centre hypothetically called the Centre for Armed Forces Innovativeness (CAFI) may be created to serve as a tri-services agency under the Department of Military Affairs. The offices of the ADB and similar organisations of the Indian Navy and the Indian Air Force may be subsumed under this to avoid redundancies, and create common technological products for the three forces.

Though the private and military conception of vehicles is very different, there is likely to be some overlap between the two, especially in the fields of green energy, and likely use of 5G communications and certain sensors. If technological demonstrations are to be believed, then the Indian military is well on its way to thinking about unmanned ground vehicles (UGVs) seriously.[222] This is a parallel initiative, with driverless cars in the private sector. A lot of features can overlap, especially in terms of sensors, connectivity, data analysis, storage, and communications. One of the more critical parts is that the usage of semiconductors — especially in the leading edge category — will increase. This will be coupled with the need to establish massive data centres, and protocols mandating the localisation of data.

Can this entire enterprise be handled by the State? Or, does the private sector needs to step in? Even within the UGV segment, we can have a hybrid version: an Army way of manned-unmanned teaming (MUMT). This will involve advanced driver assistance systems (ADAS), telematics, and electric powertrains. A case is made for converting the current category of tanks, BMPs, and other vehicles to some kind of connectivity-capable machines that can function in a net-centric environment. If we go the whole hog in greenification, then semiconductors will play a huge role in the EV sector in the military too. Charging stations will also be required, along with powertrains. Again, plugging them into a network, and the generation of data will require several advanced chips, especially in the memory and logic IC category.

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[222] Dangwal, A., 'Indian Army to Get 'Unmanned Tanks' for STRIKE Mission; UGVs To Modelled On Heavy-Weight Arjun MBTs', *Eurasian Times*, 13 April 2022, at https://eurasiantimes.com/indian-army-to-get-unmanned-tanks-for-strike-mission-ugvs/, accessed 11 September 2022.

In the current scenario, India's Vedanta Group and Taiwanese Foxconn have agreed to set up a fab in Gujarat. On 13 September 2022, Memorandums of understanding (MoUs) were signed between the companies and the Gujarat government for setting up a semiconductor and display fab with an investment of over Rs 1.54 lakh crores.[223] This is part of a 20-year vision plan announced by the Indian government to boost semiconductor R&D, design, and manufacturing in India. The plan was unveiled in Dec 2021, with a focus on semiconductor fabs, design fabs, compound semiconductors, and OSAT.[224] This is based on the fact that India's consumption of semiconductors is expected to cross US$ 110 billion by 2030.[225] The recent auctioning of the 5G spectrum, and an aim to exploit digital infrastructure for connectivity, e-commerce, and education (among others), through IoT and 5G is one of the primary drivers behind ISM. For this, on 22 March 2022, the Union Cabinet approved the Semicon India program for the development of the semiconductor and display manufacturing ecosystem in India, with a total financial outlay of Rs 76000 crores, or US$ 10 billion.[226] Support will be provided to the industry where the government will cover up to 50% of the project cost and, so far, 5 proposals have been received in the first

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[223] 'Vedanta, Foxconn to invest Rs 1.54 lakh crore to set up semiconductor ecosystem in Gujarat', *The New Indian Express,* 13 September 2022, at https://www.newindianexpress.com/business/2022/sep/13/vedanta-foxconn-to-invest-rs-154-lakh-crore-to-set-up-semiconductor-ecosystem-in-gujarat-2497833.html, accessed 19 September 2022.

[224] 'India Semiconductor Mission', Press Information Bureau, 23 March 2022, at https://pib.gov.in/PressReleasePage.aspx?PRID=1808676, accessed 10 August 2022.

[225] 'India's semiconductor consumption will be highest in the world, worth $110 billion by 2030: MOS IT', *The Economic Times*, 29 April 2022, at https://government.economictimes.indiatimes.com/news/technology/indias-semiconductor-consumption-will-be-highest-in-the-world-worth-110-billion-by-2030-mos-it/91170308, accessed 11 September 2022.

[226] 'India Semiconductor Mission', Press Information Bureau, 23 March 2022, https://pib.gov.in/PressReleasePage.aspx?PRID=1808676, accessed 10 August 2022.

round. Proposals will be examined over a period of 6-8 months. Key players include Vedanta Foxconn (plant to be set up in Gujarat), Singapore-based IGSS Ventures Private, and ISMC (International Semiconductor Consortium). While Foxconn plans to invest US$ 22 billion in Gujarat, ISMC will invest US$ 3 billion in Karnataka, and IGSS $3.2 billion in Tamil Nadu.[227]

The ISMC plant is likely to manufacture 65nm analog semiconductor chips, which will be used in automotive, telecom, consumer electronics, defence, aerospace, and industrial automation. ISMC is a joint venture between the Abu Dhabi-based NextOrbit Ventures and Tower Semiconductor of Israel. Intel will most likely take over Tower. The timeline for the plant is to start operations in four years. As per the comments of the Minister of Electronics and Information Technology during a press conference, proposals worth US$ 20.5 billion have already been received for setting up semiconductors and design fabs. A robust electronics manufacturing sector in India has been envisaged, which will reach a value of US$ 400 billion by 2030. Around 25% of this capacity will be semiconductors; thus, by 2030, India's requirement for semiconductors will be over US$ 100 billion.[228] India has a robust chip design industry; but (like other countries), IP is with companies based in foreign countries. There is a need to design Indian chips so that IP rights remain within India.

Compound fabs, design fabs, and OSAT and ATP facilities as well as design companies are also planned to be promoted. In terms of semiconductor design, India is much ahead of China. But there is a need

[227] 'Vedanta-Foxconn JV, IGSS Ventures, ISMC propose to set up electronic chip manufacturing plants with USD 13.6 billion investment: Statement', *The Times of India*, 19 February 2022, at https://timesofindia.indiatimes.com/vedanta-foxconn-jv-igss-ventures-ismc-propose-to-set-up-electronic-chip-manufacturing-plants-with-usd-13-6-billion-investment-statement-pti-prs-abm-abm/articleshow/89687663.cms, accessed 24 September 2022.

[228] 'Ashwini Vaishnaw Explains Pli Scheme for Semiconductor Ecosystem Development in India', YouTube, 2021, at https://www.youtube.com/watch?v=NaMUQQtlrNA, accessed 11 September 2022.

to add value to Indian products by creating value within the country, and looking at manufacturing chips within India. Since 40-50% of the entire value of the chip manufacturing ecosystem is design,[229] India can harness this. Indian design firms that can beat global players will generate momentum for ATP, which can then lead to semiconductor fabrication capacity. In terms of sales, a calibrated scheme of giving up to 6% tax incentives is also planned over the next five years, at the end of which these incentives will be reduced to. 4%[230] The challenges include the requirement of fiscal space, coordination and cooperation between the Centre and the states for land acquisition, water provision. and power consumption. Instead of looking at autarky, we need to look at increasing India's criticality in the global supply chain.

Design needs to be incentivised, being low-hanging fruit. It is equally important to fund the losses of the private industry in order for them to be globally competitive. Looking at the history of semiconductor setups in other countries, a deliberate State-sponsored program needs to be put in place so that losses and experimentations are heavily subsidised, especially in order for these companies to remain competitive. A C2S (Chips to Start up) program has been created that will incentivise Bachelor of Technology (BTech), Master of Technology (MTech), and Ph. D degree holders to set up start ups in this sector.[231] The government is looking at a talent pool of around 85,000. This entire initiative is likely to generate 35,000 direct, and more than one lakh indirect jobs.[232] India's growth trajectory and national security is attendant on the success of this program. The Department of Electronics & Information Technology and M/s

229 'Semiconductors: U.S. Industry, Global Competition, and Federal Policy', Congressional Research Service (CRS), Washington DC, 2020.

230 'Ashwini Vaishnaw Explains Pli Scheme for Semiconductor Ecosystem Development in India', YouTube, 2021, at https://www.youtube.com/watch?v=NaMUQQtlrNA, accessed 11 September 2022.

231 'Ashwini Vaishnaw Explains Pli Scheme for Semiconductor Ecosystem Development in India', YouTube, 2021, at https://www.youtube.com/watch?v=NaMUQQtlrNA, accessed 11 September 2022.

232 Ibid.

Canbank Venture Capital Fund Ltd. plan to launch an Electronics Development Fund (EDF), which will be a 'Fund of Funds'[233] to invest in 'Daughter Funds', and provide risk capital to companies developing new technologies in the area of electronics, nano-electronics, and IT.

A number of initiatives have already been announced, or have started. Infineon Technologies, a German semiconductor firm, has partnered with the National Skill Development Corporation (NSDC) to impart training to youth on chip technology.[234] Aricent, a US-based product engineering company, acquired the Bengaluru-based chip design services company SmartPlay, in 2015.[235] The Indian Electronics and Semiconductor Association (IESA) has signed an MoU with the Singapore Semiconductor Industry Association (SSIA) to establish and develop trade and technical cooperation between the electronics and semiconductor industries of both countries.[236] The Centre of Excellence in Nanoelectronics (CEN), at Indian Institute of Technology (IIT) Mumbai, has a small fab-like facility in collaboration between IIT Mumbai and the Indian Institute of Science (IISc) Bengaluru that offers research in the design, fabrication, and characterization of traditional complementary metal oxide semiconductor (CMOS) nano-electronic devices, novel material based devices (III-V Compound Semiconductor devices, Spintronics, Opto-electronics),

233 Ibid.

234 'Infineon, NSDC partner for Semiconductor Skill Development', *The Economic Times*, 6 October 2015, at https://economictimes.indiatimes.com/industry/cons-products/electronics/infineon-nsdc-partner-for-semiconductor-skill-development/articleshow/49247680.cms?from=mdr, accessed 11 September 2022.

235 Poovanna, S., 'Aricent acquires SmartPlay for $180 million', LiveMint, 11 August 2015, at https://www.livemint.com/Companies/xDGSOQHUrETM6CcVFA5NXP/Aricent-acquires-SmartPlay-for-180-million.html, accessed 19 September 2022.

236 'US Semiconductor Industry Association signs MOU with IESA', *The Times of India*, 22 April 2022, at https://timesofindia.indiatimes.com/gadgets-news/us-semiconductor-industry-association-signs-mou-with-iesa/articleshow/90806998.cms, accessed 4 September 2022.

MEMS, Bio-MEMS, polymer-based devices, and solar photovoltaics to researchers across academia, industry, and government laboratories, all over India.[237]

Relevant circles within India have been advocating for investment by the central government, with a long-term strategic vision in the revolutionising fields of Gallium Nitride (GaN),[238] and the Mercury Cadmium Telluride (HgCdTe) based non-silica semiconductor foundry and fab because of their wide-ranging use — like the High Electron Mobility Transistor (HEMT) made from GaN in power electronics, both for civilian and military applications, which can switch at high speed,[239] and can handle high power and high temperature without needing any cooling. It has also made HgCdTe based high-quality sensors for military space requirements.[240] IISc's Centre for Nano Science and Engineering (CeNSE), Bengaluru, which produces GaN based semiconductors, has requested for a Rs 3000 crore grant from the government to set up an indigenous foundry within the campus. This has received preliminary approval from the central government.[241] This is an unexplored area, and may be where

237 'Preamble: Centre of Excellence in Nanoelectronics', Centre of Excellence in Nanoelectronics. (n.d.), at http://www.cen.iitb.ac.in/cen/about-us/preamble.php, accessed 24 September 2022.

238 Gargeyas, A., 'The Role of Semiconductors in Military and Defence Technology', *Defence and Diplomacy*, 11(2), 2022.

239 'GAN HEMT for high-reliability military and Space Power Electronics', Military Aerospace Electronics, 10 March 2020, at https://www.militaryaerospace.com/power/article/14169437/power-electronics-highreliability-gan, accessed 24 September 2022.

240 Kopytko, M., JóŸwikowski, K., Martyniuk, P., Gawron, W., Madejczyk, P., Kowalewski, A., Markowska, O., Rogalski, A., & Rutkowski, J., 'Status of hgcdte barrier infrared detectors grown by MOCVD in Military University of Technology', *Journal of Electronic Materials*, 45(9), 2016, pp. 4563–4573, at https://doi.org/10.1007/s11664-016-4702-3.

241 A, J. T., 'IISc to get Rs 3,000-crore foundry to produce "wonder" nano material', *The Indian Express*, 7 July 2017, at https://indianexpress.com/article/education/iisc-to-get-rs-3000-crore-foundry-to-produce-wonder-nano-material-4741048/, accessed 22 September 2022.

we can focus our efforts to emerge as a manufacturing hub for relative legacy chips. We don't require to build leading-edge foundries; we need to have a resilient supply chain backed by the Quad.

Conclusion

The role of semiconductors in promoting India's national security and economic growth cannot be overstated. The future of warfare, like India's future growth trajectory, depends on the increasingly critical role played by technologies, such as 5 G-based IoT, quantum computing, unmanned system, and AI. All these data-dominant technologies depend heavily on the availability of advanced semiconductors, which are themselves nearing the end of Moore's law-mandated exponential efficiencies. A race is on for advanced materials, novel methods of design, and building different algorithms to ensure that the progress associated with these technologies is not stalled for want of computing power. Another prerogative, that of Climate Change, is linked with the availability of adequate chips for EVs of all kinds to run and function.

Similar other programs are linked to the availability of specific chips which, today, are unevenly concentrated in East Asia, raising the challenge of major chip shortages in case the region is affected by a crisis or conflict. The role of China is either aggravating a conflict in Taiwan or North Korea, its growing ambition to be the top AI power in the world, and its aggressive stance towards its neighbours — all are subsumed under an expectation of continuous access to advanced chips. The USA, so far under an assumption that the Cold War era export controls could work against China too, has tightened restrictions on that technology which it considers sensitive and foundational. The CHIPS Act of 2022 also aims to incentivise domestic and foreign fabs to set up their plants on US soil, creating redundancies against supply chain disruption. The Act also aims to spur research in basic science, develop a human resource pool indigenous to the USA, prevent Chinese pilferage of US technology and researchers and, finally, ensure that China remains at least 2-3 generations behind the USA, in terms of node sizes. Within India, the government has created an ambitious scheme to incentivise domestic and foreign manufacturers to create fabs in the county, offering a number of measures to attract investment.

Companies have responded positively, with two multi-billion-dollar agreements on the verge of being signed. However, in the current scheme, the entire focus is on electronics, consumer goods, and display fab industry, with scant attention being paid to the requirements of the Indian Armed Forces. This is more so because the forces are still functioning on a variant of conventional war, which was more prevalent in the 1980s, and involved the use of big-ticket platforms such as tanks and aircraft. For the needs of the Armed Forces to be taken into account, there is a requirement for a major doctrinal and operational change within the Armed Forces, where EW, cyber, AI, and unmanned systems, in autonomous/semi-autonomous modes, play the central rather than peripheral role. The way the forces wage war will decide how the semiconductor industry will respond to the incentive.

India's requirement for the indigenisation of semiconductors, therefore, transcends all measures of national security since ICs, chips, and semiconductors form the basis for the country's ability to provide essential services to its citizens, create a model worth emulating for the Global South, modernise its Armed Forces, and attempt to mitigate the effects of Climate Change.

The Indian government has rightly given a clarion call for India to be a Chip Maker rather than a Chip Taker. The requirement of semiconductors in India's national security domain has become critical since they form the substrate of every important activity in the country - from the economic to the military domain. Technologies such as artificial intelligence (AI), quantum computing, blockchain and big data analytics are made possible only due to the availability of advanced semiconductor chips. The world's move towards mitigating the effects of climate change through the use of green technology is also heavily dependent on the continued availability of specialised chips. However, the manufacturing of these chips is a complex process and only a handful of countries dominate the entire supply chain which is extremely vulnerable and sensitive to changes. These reasons have made semiconductors one of the most vaunted products in human history and countries around the world have resorted to export controls and outright bans against the sale and transfer of this product and related technologies. In this scenario, it is imperative for India to chalk out a path for self-reliance using indigenous talent and expertise as well as become part of resilient supply chains from trusted geographies.

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