EMERGING TECHNOLOGIES AND POLICY PROGRAM

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IN PURSUIT OF A SEMICONDUCTOR INDUSTRY

What India Can Learn from South Korea and Singapore

CSDR
COUNCIL FOR STRATEGIC AND DEFENSE RESEARCH

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ABOUT THIS REPORT

This report analyzes the historical development of Singapore's and South Korea's semiconductor industries to extract strategic lessons for India's current Semiconductor Mission. Despite India's past failures in establishing a chip industry due to technological, capital, and policy constraints, the country now seeks to leverage geopolitical opportunities and international partnerships to build a domestic semiconductor sector. The report examines how Singapore successfully used "technology leverage" through multinational corporations, while South Korea employed its chaebols (conglomerates) to achieve rapid catch-up in memory chip production. Both countries prioritized broader economic reforms, talent development, and strategic investments before intensifying semiconductor efforts, offering valuable templates for India's semiconductor ambitions.

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Executive Summary

- This report analyzes the historical trajectories of the semiconductor industrial development in Singapore and South Korea to extrapolate strategic lessons for India's Semiconductor Mission, amidst geopolitical tensions that spill over into and threaten to fragment global supply chains.

- Despite multiple failures in past Indian efforts to establish a semiconductor industry due to a lack of technological ecosystems, capital investments, and adequate incentives; as well as bureaucratic delays, infrastructure issues, a restrictive business environment, and other factors, India has nevertheless identified a strategic opportunity to leverage its economic heft and international partnerships to kickstart the development of a semiconductor sector once again.

- While Singapore and South Korea followed different institutional pathways, offering unique templates and insights for industrial development, there were also fundamental similarities in their approaches that assume considerable significance. For instance, both Singapore and South Korea prioritized broader economic, trade, business, and infrastructure reforms before they intensified their efforts to establish a domestic semiconductor industry.

- Singapore's success was a result of continuous interventions by state agencies to attract investments, help shape and foster the industry's development, with special emphasis on technological upgradation and technical skills, as well as the creation of 'backward linkages.'

- Importantly, Singapore's model of leveraging MNCs as a way into the high-technology semiconductor sector and the development of the 'absorptive capacity' required to continuously move up GVCs was the first successful case of its kind and starkly differed from the 'indigenous development' approaches employed by Taiwan, Japan, and South Korea. Singapore also benefited significantly from regional cooperation and a division of labor in its later stages.

- South Korea urged its large family-owned conglomerates, known as chaebols, to take center stage, acquire and indigenize technology, and quickly catch up with the US and Japan in the semiconductor sector. South Korea's case is particularly relevant because its chaebols exemplify the "latecomer advantage,' where they secured access to knowledge and technologies from advanced firms in other countries and leapfrogged over intermediary stages to establish a viable industry at home.

- South Korea paid a significant 'price of entry,' however, for the 'capital as leverage' to launch its semiconductor industry. The chaebols had invested $4 billion in upfront investments by 1989 alone, and the royalty fees charged by U.S. firms for their chip designs and process technologies, along with interest rates, constituted the largest portion (close to 28%) of their total costs. Importantly, South Korea continued to invest aggressively even during cyclical downturns in the global chip market, emerging stronger when the market recovered.

- Apart from subsidies through the PLI scheme, India also needs to focus on broader economic, trade, and infrastructure reforms to improve the "ease of doing business" in the country, given that the capital-intensive nature of the sector means significant risks come with investments. Another key lesson from Singapore and South Korea's initial trajectory is that focus on ATMP/OSAT facilities, which are less capital-intensive and would benefit from India's large workforce, can be leveraged later. This would enable a technical workforce and ecosystem to emerge before significant investments are made in the fabrication space.

- India must cultivate a pool of highly specialized talent through technical knowledge partnerships with countries and foreign firms, as well as domestic programmes, to develop the absorptive capacity needed for its semiconductor sector to develop and grow. Similarly, investments in R&D will play a deterministic role in the future trajectory of India's semiconductor industry and its transition towards a knowledge-intensive economy.

- While capital investments are important, they alone will not be sufficient for India's semiconductor aspirations to materialize, given that other countries have more heavily invested and due to a range of other reasons. Therefore, India will need to focus on building other sources of leverage, such as an ancillary industry and skilling its abundant workforce, to gain competitive advantages and move up the Global Value Chains (GVCs).

Introduction

The global semiconductor value chain is now at the forefront of geopolitical and national security concerns for major countries around the world. The 'chip famine'—a result of supply chain disruptions related to the Covid-19 pandemic in 2020—ended in 2023, but not before it underscored a stark realization: nations cannot take a steady inflow of semiconductors for granted—a commodity so integrated into dozens of industrial sectors that it has become irreplaceable. To illustrate, the microchip shortage cost the US economy an estimated $240 billion in 2021 alone.[1]

Simultaneously, a race to dominate the next generation of advanced technologies, including AI, has become a central aspect of the great power rivalry between the US and China. Since 2020, Washington has enacted a series of trade restrictions and export controls intended to cut off Chinese access to high-end semiconductors that are essential for AI development and to prevent Beijing from gaining a competitive edge.[2] This has led to a 'Chip War,' characterized by multiple rounds of escalation that have spilled over into other economic sectors, such as critical minerals.

Notably, the extremely complex and global nature of an advanced chip's value chain (discussed in a later section) has led the US to pursue deeper cooperation with its allies, including Japan and Taiwan, to contain China's technological influence. As a result, semiconductor supply chains have started to fragment, and heightened geopolitical risk assessments surrounding them have prompted major countries to announce new policy measures focused on improving supply chain resilience. Over the past four years, the US, Europe, Japan, South Korea, Taiwan, and even smaller nations such as Vietnam and Malaysia have dedicated billions of dollars in incentives to develop or strengthen their semiconductor industries. Evidently, global supply chains are thus poised for significant reconfiguration in the near future.

At this moment of change, India has recognized a strategic opportunity to leverage its economic strength and international partnerships—particularly with the US, the EU, and Japan–to establish a complete semiconductor industry of its own. In 2021, New Delhi launched a policy initiative aimed at attracting investments and technology transfers to set up chip manufacturing facilities in the country. In exchange, India pledged $10 billion in subsidies and promised to remove bureaucratic hurdles.[3] Policymakers emphasized the country's large, technologically skilled workforce and a $100 billion domestic consumer electronics market to highlight the rationale behind 'Make Chips in India' for both global semiconductor players and domestic contenders.

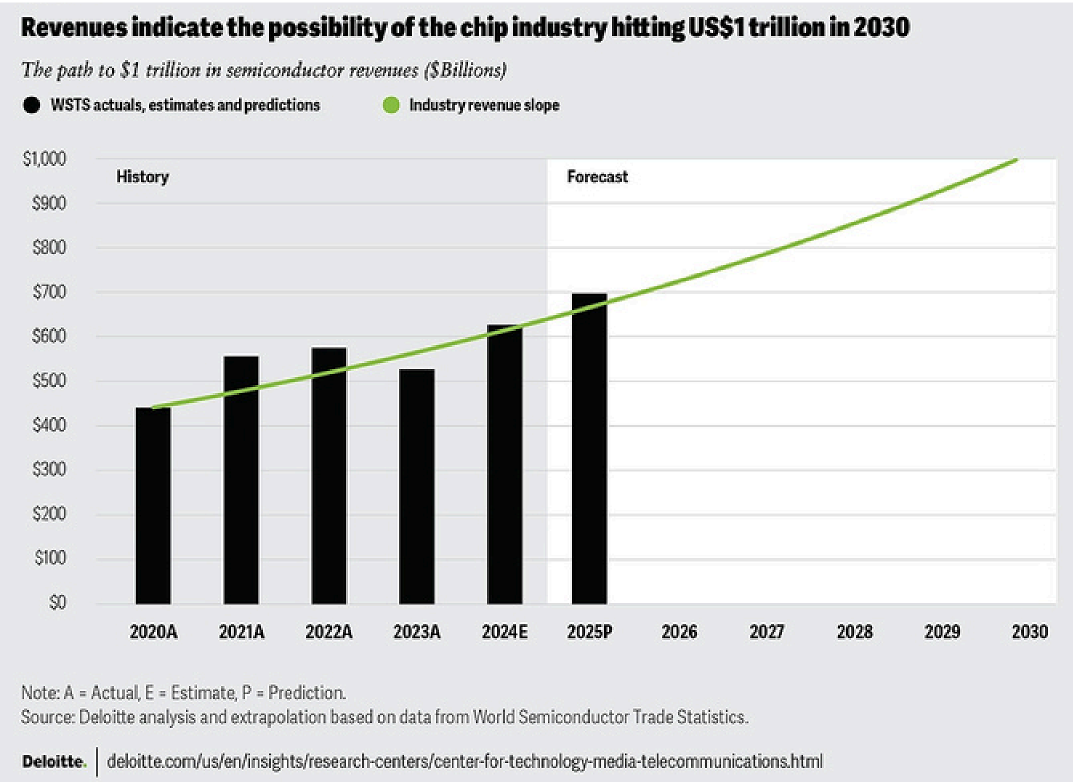
As a result, the country's semiconductor journey has gradually begun, and the Union Cabinet has approved funding for five semiconductor units, including a fabrication facility (the most capital-intensive segment of the semiconductor value chain) to be established in Gujarat.[4] While this is significant progress for a country with a nearly nonexistent semiconductor industry, despite numerous past efforts to develop one, it is also true that India has a long way to go before it can achieve relative economic security in this high-tech sector and effectively integrate into global supply chains.

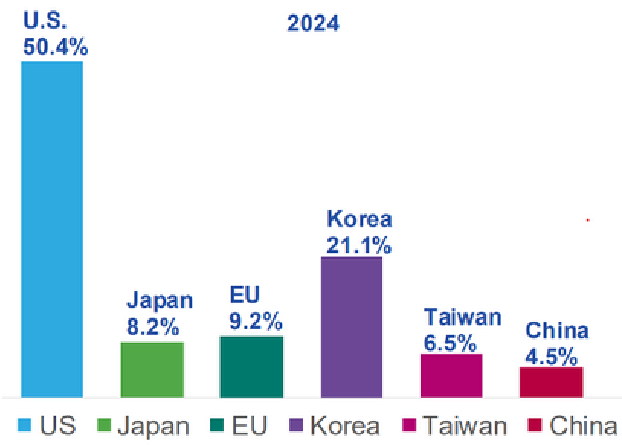
In this context, this paper aims to offer strategic lessons for India's semiconductor mission based on the historical experiences of Singapore and South Korea. In the latter half of the 20th century, both countries built a domestic semiconductor industry from the ground up, which continues to play a critical role in global supply chains today. Moreover, they remained largely dependent on foreign aid well into the 1960s. Importantly, both countries adopted varied approaches, highlighting both fundamental similarities and differences that were remarkably successful.

The Global Semiconductor Supply Chain

The semiconductor industry stands out globally due to its scale and complexity. It is a sector that demands significant capital and expertise, yielding commensurate returns. In 2024, the SIA estimated global semiconductor sales at $627 billion, setting a record high and reflecting a 19% increase from the prior year.[5]

The global supply chain supporting this economic scale is highly specialized and complex. While the technologically advanced segments of the value chain are concentrated, the supplier network essential for production is widespread. A typical integrated circuit (IC) chip, which can contain hundreds of millions or even billions of transistors packed into less than a square inch of silicon, involves over 500 distinct production stages or crosses as many as 70 international boundaries before reaching the average consumer.[6] A high-end semiconductor company, such as TSMC, can have tens of thousands of suppliers located across various parts of the globe, with hyper-specialized firms often holding a virtual monopoly over critical technological capabilities at specific performance levels.[7]





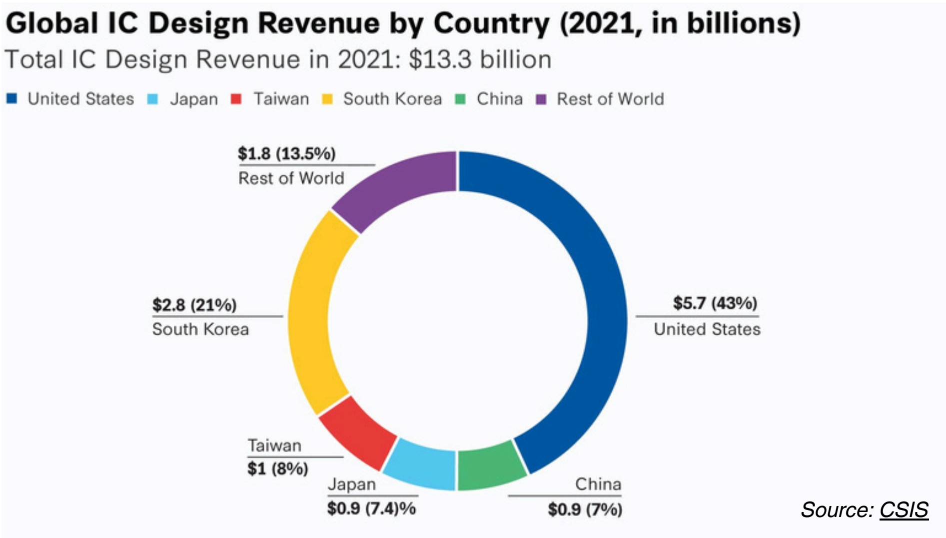
Global Market Share of Semiconductor Shipments by Company HQ Location

Source: SIA 2025 Factbook

The semiconductor value chain can be broadly divided into three parts:

Design

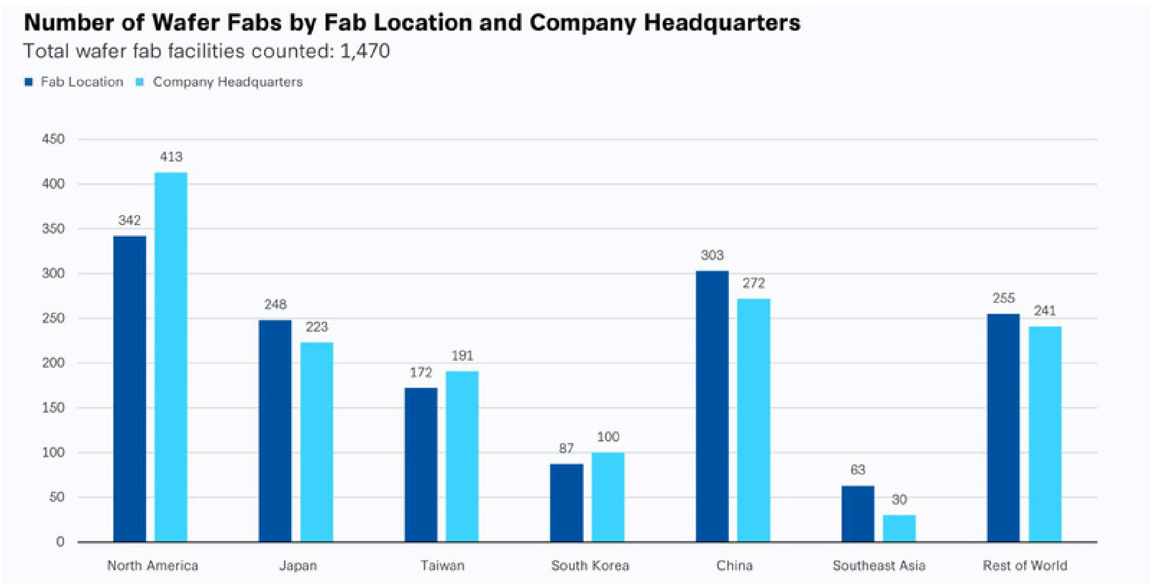
IC design is achieved using core intellectual property (IP) and specialized electronic design automation (EDA) software to develop the blueprint of a chip's architecture, which requires a team of engineers to map a set of complicated interactions and layers to optimize for different parameters and technical requirements.



Source: CSIS

Fabrication

Fab facilities print the design of an integrated circuit and layer transistors onto a raw silicon wafer. This process requires a variety of raw and manufactured materials, such as photomasks and photoresists; certain processed chemicals as necessary inputs; and highly specialized and sensitive equipment, such as extreme ultraviolet (EUV) lithography systems, to achieve an exceptionally high degree of precision (more than in any other industry in the world).



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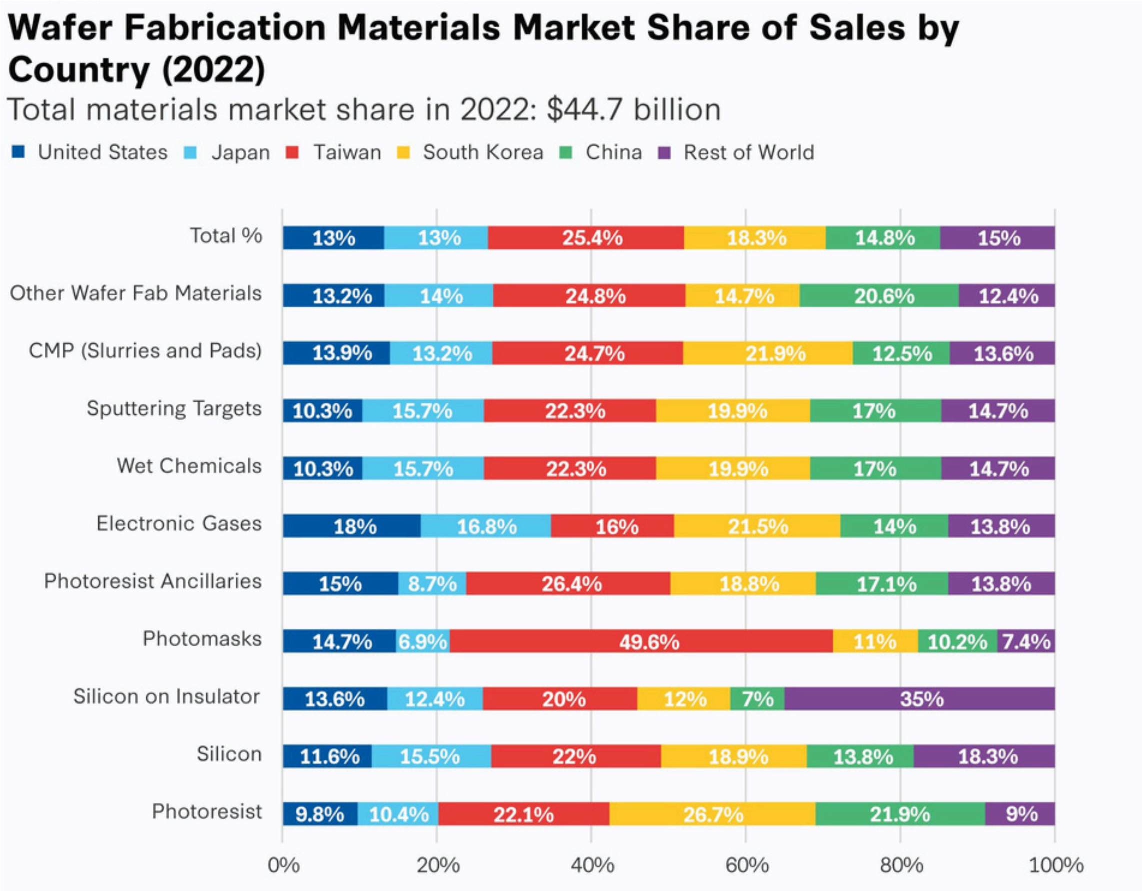
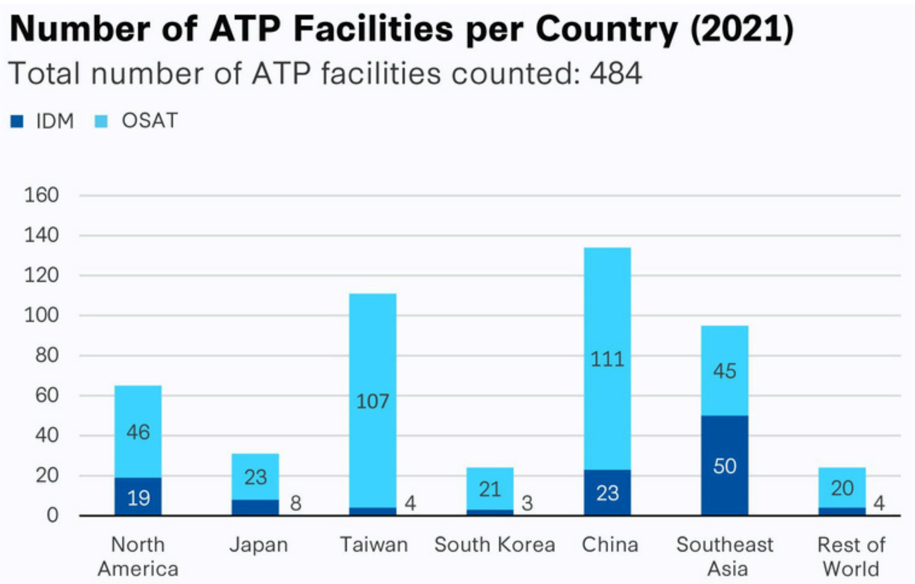


Source: CSIS

Assembly and Test

Assembly, Testing, Marking, and Packaging (ATMP) facilities cut, separate, test, and assemble the fabricated chips for integration into the final product. While this segment of the value chain is relatively less complex, it still requires specialized assembly equipment and is a more labor-intensive process.



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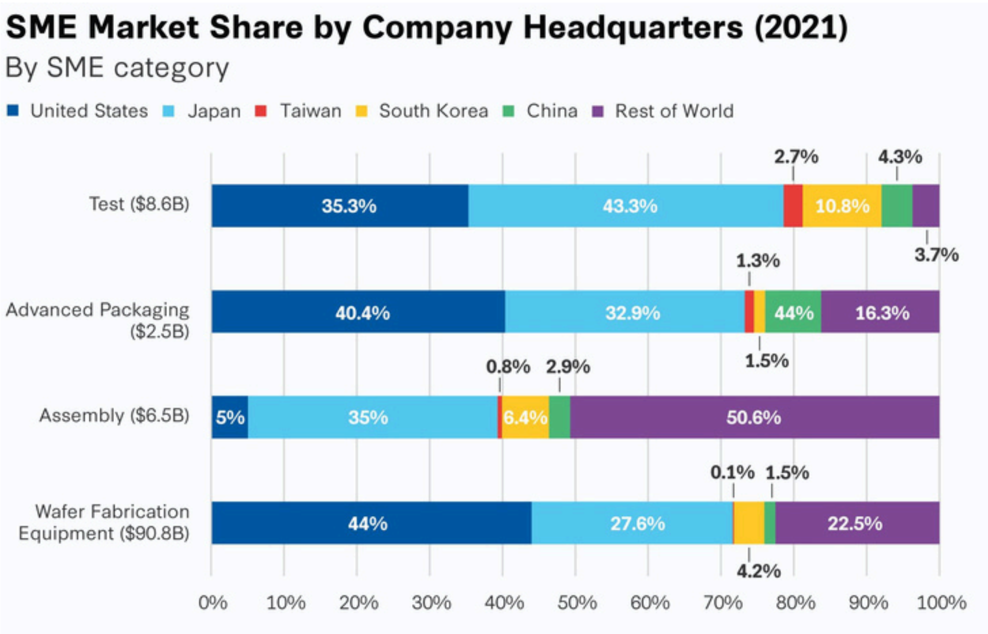

Source: CSIS

Government incentives by major region (left to right by size of GDP)

		US	Mainland China	EU	Japan	South Korea	Taiwan
Guidance	Target	Achieve resiliency in semiconductor supply chain	Reach 70% self-sufficiency by 2025	Gain 20% global share by 2030	Earn $112B sales by 2030	Secure foothold in Logic, bolster fab leadership	Breakthrough 1 nm by 2030
	Guiding policy	CHIPS and Science Act, 100-Day Supply Chain Review	National IC Outline, 14th Five Year Plan	Digital Compass 2030	Strategy for Semis and the Digital Industry	K-Belt Semiconductor Strategy	Angstrom Semiconductor Initiative, Moonshot program
Measures	Key Incentive amounts	**$39B** in grants[1]	**$142B** in equity funds	**$47B** in grants	**$17.5B** in grants	**$55B** in tax incentives	**$16B** in tax incentives[4]
	Key Initiatives	25% investment tax credit Grants under the CHIPS Act State-level support	Big Fund I, II, III and local funds State-owned enterprise leaders National science fund	Grants and loans under EU Chips Act Tax credits State aid allowances[2]	National fiscal funding Leading-Edge Semiconductor Technology Center	Tax incentives under K-Chips Act Private-public education programs	Financial subsidies under the Chip Innovation Program Industry-academia co-op, tax credits
Impact	New fab & ATP investments since 2020[3]	26	~30[5]	8	4	3	7

1. $39B for manufacturing; $13.2B for R&D and workforce development
2. Important Projects of Common European Interest (IPCEI)
3. Comprises fab and ATP projects that have been announced, started, or completed since 2020
4. 25% tax credit pledging to give back $2.25B per annum over 7 years.
5. May undercount the total number of sites in China.

Source: Gartner; SIA; Press releases; Company disclosures; Government websites; BCG analysis

Source: BCG and SIA Report, May 2024

A Short History of India's Semiconductor Past and a Futuristic Mission

First attempts and the story so far

As early as 1962, the Indian public sector giant Bharat Electronics Limited (BEL) began manufacturing germanium-based transistor chips, with technical expertise supplied by Philips, although its operations were still limited in scale.[8] In the early 1980s, India made a more concerted effort to establish a semiconductor industry. The Rajiv Gandhi administration relaxed technology acquisition requirements and import duties on electronic equipment, undertaking several trips to Europe, Japan, and the U.S. to attract investments into India.[9] In 1984, Semiconductor Complex Limited (SCL) was established as a public sector unit, with adequate funding and access to a pool of talented scientists and engineers from BEL and other institutions.[10] SCL formed a joint venture with the U.S.-based Microsystems Inc. and licensed technology from Rockwell and the Japanese firm Hitachi.

Over the years, SCL developed the expertise to manufacture chips on the 800 nm node and, by the late 1980s, was nearing the level of technological capability of other global semiconductor companies.[11] Meanwhile, BEL advanced to producing polysilicon wafers in partnership with Metkem Silicon Ltd. However, from that point onward, both government-supported ventures stagnated, and their initial successes and breakthroughs did not translate into exports or domestic products. The knowledge spillovers remained minimal, and SCL could not progress beyond fulfilling government demand.[12] The government requested BEL to cease silicon production entirely, allowing SCL to take over that space and shift its focus to assembly instead.

Indian efforts to develop a semiconductor industry faced several challenges. First and foremost, cycles of rapid technological upgrades and corresponding capital investments are essential for semiconductor companies to compete in a highly competitive global market. In the industry, this is referred to as Moore's Second Law or Rock's Law: the cost of constructing a semiconductor chip fabrication plant doubles every four years. As Pranay Kotasthane and Abhiram Manchi discuss in their book, When the Chips Are Down, both SCL and BEL encountered resource and knowledge limitations, which impeded their ability to keep pace with Rock's Law.[13]

> "SCL developed the expertise to manufacture chips on the 800 nm node and, by the late 1980s, was nearing the level of technological capability of other global semiconductor companies...BEL advanced to producing polysilicon wafers in partnership with Metkem Silicon Ltd. However, from that point onward, both government-supported ventures stagnated, and their initial successes and breakthroughs did not translate into exports or domestic products.

There were many other constraints at play: a lack of genuine incentives for government entities to compete and an aversion to internal competition; reluctance and uncertainty in trade and business policies; delayed policy implementation as bureaucracies struggled to keep pace with fast-moving industry timelines; inadequate infrastructure support; strict import controls, high tariffs, and a poor foreign exchange situation that collectively limited a stable supply of modern semiconductor equipment; and insufficient specialized talent.[14]

In the case of SCL, alongside these detrimental factors, a massive fire broke out in 1989 that devastated its fabrication facility, and it never fully recovered from the incident.[15] ISRO would eventually revive the fab, and it currently produces a limited number of chips for defense and strategic requirements (such as Mission Mangalyaan and Chandrayaan-3) on the 180 nm node, which is 12-13 generations behind. Its 8-inch fab still uses decades-old equipment. However, in 2023, the Government of India announced plans to invest around $1.2 billion to modernize the facility, though without a project timeline. Recently, in February 2025, the company invited bids for the same.[16]

After economic liberalization, India made multiple unsuccessful attempts to re-enter the semiconductor industry. In 2007, a Fab City (industrial park) was launched with significant fanfare near Hyderabad, where SemIndia and Nano Tech Silicon India committed to investing $3 billion and $2 billion, respectively, as did five other companies.[17] An OSAT plant received support from the global chip giant AMD, which promised $500 million in investments and technology transfers. However, the global financial crisis of 2008 derailed the initiative before it could even commence.[18]

In 2013 and 2014, two fabs were announced: the Jaypee Group collaborated with TowerJazz from Israel and IBM from the United States, while HSMC partnered with STMicroelectronics from France and SilTerra from Malaysia on their respective projects.[19] In 2015, Cricket Semiconductors, based in the US, entered the global conversation, and disclosed plans to establish a specialized analog fab in India.[20]

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However, all three projects failed to launch. As Kotasthane and Manchi explain:

"The common thread in these failures is a poor environment for businesses. A combination of three factors—an uncertain tax and policy environment, poor infrastructure, and high trade barriers — made chip fabrication an unattractive proposition in India… A chip fabrication unit can take up to four years to set up and requires billions of dollars as upfront capital. Unless investors have complete confidence in the country's business, tax, and trade regimes, they won't put their necks on the line. India's policies failed to reassure investors on these counts."[21]

Over time, the only segment of the global semiconductor value chain that India has significantly integrated into, is chip design. Currently, eight of the top ten global semiconductor companies, based on revenue, have design centers in the country, and approximately 20% of the world's design engineers are in India.[22] These roughly 30,000 engineers produce between 2,000 and 3,000 integrated circuits and chip designs annually.[23]

However, while these figures are impressive, very little of the core IP produced belongs to Indian firms, and most design specialists are employed by foreign MNCs that have outsourced operations to the country. In fact, the cumulative revenue of domestic design firms in India is estimated at $20 million, which, as outlined in a previous section, is negligible compared to global chip design revenues.[24] Consequently, this renders the much-touted claims about India's 'comparative advantage' or 'talent leverage' in the semiconductor race erroneous, especially since chip design houses require minimal infrastructure to operate, and thus, can easily move operations with STEM professionals who enjoy incredibly high global mobility.

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The New Indian Semiconductor Mission

In December 2021, the Production-Linked Incentive (PLI) scheme for semiconductors was launched with an allocation of $10 billion.[25] This represented the Government of India's largest political and financial commitment to the semiconductor industry to date, as well as to any industry within the PLI's scope. In fact, the semiconductor industry has been granted nearly three times more funding than the Government of India's second-largest PLI scheme (for the automotive sector). Moreover, unlike other PLI schemes, where financial incentives are linked to the percentage incremental revenue of domestic manufacturers, the scheme for the semiconductor industry provides upfront capital to projects. These clearly indicate the strategic value New Delhi has placed upon chips.

The scheme applies to semiconductor fabs, ATMP/OSAT units, and display fabrication facilities, offering to cover up to 50% of the project cost for setup. States such as Gujarat and Maharashtra have provided additional incentives beyond this. An independent nodal agency, the Indian Semiconductor Mission, has been established within the Digital India Corporation (created by MeitY) to vet applications and coordinate policy implementation. Projects are selected based on investment and revenue thresholds, technological capabilities or proposed partnerships and tech transfers, and the planned capacity of the plant, with final approval resting with the Union Cabinet. After approval, the Government of India disburses the incentives on a pari-passu basis—subsidy payments start upfront and are distributed over several installments, dependent on Quarterly Review Reports and various other conditions.[26]

Parallelly, New Delhi has placed technological cooperation, particularly in semiconductors, and the need to attract related investments into India at the forefront of its international partnerships. It has signed semiconductor-related MoUs and agreements with the US, the EU, Japan, and Singapore and explored cooperation with other countries, such as South Korea or Taiwan, through other diplomatic means. At the multilateral level, it has welcomed Quad's efforts to diversify semiconductor supply chains.

So far, five semiconductor projects have been approved and are currently under construction. Tata Electronics has partnered with Taiwanese foundry Power Semiconductor Manufacturing Corporation (PSMC) to establish an $11 billion fab in Dholera, Gujarat, for which PSMC will transfer 28nm ('mid-level') node process technology.[27] Tata has also invested in an OSAT facility in Assam and announced plans to build a display fab in collaboration with PSMC and Himax, which is also based in Taiwan. Meanwhile, Micron (US-based), CG Power (Indian), and Kaynes Technology (Indian) have invested in the other three ATMP/OSAT units.[28]

> "So far, five semiconductor projects have been approved and are currently under construction. Tata Electronics has partnered with Taiwanese foundry Power Semiconductor Manufacturing Corporation (PSMC) to establish an $11 billion fab in Dholera, Gujarat, for which PSMC will transfer 28nm ('mid-level') node process technology.

By the end of 2024, the Indian Semiconductor Mission's $10 billion budget was exhausted.[29] Reports suggest that the Government of India is poised to launch Phase II of the Indian Semiconductor Mission, with a blueprint in development, although the final budget (expected to be between $10 and $15 billion) remains unclear. News reports indicate that there are also plans to provide support for auxiliary industries such as gases, chemicals, equipment, and raw materials — aligning with its commitment to enhance domestic value addition.[30]

In summary, India has begun establishing a modest semiconductor ecosystem, which is, itself, an achievement. However, India's journey has only just started, and no country in the world can genuinely be self-sufficient in this sector due to the highly specialized and differentiated nature of global value chains (GVCs). Therefore, the most effective way to reduce dependencies and enhance supply chain resilience is through developing technological capabilities and capacity. In other words, India must integrate meaningfully into key segments of semiconductor value chains to support its semiconductor industry and ensure it remains competitive as technology rapidly evolves.

Gujarat Chief Minister Bhupendra Patel, Union minister for electronics and information technology Ashwini Vaishnaw, Tata Sons chairman N. Chandrasekaran and others during the foundation stone-laying ceremony of three semiconductor facilities in March 2024. (PTI)

In this context, India has significant strategic lessons to learn from two East Asian countries that began this trajectory more than six decades ago and continue to be firmly embedded in global supply chains today.

The Semiconductor Journeys of Singapore and South Korea

This section analyzes the history of the semiconductor industries in Singapore and South Korea, as well as the strategies and policies both countries employed in the latter half of the 20th century to establish these industries. While India has alternative templates available, such as those used by Japan, Taiwan, or Malaysia, they are not as well-suited to the unique factors and environment that will shape India's semiconductor trajectory.

For example, Japan gained a significant second-mover advantage (after the U.S.) thanks to Washington's reconstruction efforts in the post-WWII era, which provided early access to technology and substantial support from the U.S. to develop large, vertically integrated firms.[31] This level of technological cooperation (or intervention) is not available to India and was arguably never extended to any other country (regardless of its status in the U.S. alliance system), with the sole exception of Taiwan.

For its part, Taiwan's success was due to a unique model of strategic public-sector-led development that created a highly specialized fabrication ecosystem within which it strategically supported many MSMEs and institutions to play differentiated and critical roles. India (or perhaps any other country) would be ill-advised to replicate this model, given its own failed experiments with PSUs in the past.

Meanwhile, Malaysia largely emulated the innovative strategy of 'technology leverage' first developed and implemented by Singapore, but it did so a decade later and could never catch up with Singapore. Interestingly, South Korea also adopted a similar approach to that of Japan, but without the same level of US assistance and a decade late. Yet, it quickly surpassed both.

Singapore’s Novel Strategy

This section traces the early stages of Singapore’s semiconductor journey from the 1960s to the late 1990s, a period within which the city-state emerged as a transnational hub for multi-national and national firms integrated into virtually every segment of the Semiconductor Global Value Chain (GVC) – from IC design to fabrication to ASAT, as well as in ancillary services such as equipment and materials.

The key player in this success was Singapore’s Economic Development Board (EDB) – a statutory agency under the Ministry of Trade and Industry, which was mainly tasked with developing and implementing industrial strategy. When the EDB became operational in 1961, the country’s GDP per capita was $450. By 1995, it had risen to $25,000.[32]

In the same year, Singapore’s semiconductor industry included around 50 companies, employed over 21,000 workers (many of whom were highly skilled), and generated revenues of approximately $9 billion (for context, the country’s total GDP was $87 billion that year). By the end of the 20th century, a nation smaller than many large Indian cities had 11 advanced chip fabrication facilities.

Prime Minister Narendra Modi, accompanied by his Singaporean counterpart Lawrence Wong, visited the semiconductor facility of AEM Holdings Ltd in Singapore in Sept 2024. (DD News)

Scholars, including John A. Mathews and others, have elucidated Singapore’s semiconductor success through the conceptual framework of ‘technology leverage,’ conceived and expertly implemented by the EDB. Within a meticulously crafted policy framework, as Mathews and Cho argued:

“[Singapore] encouraged, facilitated, and demanded the rapid transfer and diffusion of skills, technology, and access to markets by participants ranging from multinationals to indigenous Singaporean firms… [It] was one of the first countries to embark on this course, and its ability to break through into high-technology sectors provides a dramatic demonstration of the potential success of such leverage strategies.”[33]

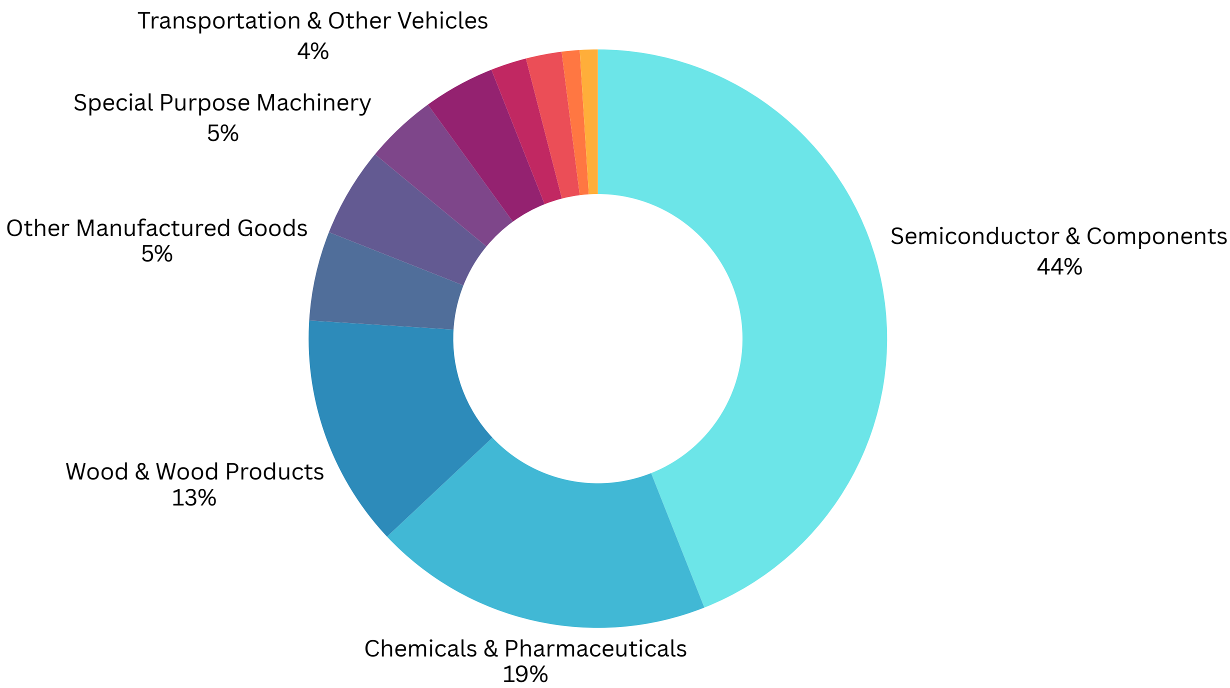
While ‘technology leverage’ is a widely recognized development strategy used globally today, it was first pioneered by Singapore at a time when much of the world was deeply suspicious of Western multinational corporations, leading to restrictive policies and regulatory conditions for them.[34]

At first, in the early 60s, the EDB embarked upon the creation of favorable policy conditions (and a ‘business culture’) for MNCs to encourage foreign direct investment (FDI) into the country.[35] Global firms that wanted to offshore were primarily interested due to cheap labor costs and the presence of a large number of English speakers, but Singapore left no stone unturned.

In 1962, the EDB significantly streamlined the process of acquiring industrial land on the island, marking one of its first major initiatives. The city-state offered tax incentives and breaks to establish businesses while also liberalizing its immigration and work-permit system to facilitate the residency and employment of foreign professionals in Singapore—an essential element of its success, especially given the shortage of a skilled workforce at that time.[36]

Meanwhile, the EDB established offices in cities such as New York, Tokyo, and other global business hubs to attract capital inflows. As importantly, it initiated infrastructure projects, including the Jurong Industrial Park, which was developed with a World Bank loan, to achieve the same objective. In fact, out of the 14 World Bank loans obtained by Singapore, 10 were designated for infrastructure projects.[37] Additionally, the EDB launched technical education programs to upskill the country’s workforce. In 1968, the Development Bank of Singapore (DBS) was also created as a public-private partnership to specifically offer industrial loans for new ventures.[38]

Singapore’s 2023 Manufacturing Industry Output (MIO) Value by Aggregate Sector (USD Fixed)



Source: Interact Analysis

Given the significant transformation of Singapore's policy and infrastructure landscape, the semiconductor sector rapidly industrialized, even as domestic value addition remained low due to heavy reliance on MNCs.[39] In 1969, U.S. chip giants National Semiconductor and Fairchild moved their assembly units to Singapore, and by the mid-1970s, global semiconductor leaders such as Texas Instruments, Signetics, Radio Corporation of America (RCA), Intel, and American Microsystems had already started various production activities.

At this stage, Singapore started to encourage the growth of local firms (or auxiliary industries) that would supply goods and services to foreign companies. In other words, it established "backward linkages" between the multinationals and its domestic sector.[40] A Local Industry Upgrading Program (LIUP) was created, offering benefits and grants to SMEs, such as those in the semiconductor sector, to support this initiative.

Singapore's 'vendor development' and 'supplier upgradation' programs were very successful. SMEs emerged as local specialist materials and equipment providers who could supply multinational corporations engaged through various electronics contract work or waste treatment activities.[41] Others developed a specialization in fabricated metal products, derived chemicals (such as highly pure hydrogen peroxide), and precision machinery.[42]

> "Singapore's 'vendor development' and 'supplier upgradation' programs were very successful. SMEs emerged as local specialist materials and equipment providers who could supply multinational corporations engaged through various electronics contract work or waste treatment activities.

Such clusters were not only essential for the growth of the semiconductor sector and other advanced industrial sectors in parallel, but they also offered additional leverage for the city-state as MNCs gradually came to rely upon this ecosystem for affordable, convenient, and high-quality support and services that could meet their rigorous standards ('backward linkages').[43] This was one way through which Singapore incrementally integrated into GVCs.

Even more importantly, Singapore consistently encouraged (and sometimes pressured) multinationals to not only enhance and expand their operations, but also transfer internal capabilities. In the early 1980s, for instance, high wages were introduced (albeit, with mixed results) on the island to induce firms to invest in greater training for their employees and force out firms that simply wished to pursue low-cost (and low-value addition) operations without transferring skills or technology. This strategy of 'knowledge diffusion' from semiconductor giants was further backed by multiple policy initiatives.

Key among these was a 'Skills Development Fund,' launched in 1979, through which Singapore made large public investments in industrial training.[44] Multiple institutes were established in partnership with the MNCs to provide short and long courses in precision engineering, electronics assembly, and other relevant subjects, as well as expose those enrolled to latest equipment and technologies. Another key initiative was the Semiconductor Process Capability Development Program (launched by the NSTB).

When existing ASAT operations became increasingly knowledge-intensive in the 1980s and 1990s, this strategy and related investments paid off. After the 1985/86 recession in the global electronics industry revealed key vulnerabilities and highlighted a stark financial dependency on MNCs, the EDB doubled down on this strategy and leveraged the support of the very MNCs Singapore was dependent on to enhance the country's workforce and stimulate horizontal supply-chain integration into the domestic sector.[45]

In 1991, the National Science and Technology Board (NSTB) was created and went on to quickly establish several new R&D institutes in Singapore, which often received support and projects from various global firms, particularly HP.[46] In the same year, Singapore created the Institute for Microelectronics (IME) as a research center under the National University of Singapore (NUS) and NSTB.[47] It has since become a globally recognized research institute for microelectronics, with many of its projects directly commissioned by MNCs and semiconductor companies based in Singapore and beyond. In 1996, CMS also formed partnerships with the NUS and the Nanyang Technological University (NTU) to research and enhance advanced fabrication capabilities. Consequently, virtuous cycles of improvement in the country's domestic skills and technological expertise followed.

The EDB and the NSTB would also outline industrial and infrastructure upgrade initiatives based on current and future needs of the semiconductor sector and implement policies to address them, often ahead of schedule. Singapore sought out multinational corporations (MNCs) willing to invest in higher value-added activities and expand their operations beyond just assembly. A key factor behind their attraction to Singapore was labor rigidities encountered in other regions, particularly in Europe (for SGS Thompson, for instance). In contrast, in Singapore, the EDB secured the support of labor unions, such as the National Trade Unions Council, to facilitate automated production lines that could operate for up to 24 hours a day across two 12-hour or three 8-hour shifts.[48]

Companies such as the US-based Hewlett-Packard (HP) and the European company SGS-Thomson (now STMicroelectronics) implemented liberal skills transfer programs and gradually expanded their operations on the island state. They, and others, invested in IC design centers, advanced ASAT units, wafer fabrication plants, and a steady growth in R&D activities across all three segments followed in parallel, which helped Singapore move up the technology ladder and sustain higher value addition.[49]

Meanwhile, as wages in Singapore rose (due to the increasingly skilled workforce focusing on high-value-added services), the city-state fostered regional cooperation, which naturally established a technical division of labor within Southeast Asia, particularly in the semiconductor sector. For example, in 1989, Singapore, Johor (Malaysia), and Riau (Indonesia) established a 'growth triangle' known as SIJORI. Five years later, SIJORI was transformed into the Indonesia-Malaysia and Singapore Growth Triangle (IMS-GT) – a broader arrangement that, for instance, led to the development of the Batam, Bintan, and Karimun Free Trade Zone in the Riau Islands, supported by Singapore's sovereign wealth fund, Temasek Holdings.[50]

> “Meanwhile, as wages in Singapore rose (due to the increasingly skilled workforce focusing on high-value-added services), the city-state fostered regional cooperation (in fact, it was the first country to do so), which naturally established a technical division of labor within Southeast Asia, particularly in the semiconductor sector. For example, in 1989, Singapore, Johor (Malaysia), and Riau (Indonesia) established a 'growth triangle' known as SIJORI.

These crucial regional connections with Malaysia and Indonesia (as well as China and the Philippines) enabled Singapore to offload labor-intensive activities in the lower-value-added segments of the regional semiconductor supply chain to these countries as the city-state itself continued to enhance core technological capabilities and advance up GVCs.[51]

Eventually, Singapore would also make the state-owned enterprise, Singapore Technologies Group (STG)—already a capable defense equipment producer—diversify into the semiconductor sector. In 1987, STG signed a significant technology transfer agreement (3.0-micron node) with the US-based Sierra Semiconductor to establish a wafer fabrication venture, Chartered Semiconductor Manufacturing (CSM). When the US firm National Semiconductor, which was also an investor withdrew from the agreement early on, STG acquired Sierra's stake and embarked on its own as a pure foundry based on the TSMC (Taiwan) model, along with an additional design firm, TriTech.

CSM rapidly upgraded its technological capabilities through an in-house development team to enhance the technology transferred, and later through additional technology licenses with IBM, AT&T, and Toshiba (as well as joint ventures with HP and Lucent).[52] By 1997, the foundry had positioned itself at the forefront of chip production and became of the world's largest IC foundries. STG also launched Singapore Technologies Assembly and Test Services (STATS), which provided ASAT services to complement its IC design and fabrication services, thus making it a 'full-service IC producer.'

Meanwhile, Singapore strategically established three 'wafer fabrication parks' in Woodlands, Tampines, and Pasir Ris to host many of its fabs, integrated with specialized services such as uniform-band power supply, ultrapure water supply, and waste treatment facilities, optimized for service delivery by auxiliary industries. In 1994, Singapore launched a $1 billion Cluster Development Fund (expanded to $2 billion within five years), managed by the EDB, to invest in various fabrication units and other operations on the island. This would further enhance its leverage over MNCs while also providing vital assurances to the MNCs, given the government's own stake.[53]

In summary, Singapore's success was a result of continuous interventions by state agencies to attract investments, help shape and foster the industry's development, with special emphasis on technological upgradation and technical skills, as well as the creation of 'backward linkages.' Importantly, Singapore's institutional pathways to leverage its way into a high-technology sector and develop the 'absorptive capacity' required to continuously move up GVCs was the first successful case of its kind. That it starkly differed from the 'indigenous development' approaches employed by Taiwan, Japan, South Korea, makes the Singapore case of singular importance.

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As semiconductor industries became highly specialized and giants such as South Korea and Taiwan parallelly emerged with formidable indigenous tech capabilities, Singapore's limitations, such as its small size and its overt reliance on MNCs, forestalled its upward trajectory into the higher ends of the semiconductor industry over the course of the 21st century. Arguably, however, Singapore had already reaped the benefits of its approach to advanced industrialization, and therefore, sensibly diversified into a service-sector led economy. Today, it's a global financial capital, a beacon of prosperity with the second highest GDP per capita ($93,000), and one of the most 'open economies' in the world. In areas of the semiconductor industry, where domestic value addition was historically high, Singapore continues to punch above its weight. At present, the city state accounts for 10 percent of all chips produced worldwide (albeit on legacy nodes) and holds a 20 percent share in the global semiconductor equipment market.[54]

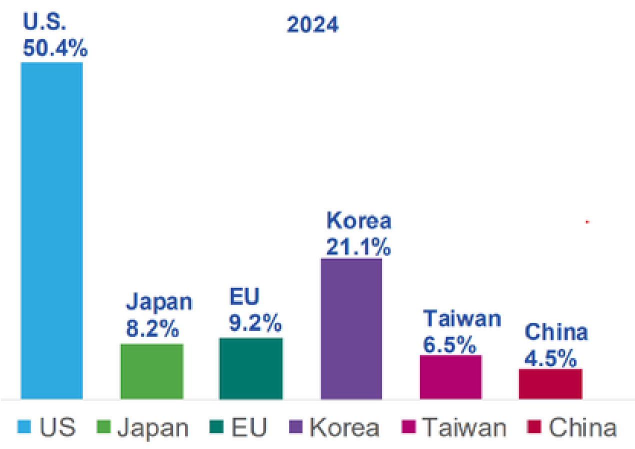
The 'Latecomer' South Korea

This section outlines the South Korean semiconductor phenomenon from the mid-1960s to the mid-1990s, during which South Korea rapidly emerged as a powerhouse in memory chip production, effectively dismantling the US-Japan duopoly. Similar to Singapore and the other East Asian Tigers, South Korea's semiconductor success can be attributed to strategies within the 'technology leverage' framework. However, it followed an institutional pathway distinct from Singapore's, urging its large family-owned conglomerates instead, known as chaebols, to take center stage, acquire and indigenize technology, and quickly catch up with the US and Japan in the semiconductor sector.

Over the course of about a decade, starting in the mid-1980s, three South Korean giants—Samsung, Hyundai, and Lucky-Goldstar (now known as LG)—emerged as significant chip producers specializing in DRAM memory chips. Today, South Korea stands as the second-largest semiconductor producer in the world (it held a 17.7% market share in 2022). At present, 70% of the global market share in DRAM chips is held by just two South Korean firms, Samsung and SK Hynix (formerly Hyundai Electronics, and later, Hynix, which was then acquired by the SK Group).

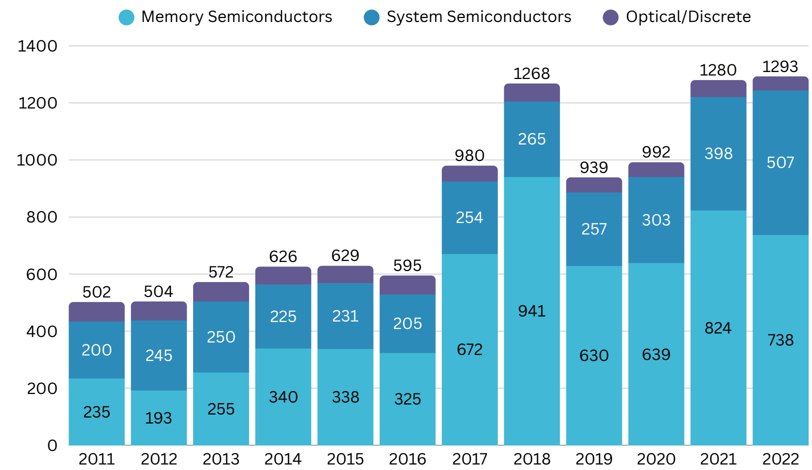
South Korea's case is particularly relevant because all three aforementioned chaebols exemplify "latecomer firms,' which secured access to knowledge and technologies from advanced firms in other countries (at the time, the U.S. and Japan, who were embroiled in intense strategic competition and a trade war over semiconductors) to establish a viable industry at home.[55] They may be the most well-known instances of the 'latecomer's advantage' in action (as defined by economic historian and development theorist Alexander Gerschenkron) – the ability of a firm to align with a specific technological trajectory, import the latest technologies and process knowledge, and enter a new (highly competitive) industry with maximum efficiency.

Global Market Share of Semiconductor Shipments by Company HQ Location



Source: SIA 2025 Factbook

South Korea's Semiconductor Export Trend (2011-2022) in USD hundred million



Source: OMIDA 2023

By 1983, when Lee Byung-Chull (Founder and Chairman of Samsung) famously wagered his company's future on memory chip production, South Korea had already established much of the foundation necessary to shift from an import-substitution economic model to an export-led growth model that relied significantly on its chaebols' capacity to industrialize and advance technologically.[56]

The Economic Planning Board was created in 1962 (a year after the military assumed control of the country and President Park came to power) to oversee these efforts and played a crucial role in developing strategies for targeted sectors, as did the Ministry of Commerce and Industry (MCI). At this point, the government was deeply involved – it set production and export goals for South Korean companies, rationed their credit lines, and either rewarded or punished each firm based on their performance, even reviewing their technology licenses and capital equipment imports.[57] The Presidential Blue House met with top industry leaders and government officials monthly to ensure that investments were strategically channeled and growth targets were achieved.

In the semiconductor sector, South Korea initially aimed to attract multinational semiconductor companies. The Foreign Capital Inducement Law was enacted in 1963 to loosen restrictions on foreign investment, with the terms of Foreign Direct Investment (FDI) set by the Economic Planning Board under this legislative framework.[58] With an abundance of low-cost labor, American companies—and Japanese firms after relations with Tokyo were normalized—established assembly facilities.[59] In response, Washington exempted U.S. tariffs on products assembled abroad and encouraged investment to flow into South Korea to advance its own geopolitical goals (for example, South Korea provided military assistance to the U.S. during the Vietnam War).[60]

In 1966, the government approved Fairchild's proposal to establish an exclusively owned semiconductor facility (the first of its kind) with access to the South Korean domestic market, despite initial hesitance regarding the chip giant's terms and conditions. Soon, other companies, such as Signetics and Motorola, followed suit, and by mid-1970, there were nine American and seven Japanese ATMP/OSAT facilities in the country.

South Korea focused on developing critical requirements for the electronics industry, such as technical expertise and infrastructure. Alongside various programs and institutions, the South Korea Institute of

Science and Technology (KIST) was established in 1966, helping to nurture the technical skills and knowledge that would later allow the country to rapidly absorb advanced technologies.

In 1969, the Electronics Industry Promotion Law was enacted, and the Ministry of Commerce and Industry created an Eight-Year Plan to support this initiative. Kumi, the site of a planned facility by the Japanese company Toshiba under a joint venture, was designated as the country's first Electronics Industrial Complex in 1970, with the necessary infrastructure built in the area at remarkable speed under direct orders from President Park. That same year, Masan was designated as a Free Export Zone, modeled after Taiwan's initiative, and by 1973, three Japanese semiconductor companies—Toko, Sanyo, and Sanken—had established plants in the port city.[61]

During this period (the 1960s), fueled by all the activity, many chaebols began to enter the electronics industry. Goldstar emerged as a domestic pioneer in this sector, while Samsung entered the market through joint ventures with Japanese firms Sanken and NEC, all while pursuing ambitious plans for vertical integration.[62] Other companies, such as Anam (South Korea's first independent assembly operation), emerged as contractors for the MNCs. By the mid-1990s, Anam would become the largest IC packaging and assembly contractor in the world. Meanwhile, the South Korea Electronics Industry Cooperative was established by the MCI in 1967 to facilitate coordinated industrial policy through a single association.[63]

In 1971, South Korea faced a setback when major firms began defaulting on their debts, prompting intervention from the IMF. But the period that followed saw chaebols absorbing smaller companies in the electronics industry, which, in turn, laid the groundwork for South Korea's next phase of more capital- and technology-intensive industrial development.[64]

A key objective of South Korean policy throughout the 1970s was to develop advanced technological capabilities, particularly in the semiconductor industry. In the 1973 'State of the Nation' address, President Park announced this new direction for industrial development in the country. That same year, the Law for the Promotion of Technology and Development was enacted, requiring electronic firms to implement measures which ensure their new products were export-competitive.[65]Additionally, the National Council for Science and Technology was established to enhance South Korea's absorptive capacity and thereby indigenize production.

The following year, in 1974, the MCI announced a six-year plan for this objective. Taxes were lowered, resources were mobilized through the National Investment Fund (NIF), and rapid construction of industrial complexes, such as the aforementioned Kumi, followed.[66]

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South Korea Semiconductor and Samsung Semiconductor were established, with the latter eventually acquiring the former. By the end of the 1970s, a relatively small-scale but domestic semiconductor sector had emerged in the country, led by at least three chaebols – Samsung, Goldstar, and Daewoo – in chip fabrication. The telecom sector, which was largely publicly owned, was also reorganized by the government, with profitable segments assigned to these three companies, enabling them to develop their semiconductor operations.[67] However, at this stage, in the early ‘80s, their technological capabilities were still in the formative stages, and none of the chaebols had achieved VLSI capabilities.[68]

South Korea recognized that to engage in VLSI semiconductor production and compete with the Japanese and Americans, a much greater commitment of resources from both the private sector and the government would be necessary. Consequently, the Presidential Blue House (now led by General Chun Doo Hwan after Park’s assassination in 1979) coordinated with various state agencies to develop a Comprehensive Industry Development Plan for the semiconductor industry, which was adopted in 1981, and was soon followed by the Long-Term Plan for the Promotion of the Semiconductor Industry (1982-86).

Importantly, the state’s heavy-handed approach significantly diminished, even as the chaebols faced pressure to make substantial commitments.[69] Under these plans, wafer fabrication was prioritized over testing and assembly facilities, and the mass production of memory chips was recognized as the most viable strategy to enhance exports and reduce reliance on domestic demand.[70] After all, memory chips were standardized and used in a variety of products for which demand was increasing; designs could be licensed from U.S. firms, and wafer fabrication technology could be obtained in the open market. Nevertheless, it posed significant risks for South Korean companies and would necessitate very large capital investments (hundreds of millions).

Although no one could have predicted at the time how successful this strategic focus would become, a total public investment of $400 million (ten times larger than anything previously envisioned) was announced for the semiconductor sector. Of this amount, 40% was financed by the NIF, while the Electronics Industry Promotion Fund, which didn’t exist at the time, would later commit the remaining funds.[71] What’s truly remarkable is that these commitments occurred alongside another financial crisis in the South Korean economy and yet another intervention by the IMF.

Convinced of the government’s serious commitment to spread and mitigate entry risks, Samsung, Hyundai, and Goldstar all announced their significant involvement in VLSI-level chip production, particularly for DRAMs (memory chips) by 1982. Samsung initiated the movement with a high-risk $133 million investment that surprised both its managers and the industry.[72] Following suit, Goldstar and others like Daewoo and Taihan quickly joined in. Hyundai then surpassed everyone with a $400 million commitment over the next five years, prompting Samsung and Goldstar to further increase their investments.[73] This fierce

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competition (upgrade capabilities or perish) among chaebols was a defining characteristic and arguably a key driver of their success.

Between 1983 and 1986, South Korean companies invested $1.2 billion in their plans (more than ten times the amount invested in Taiwan's semiconductor industry during the same period) and another $2.8 billion in the following three years. The government provided low-interest loans to the chaebols at a time when other sectors faced reduced targeted credit, but did not further intervene in their plans (unlike in the 60s and 70s).[74] This granted the firms significant financial leverage—a crucial factor in their success—but also led to major issues for some that failed to implement effective corporate strategies. (Ultimately, the significant bankruptcies of certain chaebols in 1997 would mean that South Korea was among the hardest-hit countries during the Asian Financial Crisis).

Acquiring design and process technology, however, was easier said than done, despite their financial resources. This era saw many US giants, such as National Semiconductor, Motorola, Texas Instruments, and Intel, experience significant declines in their profit margins due to Japanese manufacturers that outperformed them in an industry of their own making. Meanwhile, the Japanese companies understood better than anyone that South Korea planned to follow a similar path (South Korean strategy largely mirrored Japan's from a decade earlier) and chose not to engage (with the notable exception of Sharp). In other words, nobody wanted 'another Japan.'[75]

The chaebols targeted Silicon Valley, which at the time housed many start-ups, including Mosel, Vitelic, and Micron (although these were not strictly located in Silicon Valley, they shared its culture), possessing advanced design capabilities but lacking fabrication facilities. In exchange for licenses on their designs, South Korean firms not only offered to pay generously to companies that often struggled with capital but also committed to producing chips for them – a highly lucrative proposition for many.

The three chaebols also established 'listening-post' companies in the Valley to scout the market for engineers, often South Korean-Americans, offering them attractive salaries and appealing to their nationalistic sentiments to take jobs in South Korea. (Samsung sometimes paid highly trained engineers up to three times the salary of the chairman). They played a crucial role in the rapid absorption of technical know-how for VLSI production, as the chaebols 'leapfrogged' over intermediate phases. Consequently, tech upgrade cycles followed. Another key source of technological capability came from purchasing

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specialized materials and equipment, which skilled engineers would adjust to enhance yields and integrate into their production systems.

In fact, a key factor in South Korea's semiconductor success was its ability to internalize new product and process technologies as core capabilities while simultaneously working on the development of next-generation technologies. In December 1983, when Samsung announced that it had developed both the product and process expertise required to manufacture 64K DRAMs (the latest in its generation), it surprised not only South Korea but much of the world.[76] Yet, even before the chips were ready, Lee had already ordered two development teams (one in South Korea and the other in Silicon Valley) to begin work on the next-gen 256K DRAM.[77] This highly innovative strategy would later be replicated by Samsung's competitors, such as Hyundai.

Unfortunately, by the time South Korean chips entered the market in the mid-1980s, the global semiconductor industry was experiencing a cyclical recession, and the US-Japan 'chip war' was at its height. In other words, the commercial environment was unfavorable for South Korea, and despite the country's Herculean efforts to launch its semiconductor industry against significant challenges, the early sales of the chaebols were modest.

Within the government, a serious debate unfolded during this period. The EPB (backed by South Korean banks) argued that the high-risk financial support provided to the semiconductor industry, at the expense of other sectors, had proven to be a disaster, suggesting that South Korea had no future in this business.[78] Meanwhile, the MCI contended that sales would increase when the market improved if South Korean firms persevered and continued to enhance their technology capabilities. The Ministry of Science and Technology strongly supported the MCI's position, maintaining that such support would ensure a long-term transition to a knowledge-driven economy for the country. While the debate itself remained unresolved, the government reduced its low-credit financial support, leaving semiconductor firms to fend for themselves.[79]

This period arguably marked the effective end of the government's already diminished role in the creation and growth of the semiconductor industry. South Korea would naturally continue to support this vital sector through other policy measures, but it was corporate strategies and innovations, along with a strong focus on cycles of technological advancement through the parallel team strategy, that ultimately led to South Korea's decisive success, particularly in the memory chip market.

Even as the mid-1980s was a time of great uncertainty for the South Korean semiconductor industry, the chaebols, with their deep pockets and diverse revenue streams from other sectors like telecom, were able to remain competitive, and soon enough, luck shifted in their favor.

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In 1985, the Plaza Agreement among the Group of Five led to currency realignments that favored South Korea in relation to Japan. Even more significantly, the 1986 US-Japan Semiconductor Trade Agreement limited Japanese access to the American market and set minimum prices for semiconductor products.[80] Consequently, when the personal computer market saw a boom the following year and demand for memory chips surged, South Korean semiconductor exports could effectively compete with Japanese offerings. Sales soared, and the South Korean semiconductor industry not only recovered but also thrived.

Samsung, in particular, made significant profits that allowed it to double down on its high-technology upgrade strategy. With each successive product cycle, South Korea captured an increasing market share. By 1991, when the company launched the internally developed 4M DRAM, which was quickly followed by Hyundai and LG, South Korea had nearly achieved parity with Japan. When Samsung developed the 16M DRAM, it led the world, and by 1994, South Korean firms had secured 40% of the global market share for the latest generation of memory chips.[81]

A Comparative Study and Strategic Lessons for India

The historical experiences of Singapore and South Korea provide two distinct templates, which share fundamental similarities, for India to consider in its pursuit of semiconductor ambitions. This section extrapolates the broader strategies each country employed to draw lessons for India with emphasis placed on the wider context that will influence India's own semiconductor trajectory, and offers analysis to support the same.

Each lesson is also accompanied by policy recommendations. While significant differences in historical, political, and economic contexts between the two countries in the second half of the 20th century and India today—along with the technological evolution of the semiconductor industry itself—mean that identical policies used by Singapore and South Korea cannot be replicated as is, broader lessons derived nevertheless provide a basis for policy recommendations tailored for India.

Lesson 1. The Basics

Singapore and South Korea prioritized broader economic, trade, business, and infrastructure reforms before intensifying their efforts to establish a semiconductor industry. This holds significant importance for India, as investor interest in ISM remains substantially hindered by the 'unease of doing business' in the country.[82] Although much has changed since the post-1991 era of economic liberalization, economists continue to emphasize the need to carry out second and third-generation reforms, in order to remove major barriers to high-tech industrialization in India.

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This holds great significance for India's semiconductor ambitions, given the capital-intensive nature of the industry and the long gestation periods before results materialize. While substantial subsidies indicate the Government of India's willingness to share high investment risks with semiconductor companies, greater success will depend on numerous other fundamental requirements.

These may include, but are not limited to, streamlined immigration and work permit systems to attract skilled talent; financial deregulation and access to low-interest credit; the establishment of export-free or special economic zones around semiconductor clusters; free trade agreements or upgrades with countries that supply crucial semiconductor inputs, such as Taiwan, South Korea, Singapore (or ASEAN), the US, the EU, and others; labor law reforms; and the creation of industrial parks equipped with necessary infrastructure, such as ultra-pure water supply and consistent power supply.

Given the complex requirements for creating a semiconductor ecosystem, many other policy variables could influence its success. It's also important to acknowledge that India has already made strides in some of these areas and is actively pursuing advancements in others.

Policy Recommendations:

- **Comprehensive industrial strategy:** Given that not all the aforementioned policy variables will play an equally significant role, India should devise a comprehensive industrial strategy, that complements the PLI scheme, based on a thorough study of the relationship between the semiconductor industry and the variables in play. Consequently, such a framework can provide a hierarchy of priorities to focus upon for future policy changes and interventions needed to sustain growth in India's Semiconductor Mission.

- **Relook at Tariffs:** Given that a nascent semiconductor sector will heavily depend on a vast range of imports – equipment, material, chemicals, etc. – India should carefully relook at its bucket of tariffs from the perspective of the semiconductor firms to meet their requirements, even as it balances the imperative to protect other industries and encourage import substitution. Importantly, high import costs must not put the Indian semiconductor sector at a cost-disadvantage, especially at an early stage. This assumes particular significance for the chip industry since components usually cross multiple borders, and thus even a small increase in customs duty payable, can escalate per re-entry.

- **Free Trade Agreements:** To create vital economic and trade linkages for its semiconductor sector, India should explore, expedite, or re-negotiate FTAs with countries that have a heavy presence in semiconductor activities, such as wafer fabrication materials or equipment production.

- **Industrial Parks:** Industrial Parks, similar to a 'Fab city' model earlier pursued, can help India develop clusters which meet the specialized infrastructure and supply requirements of the semiconductor sector.

Lesson 2. ATMP/OSAT Vs Fabrication

Both Singapore and South Korea initially supported the establishment of American or Japanese ATMP/OSAT facilities in their countries to create a basic ecosystem around talent and intermediary goods before advancing to semiconductor fabrication. Similarly, there are several reasons why this could be a sensible strategy for India as well.

To start, assembly plants are less capital-intensive and require a larger, low-skilled workforce than fabrication plants. This reduces the risk for Indian or foreign firms to invest and simultaneously enables them to take advantage of a significant comparative benefit (cheap and plentiful labor) over their East Asian or Western competitors. Furthermore, phone assembly facilities have already achieved some success, and skills can be partially transferred to chip assembly as a natural progression.[83] Notably, the ATMP/OSAT sector has many more participants, unlike fabrication, which is dominated by a few major players, making supply chain diversification considerably easier. Simultaneously, the value added in this segment is expected to grow over time with technological advancements as semiconductors evolve from a 'system on a chip' (SoC) to a 'system in a package' where 3D-stacked components are layered over each other.[84]

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In comparison, the fabrication segment is high-risk and requires an exorbitant amount of upfront capital, even though it is more strategically significant and offers a higher value addition. For instance, the Tata-PSMC plant is expected to cost $10 billion and will consume half of ISM's total outlay. There are several other factors that make a disproportionate focus on fabrication during the early stages of India's semiconductor journey misguided.

To begin with, diversification in the fabrication segment is currently driven by governments rather than market forces. This introduces uncertainty and results in a fundamentally different type of competition than seen in the past or in other industries. For instance, India's semiconductor partners, including the US and Japan, along with other nations like Taiwan and South Korea, have invested significantly more resources in their efforts to build fabs. Combined with their existing advantages (for example, Taiwan alone fabricates over 90% of advanced chips), this likely means that India will struggle to keep pace in the fabrication race, and many subsidies will merely allow India to produce legacy chips (such as 65 nm). This will hardly reduce India's import dependencies, particularly as chips are upgraded across generations and demand shifts, nor will it yield any strategic benefits. Furthermore, genuine concerns about operational capacity in global fabrication add to the business's risks, as the ultimate test of India's semiconductor journey will be the capability of its fabs to produce price-competitive products in a global market.

In summary, although it's true that high-technology chip fabrication will ultimately yield strategic dividends, and the country has rightly set its sights on this goal, India could benefit from initially focusing on ATMP/OSAT facilities while simultaneously developing its 'absorptive capacity' before heavily venturing into the fabrication segment.

Policy Recommendation:

Differentiated Policy for ATMP/OSAT: In the Phase II of India's Semiconductor Mission, India can separate the incentives and subsidies for fabrication units and ATMP/OSAT units to ensure that the budgetary outlay is not consumed by the far more capital-intensive fab proposals. Furthermore, India should also provide targeted secondary policy support to meet the requirements of assembly operations, including labor-law reforms and specialized training programmes to upskill a critical mass of workers.

Lesson 3. Talent is Everything

What is clear from the histories of Singapore and South Korea's semiconductor journeys, and indeed from the history of any major semiconductor power, is that a country's ability to upgrade and sustain its chip ecosystem is fundamentally linked to the cultivation of a pool of highly specialized talent and an abundance of high-skilled labor. Talent arguably becomes an even greater factor than capital infusion and serves as the pillar upon which absorptive capacity rests.

Singapore's strategy to establish technical knowledge partnerships between MNCs and its technical/scientific institutions was ahead of its time, recognizing early on that R&D ecosystems in high-tech fields have shifted toward the private sector. This yielded significant benefits, not only for its semiconductor industry but also as knowledge spilled over into other sectors.

On the other hand, South Korean chaebols invested significantly to attract top talent, leveraged technical expertise from their technology providers and equipment suppliers and crafted highly innovative corporate strategies to internalize and further develop technical knowledge. This was a key, perhaps the most decisive, factor behind their rapid success and ultimately helped create a knowledge-intensive economy for the country.

India will be best served by a mixed approach that pursues both strategies at the same time.

According to one estimate, India will require 300,000 skilled professionals for its semiconductor industry within the next three years. New Delhi's semiconductor partnerships with Singapore and the US, which are centers of expertise, will be greatly beneficial.[85] The US-supported ITSF has already focused on 'workforce development and skills training' in India, and the India-Singapore agreement is also expected to emphasize 'talent development' and 'exchange of best practices,' among other cooperative areas.[86] On the domestic front, India has introduced new courses, including a B.Tech in VLSI Design and Technology, and has plans to train over 80,000 semiconductor engineers.[87] While these are positive steps, they are not sufficient on their own, and India will need to take additional action.

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Importantly, similar to Singapore, India must recognize that new generations of technical research and knowledge are now deeply integrated (even more so than when Singapore began) within tech corporations rather than universities. This is particularly true in India, where the curriculum is often severely outdated. As a result, the country will significantly benefit from partnerships between its technical institutions and global semiconductor giants. The presence of leading semiconductor design firms in India can be utilized for this purpose, as can the future involvement of new semiconductor players entering the Indian market.

Simultaneously, like South Korea, India must also recognize that the quality of talent is highly varied. The 'cream of the crop' of semiconductor engineers will be primarily responsible not only for future technological advancements but also, first, for the internalization of existing process and product technologies. While attracting this segment of talent may be the prerogative of Indian semiconductor firms, the Government of India can find innovative ways to support them and help address the 'talent drain' to other advanced countries. For example, a prominent Indian expert has noted that Dholera (where India's first fabrication facility is being built) critically lacks a vibrant lifestyle, and without it, Tata may struggle to attract top-tier talent, who can command lucrative salaries anywhere and may require more than just financial incentives to relocate.

Policy Recommendations:

- **Address 'Brain Drain':** India should study possible innovative solutions that address outward migration of highly specialized talent and implement a policy that provides specific incentives to targeted individuals (for instance, PhDs in STEM subjects). Such a policy can employ a variety of approaches, such as tax breaks based on educational qualification and professional experience as well as lucrative grants to pursue higher order research within the country.

- **Education and Research Partnerships with Semicon Giants:** India should implement a policy framework aimed at facilitating partnerships between its technical institutions and foreign firms with specialized and advanced knowledge in the semiconductor sector. This will allow Indian students access to the latest know-how within the industry, as well as expose and familiarize them to advanced and nascent technologies as well as best practices in the sector.

- **Technical Upskilling:** Given that technical upskilling of India's labor force is critical to address the current and future requirements of the Indian semiconductor sector, India should establish targeted institutes in partnerships with domestic and foreign semicon players where short and long relevant courses and are offered. India should invest in a 'Skills Development Fund' of its own which can fund such institutes and hold them quality standards, as well as tailor financial (if needed) and other incentives for the country's workforce to enroll in the same.

Lesson 4. The Real Sources of Leverage

Currently, there is significant debate among policy communities globally about how geopolitical forces and levers will influence the future of technological supply chains. While it is accurate that countries within the US-led alliance system, especially Japan, greatly benefited from technological cooperation with Silicon Valley during the critical early years of the semiconductor industry, it is also true that, in many instances, the role of the US is often overstated.

Both Singapore and South Korea undoubtedly benefited from their relationships with the US, but market forces and their industrial strategies arguably played a much more significant role in their semiconductor success. Singapore has always been (and remains) a non-aligned country. In contrast, South Korea received limited technological assistance from Washington in the mid-1970s because the US and Japan were amid a 'Chip War', which originated from the initial transfer of American technologies to Japan. As a result, the US was considerably hesitant to transfer higher-order (fabrication) technology to South Korea, even while it supported other offshore operations, like assembly, to compete with Japan. Consequently, both Singapore and South Korea developed alternative sources of leverage that became more significant than geopolitics as they advanced in the semiconductor industry.

Singapore created a highly attractive environment for MNCs to offshore operations and then leveraged their presence and committed investments to rapidly diffuse skills and technology into a larger domestic ecosystem. The city-state also strategically established ancillary industries to support semiconductor operations, or 'backward linkages' between MNCs and domestic firms, which further acted as leverage.

For its part, South Korea paid a significant 'price of entry' and used the 'capital as leverage' to launch its semiconductor industry. The chaebols invested $4 billion in upfront investments by 1989 alone, and the royalty fees charged by U.S. firms for their chip designs and process technologies, along with interest rates, constituted the largest portion (close to 28%) of this total cost, significantly higher than labor (5%) or materials (10%).[88] Importantly, South Korea continued to invest aggressively even during cyclical downturns in the global chip market, emerging stronger when the market recovered.

Other secondary and tertiary sources of leverage were also significant in South Korea's overall approach. For example, South Korea's export-led model kept its domestic markets open to US supply, which aided trade negotiations with Washington – this contrasted sharply with the trade relationship between the US and Japan at that time.

In this context, India is similarly positioned to Singapore and South Korea in that it has strategic relationships, most notably with the US, as well as with the EU and Japan. Such partnerships will support its long-term efforts to develop technological capabilities, but India is unlikely to gain significant competitive advantages from them. Contrary to what popular media narratives often suggest, or the beliefs of many within the Indian strategic community, diplomatic efforts and international partnerships will ultimately play a relatively minor role in India's overall journey.

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Arguably, the limits of India's geopolitical leverage are already evident from its semiconductor trajectory thus far. While US-based Micron was the first entrant as an ATMP player, Indian diplomatic efforts over more than three years did not succeed in facilitating the entry of any of its major partners into the more strategic fabrication space. For another ATMP unit, the Japanese company Renesas has partnered with Stars Microelectronics, a Thailand-based firm, and the Indian company CG Power.

In fact, the French semiconductor firm STMicroelectronics reportedly declined to take a stake in the previously much-publicized Foxconn-Vedanta joint venture (which had announced its intention to invest in a fabrication facility), leading to the proposal's rejection by the Indian government. Eventually, fabrication technology arrived from Taiwan—a country with which India has a limited diplomatic relationship—in the form of PSMC's partnership with Tata Electronics.

Furthermore, Tata Electronics, along with PSMC and Himax (also Taiwanese), has invested in an OSAT facility in Assam.

Even in the ATMP/OSAT sector, it appears that 'capital as leverage' has probably played a significantly larger role than geopolitics. 70% of the Micron plant's costs will be subsidized by the GoI (50%) and the Gujarat government (20%). Moreover, all four assembly-related investments were announced after India revised its semiconductor scheme to increase capex subsidies for ATMP/OSAT from 30% to 50% in late 2022.[89]

Thus, similar to Singapore and South Korea, India must also identify sources of leverage beyond geopolitics that can influence market forces in the country's favor and assist with the future entry of other major players, allowing it to sustain its semiconductor industry.

As outlined in a previous section, 'capital as leverage' is already in play, although in a fundamentally different manner than in South Korea. However, this alone will not be sufficient, considering that other countries with stronger competitive advantages plan to inject even more funds into their semiconductor industries. Japan and the U.S. plan to invest $65 billion and $52 billion, respectively, to support their already advanced semiconductor sectors.[90] Meanwhile, the South Korean giant Samsung intends to invest $230 billion over the next 20 years, with government backing, to create the world's largest semiconductor cluster.[91] Clearly, India cannot reasonably compete based on capital alone.

There is value in the targeted creation of ancillary industries, especially in areas where Indian sectors already possess significant strength and scale—such as the domestic chemicals industry. A large and untapped source of leverage is India's abundant workforce, which, if adequately upskilled, can provide a vital advantage in labor-intensive segments of the semiconductor value chain. Meanwhile, as the Indian middle class continues to expand, so will the country's already massive domestic electronics market. To a degree, this can be leveraged to attract domestic production of semiconductors, given that domestic chips produced in India can be consequently assembled and integrated into a range of products and sold within the country, which could cut down transportation costs at multiple

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stages, as well as, help avoid the average Indian electronics tariff rate of 7.5%.[92] Another potential source of leverage for India could be its federalist structure itself. Given that Indian states have financial autonomy of their own, they can be encouraged to compete against each other, through subsidies and incentive-packages of their own, for attracting investments from semiconductor players (as indeed, Gujarat and Maharashtra did in the case of a proposed Foxconn-Vedanta fabrication plant in 2022, even though the project failed to take off). Ultimately, as discussed above, India's greatest strength may lie in 'talent as leverage,' provided it can implement innovative pathways to develop and sustain a knowledge economy.

Policy Recommendations:

- **Focus Diplomatic Energy on Specific Requirements:** Indian semiconductor diplomacy has to be informed by the key requirements of its semiconductor sector. Therefore, India should conduct extensive stakeholder consultations on a regular basis to identify the same and then focus its outreach to foreign firms, as well as governments, to facilitate these specific needs and deliver targeted gains (tariff reduction, specialized knowledge exchange, technology transfers, etc.). Such an approach will complement India's broader 'semicon partnerships' and cooperation that can help develop strengths over a longer term.

- **Differentiation in PLI Scheme for Electronic Components:** The recently announced PLI scheme for electronic components will make ancillary industries – which offer critical support to India's semiconductor sector and others – eligible for incentives, albeit with far less financial support, and thus promote 'backward linkages'. However, India should create classifications that differentiate between components, sub-components, and materials based on their domestic value addition to the semiconductor industry, and consider a hierarchy of financial support (within the scheme) based on the same. This is because the wide range of constituent components in play have varied market dynamics of their own, as well as varied strategic value to the Indian semiconductor sector.

Conclusion

Over the next decade, the global semiconductor industry hopes to capitalize on a significant surge in worldwide demand. The explosion of generative AI, crypto mining, virtual reality, autonomous vehicles, and cloud services are just a few key examples of technological innovations that require a substantial number of chips to function. The semiconductor industry is projected to grow by 6-8% annually and reach $1 trillion by 2030.[93] Clearly, strong demand presents a promising outlook for India's semiconductor ambitions.

On the other hand, many semiconductor policy experts believe that the global race to build chip facilities could lead to overcapacity for certain chip sizes, consequently creating significant cost disadvantages for new entrants. Moreover, there are real uncertainties in the evolution of semiconductor technology itself, as well as in the larger geopolitics surrounding it. For instance, open-source hardware technologies, 3D printers that assist with layer fabrication and assembly, and even silicon alternatives like gallium nitride, cubic boron arsenide, and graphene are just a few recent innovations that have the potential to disrupt the industry significantly. In fact, some scientists contend that we may be nearing the end of Moore's Law, and soon it may no longer be physically feasible to reduce the size of a chip. Even before that, some analysts contend that it may become commercially unviable to do so; for example, a single Nvidia Blackwell chip (the latest generation) is already estimated to cost $40,000.[94] On the geopolitical front, there is the possibility of China invading Taiwan, among other concerns.

Given such a range of future uncertainties in the already high-risk, capital-intensive semiconductor sector, Indian semiconductor firms and government policies will undoubtedly need to consistently adjust in real time for survival and growth. But more importantly, India will need to build fundamental strengths within its domestic ecosystem that allows for such adaptation.

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Geopolitical, trade and economic dynamics, as well as the technological landscape, also witness large shifts in the roughly 30-year period during which Singapore and South Korea's semiconductor industry developed. However, their efforts successfully surpassed challenges due to a sharp focus on developing deep-rooted competitive advantages that would endure, even as they implemented policies that allowed them to adapt and take advantage of changes in their external environment.

In the case of Singapore, it focused, first and foremost, on building a reliable business environment that assured MNCs enough to invest and expand their operations. In the later stages, the city-state implemented policies to leverage as well as deepen the MNCs' dependencies and investments for internal transfer of skills and technology within Singapore. Meanwhile, South Korea from the start placed strategic focus on guiding and developing the chaebols' ability to emerge globally competitive in the semiconductor sector. It employed an evolving industrial policy framework, with clear objectives, that could meet the demands and requirements of the chaebols (access to credit, for instance) but also imposed costs when they underperformed.

While their institutional pathways varied, the similarities between Singapore and South Korea's journey reveal the core requirements for India's semiconductor industry to sustain and thrive. This includes, but is not limited to, access to cheap imports and export markets, successful implementation of broad economic, trade and infrastructural reforms, policies that address the key requirements of its domestic players and help adapt to geopolitical and economic shifts, and a strategic focus upon building on its advantages and developing technological capabilities. For India, arguably, the most important as well as potent competitive advantage is the country's large pool of talent, which if cultivated and supported, can first unleash enormous 'technological absorptive capacity', and then evolve into 'innovation capacity.' This, more than anything else, ultimately determines the future success of any knowledge-intensive industrial sector for any country in the world, as demonstrated by the histories of Singapore and South Korea.

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