CHINA'S QUEST FOR INNOVATION AND TECHNOLOGICAL ADVANCEMENT

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EXECUTIVE SUMMARY

China’s rapid advancement in various domains of science and technology have become a topic of significant interest. There have been several explanations that seek to explain how China has been able to compete with established players, especially the United States in bolstering its domestic innovation potential. However, some common explanations such as forced technology transfer, industrial espionage, theft or state capitalism do not entirely explain how China has been able to become one of the global innovation powerhouses.

Several foundational factors such as strengthening its basic health and education metrics, along with 'Creative Insecurity' due to geopolitical competition with the US have facilitated improvements in China's innovation capacity. Furthermore, China's unique political and bureaucratic structure allows it to implement a top-down approach to policymaking. Through what has been described as "Selective Authoritarian Mobilisation and Innovation Model," China has often sought to promote research and development through this top-down approach. This ranges from direct state intervention, buying machinery from abroad, facilitating easy access to finance, promoting foreign direct investment and even industrial espionage. These policy tools have had varied levels of success.

IS CHINA AN INNOVATION POWERHOUSE?

In terms of research and innovation, China is certainly an outstanding performer in its income category globally.

11th

RANK IN GLOBAL INNOVATION INDEX (GII) 2022

Only middle-income country in GII top-30

1st

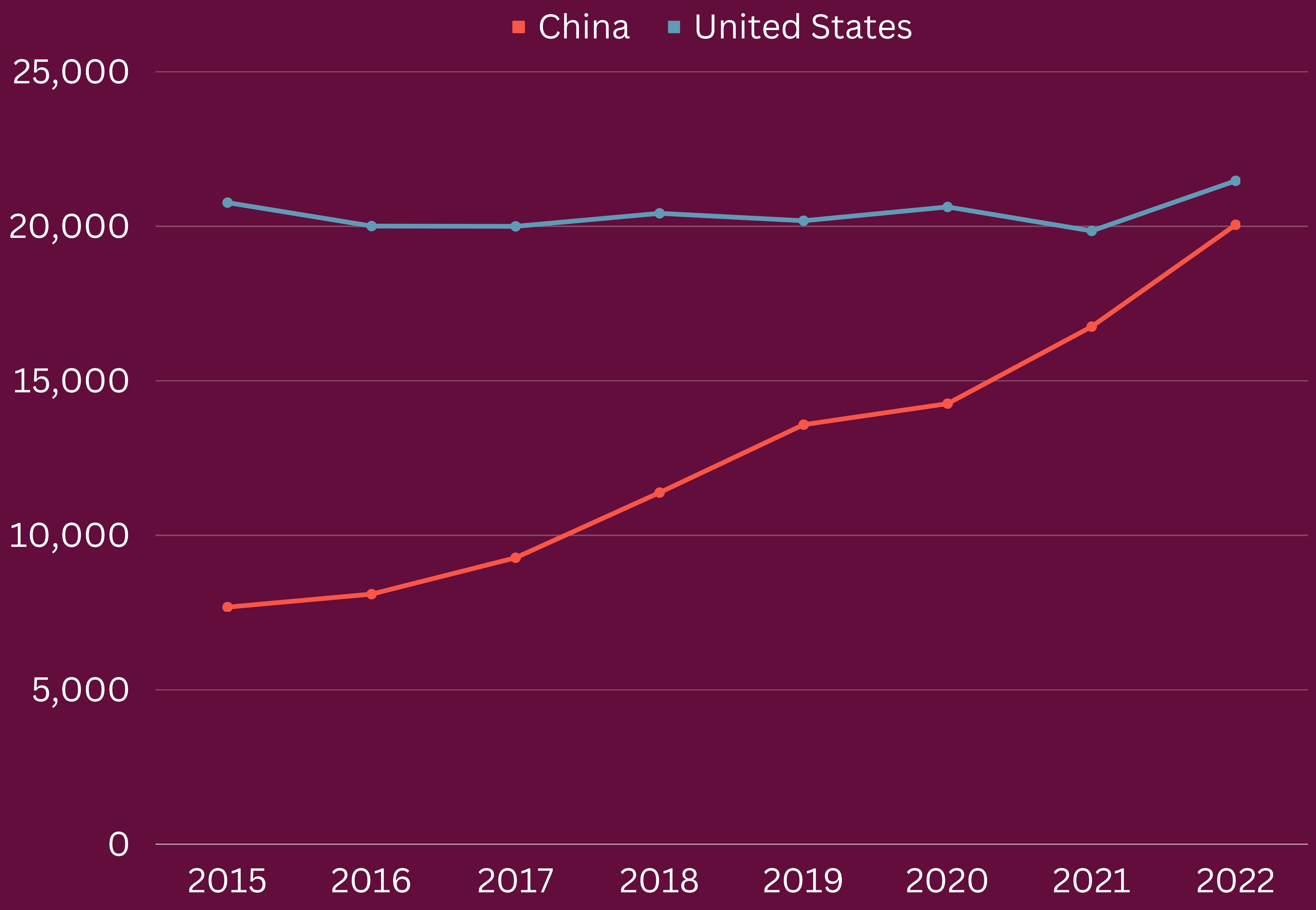
RANK GLOBALLY IN NATURE INDEX OF NATURAL SCIENCE JOURNALS

Fast catching up to United States in other natural science domains

100

SCIENCE AND TECHNOLOGY CLUSTERS

China and the United States have an equal number of clusters at 21 each in top 100 S&T clusters globally



Contributions to research articles published in the Nature Index group of high-quality science journals (2015-2022)
(Source: Nature Index)

China is rapidly closing the gap with the United States for contributions to research articles published in the Nature Index group of high-quality science journals.

In 2022, China overtook United States as the number one ranked country for contributions to research articles published in the group of natural-science journals. [1]

FOUNDATIONAL FACTORS

China's quest for developing its own research and development ecosystem and cultivating a culture of innovation involves various factors. In addition to strengthening usual health and education metrics, there are some structural factors such as competition with US that allow it to push for improving its innovation infrastructure. Furthermore, China's unique political and bureaucratic structure allows it to implement a top-down approach to policymaking in this regard.

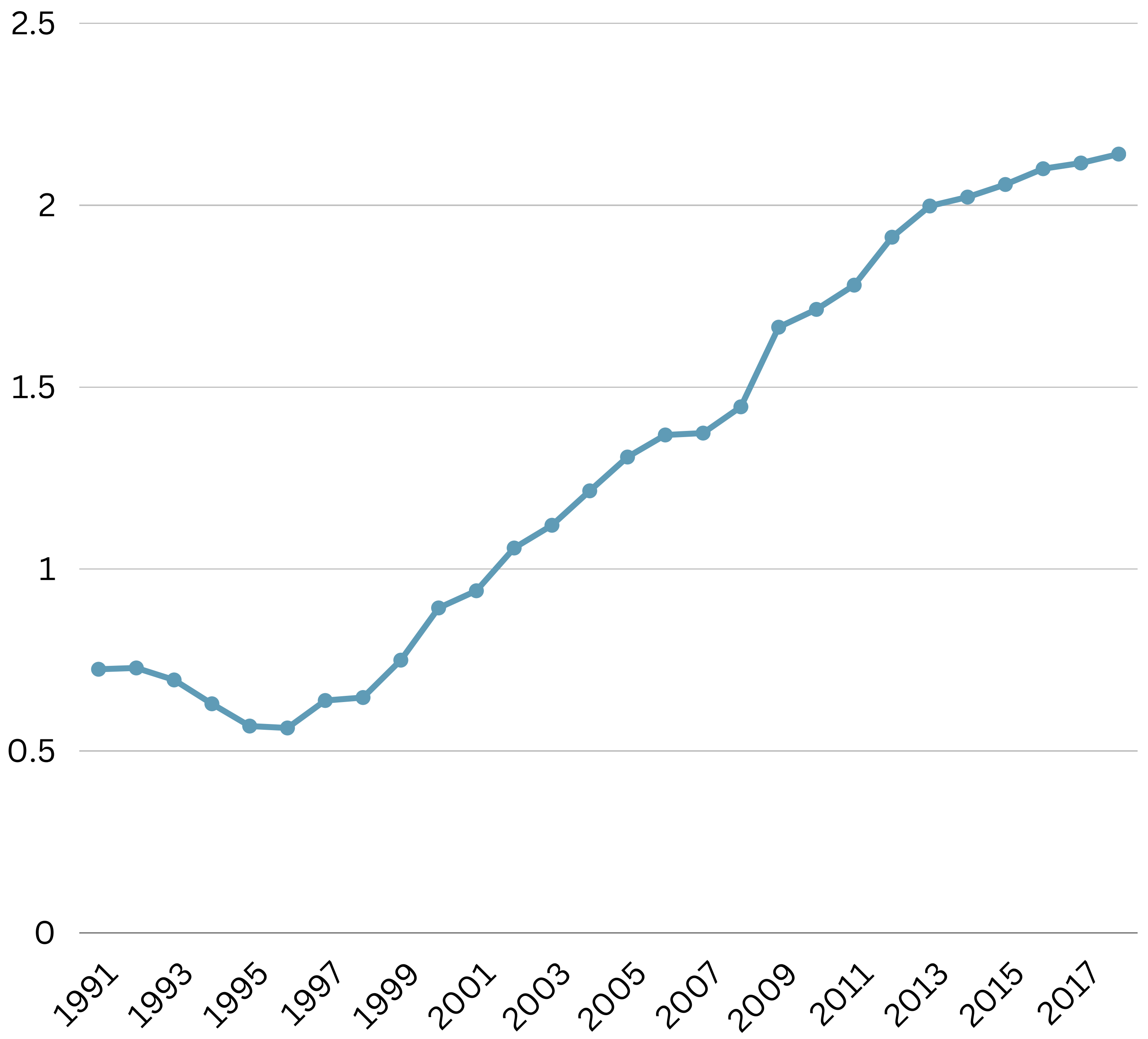
1. **CREATIVE INSECURITY**
2. **SELECTIVE AUTHORITARIAN MOBILISATION AND INNOVATION MODEL**
3. **HIGH INVESTMENT IN CAPABILITIES AND INFRASTRUCTURE**

01 CREATIVE INSECURITY

Mark Zachary Taylor in his book "The Politics of Innovation" describes Creative Insecurity as the positive difference between the threats of economic or military competition from abroad and the dangers of political-economic rivalries at home.

External economic and military threats constitute a force that can counteract the domestic distributional politics that cause S&T stagnation. When a nation-state enjoys a state of creative insecurity, its rate of innovation will tend to accelerate. [2]

Desire for competing with US for technological parity and even superiority generates this 'creative insecurity' for China.



China's expenditure on Research and Development as % of GDP (1991-2018) (Source: OECD)

02 SELECTIVE AUTHORITARIAN MOBILISATION AND INNOVATION MODEL

China's political economy is able to align incentives of powerful stakeholders. This leads to development of a unique innovation model described by Tai Ming Cheung as Selective Authoritarian Mobilisation and Innovation Model. [3] Specific features of this model allow for targeted effort towards innovation:

Selectivity: Only a few projects picked for fast-tracking in long term plans.

Authoritarian: Nature of project implementation is top-down.

Mobilisation: The model sometimes focuses on mega-projects, which are special projects that galvanise interest.

Innovation: Follows different strategies to push innovation such as technology introduction, digestion, assimilation, and re-innovation.

A recent example of such an effort is the Innovation and Development Driven Strategy (IDDS) which was approved in 2016 and focuses on indigenous innovation and on elevating the capability to conduct original innovation, integrated innovation, and re-innovation.

02.A INNOVATION AND DEVELOPMENT DRIVEN STRATEGY

IDDS focuses on indigenous innovation to elevate the capability to conduct original innovation, integrated innovation, and re-innovation. It attaches importance to systematic innovation, seeks to deepen reform in technological structures, and push for close integration of S&T and economic development. [4]

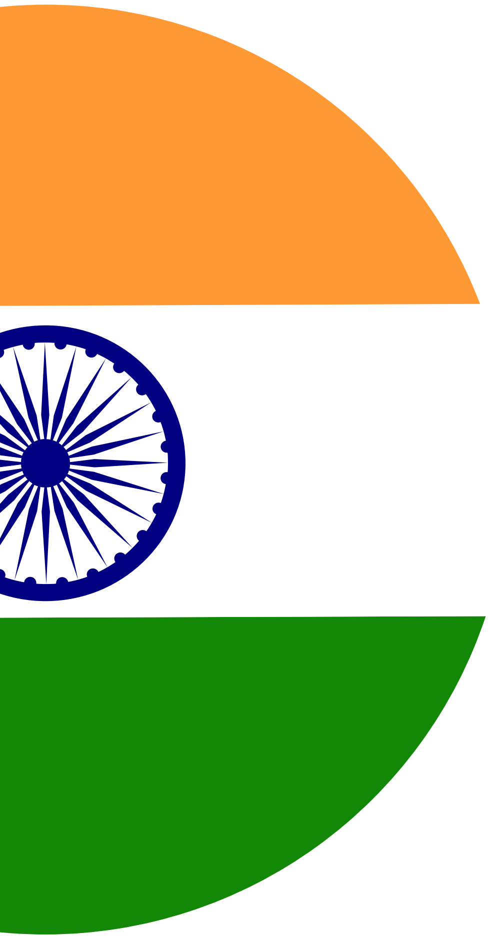
It also seeks to build a market-oriented system for technological innovation with enterprises playing the lead role and combining with industry, academia, and research institutes. Focus is also on improving China's knowledge innovation system and strengthen basic research and development (R&D) in frontier technologies.

IDDS has the following aims:

- Annual R&D expenditure to reach 2.5% of GDP by 2020 and 2.8% by 2030.
- Build large-scale national laboratories comparable to foreign counterparts such as the Lawrence Livermore and Los Alamos National Laboratories in the United States.
- Grand pivot from imitation to original innovation is the centrepiece of the IDDS umbrella and will occur during the 2020s.
- As the plan is relatively recent, it is difficult to adjudicate it as either success or failure at this stage.

03 HIGH INVESTMENT IN CAPABILITIES AND INFRASTRUCTURE

China focused on investing in its human capital as a foundation of building a technology and innovation ecosystem. China also has a long history of the acknowledgement to learn from others. This is reflected in Self-strengthening movement of 19th century and Deng's visit to Japan during its reform and opening-up phase. A comparison of India and China in such metrics is quite instructive:



In 1980 → 72.5% had no schooling In 2010 → 42% had no schooling	**Highest Educational Attainment (25 years+)**	In 1980 → 33% had no schooling In 2010 → 8.2% had no schooling
In 2010 → 4.4 years	**Average Years of Schooling**	In 2010 → 7.5 years
In 2000 → 110 In 2010 → 157	**Researchers in R&D (per million people)**	In 2000 → 547 In 2010 → 903

POLICY INSTRUMENTS

China has adopted a variety of initiatives and instruments to bolster its research and development ecosystem. Several of such policy instruments have been described by Barry Naughton in his book, "The Chinese Economy: Transitions and Growth" [5] In addition to broad seven categories described by Naughton, a few more have been added in this document to further classify steps China has taken to improve its research and development capabilities.

1. **TARGETED INDIGENOUS DEVELOPMENT**
2. **BUYING IT OUTRIGHT**
3. **BARGAINING APPROACH**

4. PROVIDING SEED INVESTMENT
5. ENCOURAGE SPIN-OFFS
6. SUPPORT DOMESTIC ENTREPRENEURSHIP
7. OPEN UP TO FOREIGN DIRECT INVESTMENT
8. STEAL IT
9. FOCUS ON THE MAKER, NOT THE PRODUCT

01 TARGETED INDIGENOUS DEVELOPMENT

This approach involves a mission mode push to pursue key goals and has worked well when there is broad agreement on priorities and objectives. These are usually national projects with significant political and economic commitment. For example, the "two bombs and a satellite program" was able to successfully build a nuclear bomb, and ICBM and an artificial satellite. [6]

However, this approach is inefficient at diffusing new technology into the civilian economy. For example, high prestige research institutes like Chinese Academy of Sciences are good at producing a single, exemplar product rather than acting as a productive asset for economy.

02 BUYING IT OUTRIGHT

This approach was pursued mainly during the first few years following the opening up of the Chinese economy under Deng Xiaoping. It involved massive purchases of industrial machinery from global technology leaders directly to bridge the technology and industrial gap. However, it was deemed to be unsustainable in the long term due to the high costs involved. [7]

China now moved away from this approach towards the import of soft-technology licensing like technology purchases.

03 BARGAINING APPROACH

China also sought to convince MNCs to share technology in exchange for access to China's market. However, MNCs were not as eager and this policy did not fructify as expected.

However, there were some individual successes. For example, in 1980s, Shanghai Bell Alcatel, a joint venture (JV) with subsidiary of Belgian Bell did transfer technology to manufacture custom large scale integrated chips (LSI). These were extensively used in the telecom industry. [8]

Interestingly, the expertise gained through this JV later helped develop domestic telecom companies like ZTE and Huawei.

04 PROVIDING SEED INVESTMENT

In order to promote development of indigenous research and development ecosystem, China used a system of competitive grants for research institutions.

For example, 86-3 Program was designed to stimulate the development of advanced technologies. Funding for programs that developed Loongson computer processor, Tianhe supercomputers, and Shenzhou spacecraft. [9, 10, 11] can all be traced to 86-3 program.

One of the most widely used instruments for this purpose are the Government Guidance Funds (GGFs).

04.A CHINESE GOVERNMENT GUIDANCE FUNDS

Government guidance funds are public-private investment funds that aim to both produce financial returns and further the government's industrial policy goals.

Advantages:

- These funds allow the Chinese state to leverage market discipline and expertise.
- They offer patient capital, a critical resource for emerging technologies.
- These funds can also complement and amplify other industrial policy measures.

Weaknesses:

- Guidance funds often don't raise as much money as planned and much of what they raise is never actually invested in projects. [12]
- There are too many guidance funds, leading to redundancy and inefficiency.
- These funds are poorly managed and fund capital has been wasted on nonstrategic and illicit activities.
- Guidance funds do not invest in early-stage companies as intended.
- Guidance funds often fail to attract truly private capital, and in some cases may even crowd private capital out of the market.

Despite many weaknesses, guidance funds still have advantages over China's traditional industrial policy mechanisms. As of the first quarter of 2020, 1,741 such funds were set up, with a target size of 1.55 trillion USD. [13]

05 ENCOURAGE SPIN-OFFS

Efforts were made to push research institutions to diffuse technologies into the civilian economy. Institutes and universities were allowed to contract with enterprises to establish commercial subsidiaries. These subsidiaries were unique in the sense that they were technically "state-owned" but were considered "civilian" in the sense that they had no direct bureaucratic supervisor. Hence, these firms enjoyed significant operational freedom. [14]

This strategy did not yield expected results and was largely unsuccessful, with the exception of Lenovo. However, it marked shift in Chinese policy where high-tech firms were given extra leeway. [15]

06 SUPPORT DOMESTIC ENTREPRENEURSHIP

Traditionally, freedom to domestic enterprises lagged when compared to those accorded to foreign multinationals. Only in 1999 did Chinese firms receive across-the-board support to enter the high-tech fields. Instead of earlier policy of supporting state-owned enterprises (SOEs), institutional support from government begun to be provided to MSMEs, startups and tech spin-offs. [16]

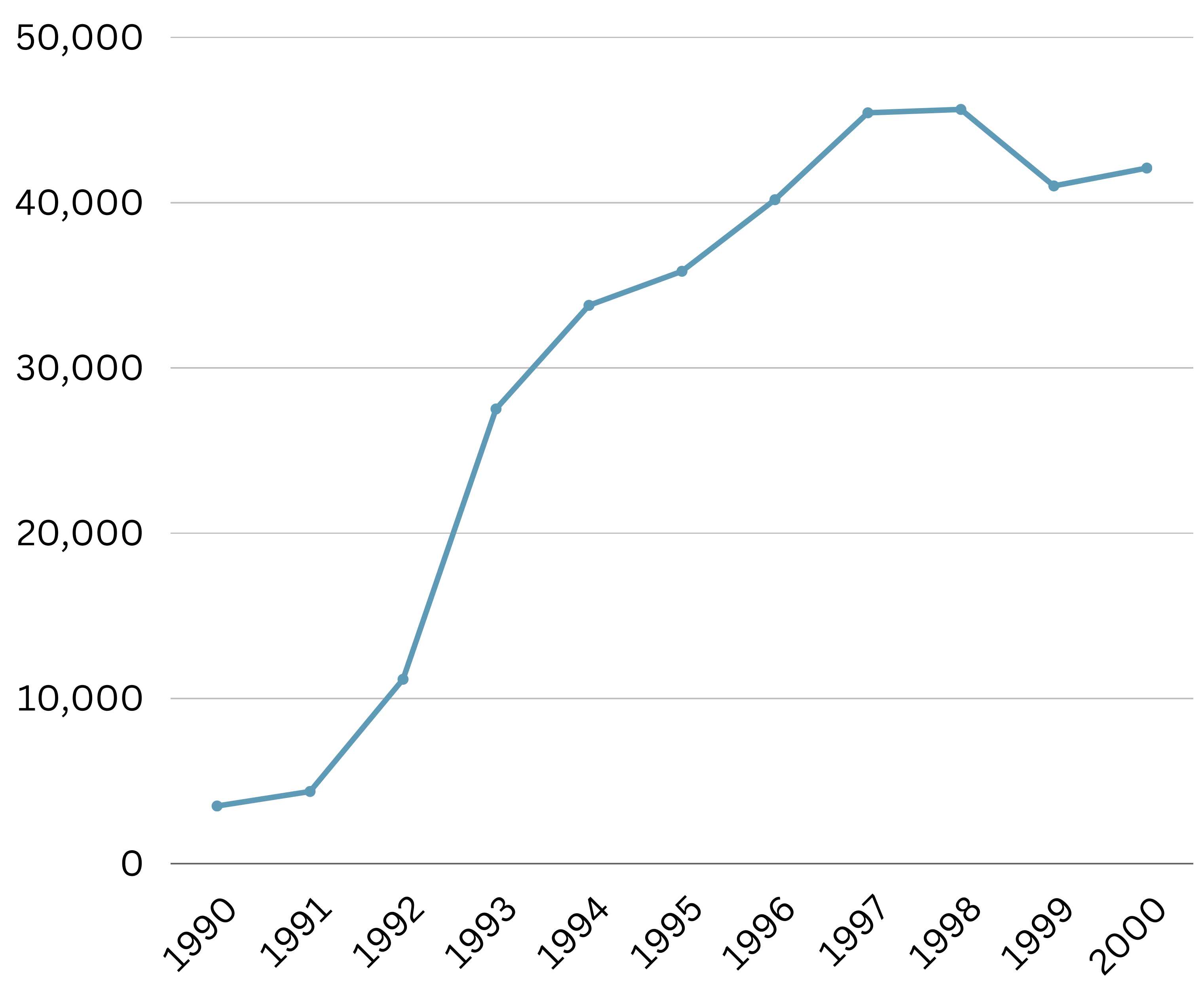
This led to a major behavioural change where non-state firms were seen as important players. Institutional support to these firms came in the form of tax breaks, low-interest credit, preference for public procurement etc.

07 OPEN UP TO FOREIGN DIRECT INVESTMENT

China realised that govt-sponsored technology development programs had not led to catching up with global best practices. [17] In 1992, large number of competitive technology suppliers were allowed in the market, leading to a surge in FDI.

China promised market access and protection of IP as incentives for foreign companies to invest, and Chinese ascension to WTO codified and made binding these promises.

FDI was able to advance China's technological capability by filling in the technological gaps, Introducing advanced technology, and Improving existing technology. [18]

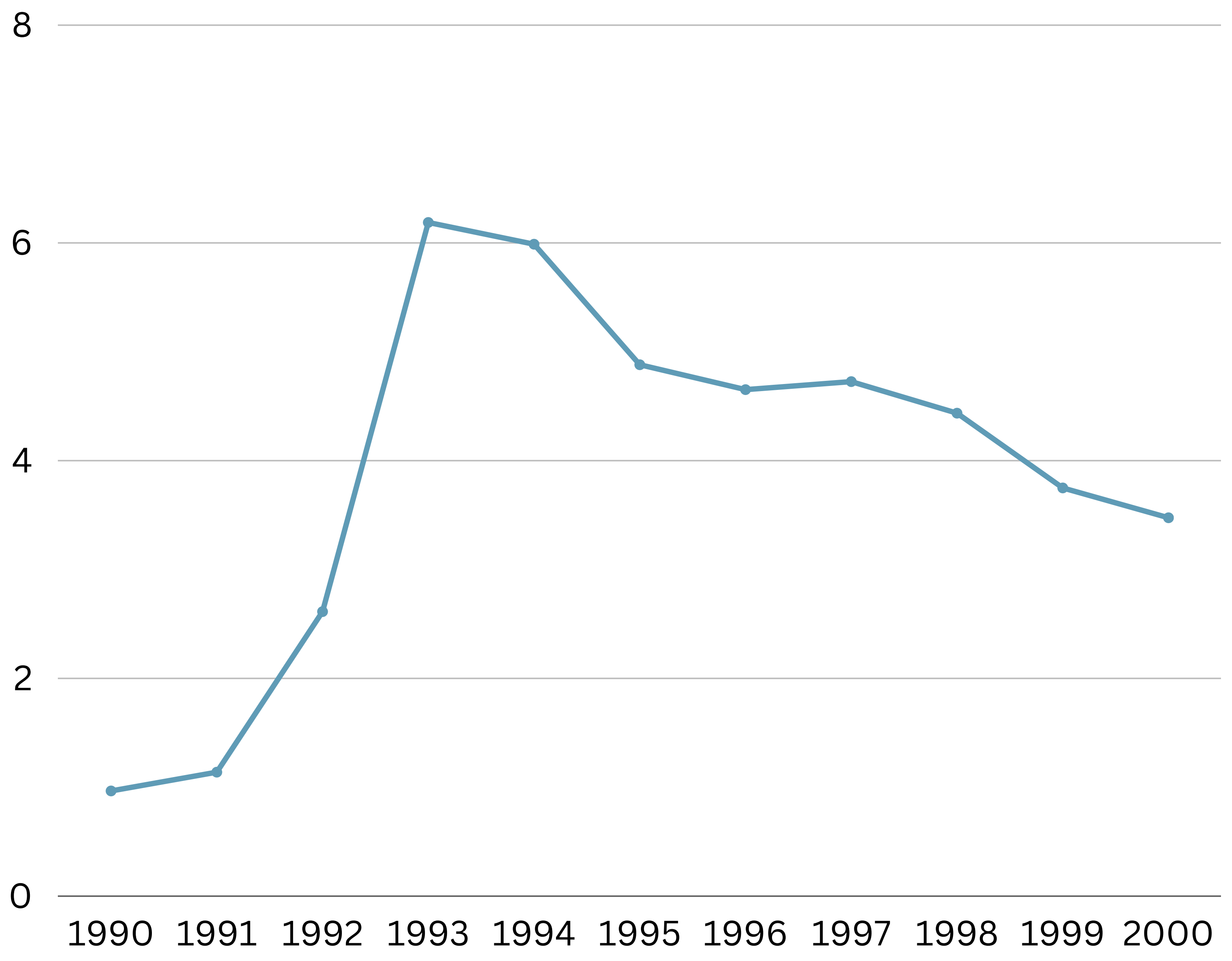


China's Foreign direct investment, net inflows (Million US$) (1990-2000) (Source: World Bank)

07 OPEN UP TO FOREIGN DIRECT INVESTMENT

Foreign-invested enterprises (FIEs) in China collaborated with domestic industry and research institutions to take advantage of China's high-calibre scientific research institutions and labour pool. For example, Oracle worked with Lenovo Group on ERP software and French Alcatel with TCL on new mobile communication technologies. [19]

The role of the transnational, ethnic Chinese technology community has served as the glue to bind foreign firms to China. Shared ethnic ties have encouraged ethnic Chinese foreign technology firms to locate core technology activities in China. This is in contrast to other foreign firms that have been relatively much slower in committing resources to technological advancement. [20]



China's Foreign direct investment, net inflows (% of GDP) (1990-2000) (Source: World Bank)

07.A IMPORTANCE OF HYBRID FIRMS

"Hybrid" companies in China are those that combine ethnic Chinese management with foreign financing. They are the main drivers of China's technological development because they avoid China's domestic financial system while enhancing China's domestic technological capabilities. [21] Famous examples of such firms include Semiconductor Manufacturing International Corporation (SMIC), Xiaomi, Baidu, Alibaba, and Tencent.

Firm Type	Financing	Operational Strategy	Technological Strategy	Contribution to Technological Upgrading
Neglected Domestic Firms	Poor	China-Based	No Upgrading	Low
Favoured Domestic Firms	Soft Budget Constraints	China-Based	Try but generally fail	Low
MNCs	Hard Budget Constraints	Foreign-based	Not necessarily in China	Variable
Hybrid Foreign Invested Enterprises	Hard Budget Constraints	China-Based	Try in China	High

Adapted from Douglas Fuller, *Paper Tigers, Hidden Dragons, 2016*

08 STEAL IT

China has deployed different strategies of industrial espionage. However, the role of state-guided industrial espionage (something done secretly) is overplayed. This is because of statutory provisions and plans declared publicly. [22] These strategies include [23]:

- Legal: China-based foreign subsidiaries, Conferences, Tech Exchanges, Enrolments at US universities, etc.
- Illegal: Violation of NDAs, Wilful patent infringement, insider operations, etc.
- Extra-legal: Transfer incentive programmes, Oversees scholar returnee facilities, Document acquisition facilities, etc.

09 FOCUS ON THE MAKER, NOT THE PRODUCT

The practice began in 1872, when China sent 120 students to the United States. Now, 25% of US STEM graduates are Chinese nationals. Chinese scientists are usually under pressure to comply with CCP directives. Researchers are told what they are doing benefits not only one's “small self ” (小 我) but a “larger self ” (大我), namely, one's homeland and kin. [24]

The goal is not always to get the talent back to China. It is about getting them to serve China even if they are overseas. eg. Chengdu High-Tech Industrial Development Zone has 31 offshore innovation centres in Japan, Europe, US, South Korea. [25]

09.A YOUNG THOUSAND TALENTS PROGRAM

- This program was launched in 2008 to recruit talent from abroad. Between 2008 and 2018, grants offered to more than 7,000 researchers [26], with majority of returnees coming from the US. Researchers are offered generous research packages, internationally competitive salary and start-up funds.

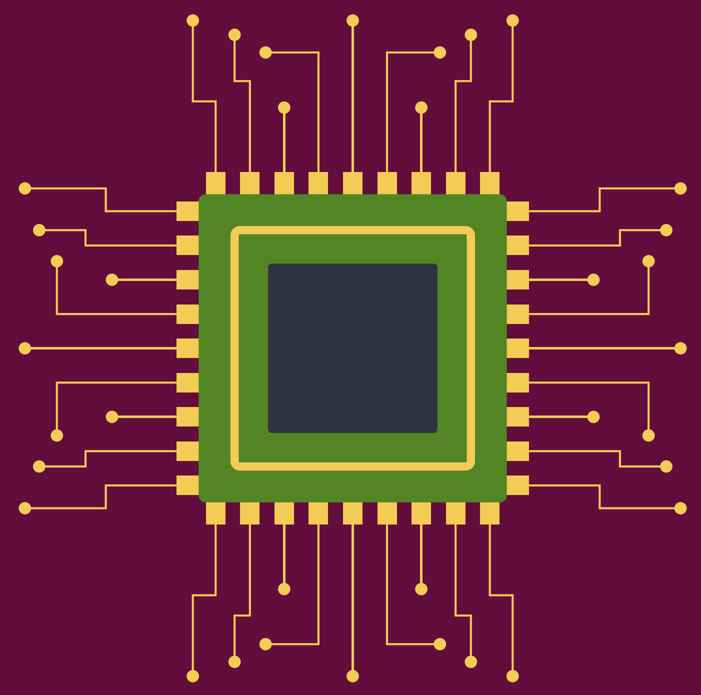
Successes:

- According to a study [27], YTT scholars published 27% more papers, including in journals ranked in the top 10% for a field as compared to matched researchers who stayed in the United States. Access to funding and research staff seems to be the main driver of the productivity gains.
- US and China are the top collaborating pair in the production of high-quality scientific research worldwide, based on their joint authorship contributions to articles in the 82 journals tracked by the Nature Index.

Weaknesses:

- YTT program created fears of spying and theft of intellectual property among US officials. [28]
- In response to these fears, especially among US officials and the public, The National High-end Foreign Experts Recruitment Plan replaced the Thousand Talents Plan in 2019. China also stopped making public the names of scientists who receive funding through this program.

CASE STUDY: SEMICONDUCTORS

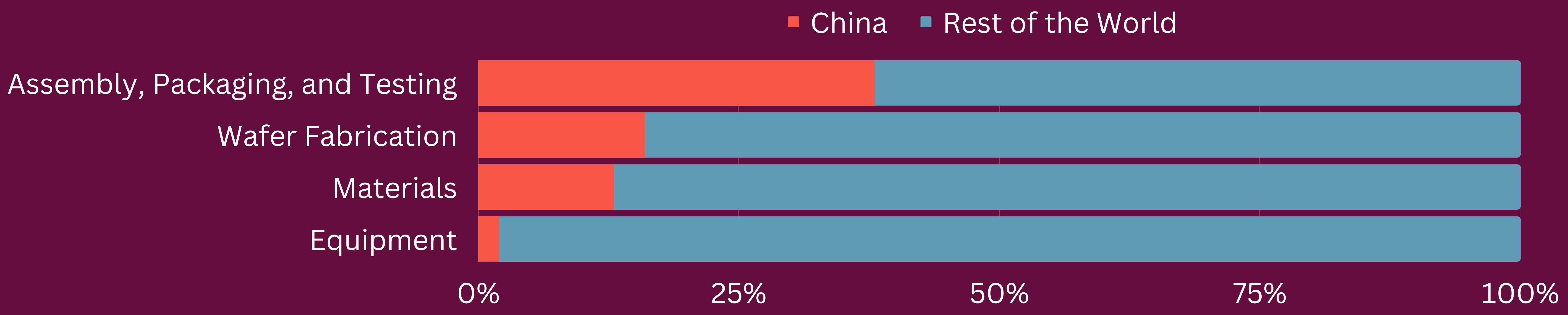


The semiconductor industry is vital to modern society, powering numerous technological advancements. It has also gained significant geopolitical importance as semiconductors are essential for advanced technologies like artificial intelligence, 5G networks, and autonomous vehicles, giving countries a competitive edge. Control over semiconductor production can impact national security, economic dominance, and influence in emerging industries, leading to strategic competition and global power shifts.

China has long sought to develop indigenous chip-making capabilities with first efforts dating back to 1956. In recent years, as geopolitical contestation in this sector has intensified, China has been actively striving to bolster its semiconductor industry. The country aims to reduce its reliance on foreign technology and become self-sufficient in chip manufacturing. China seeks to enhance its semiconductor capabilities, attract top talent, foster domestic innovation, and compete on a global scale.

CURRENT STATUS OF CHINA'S SEMICONDUCTOR SECTOR

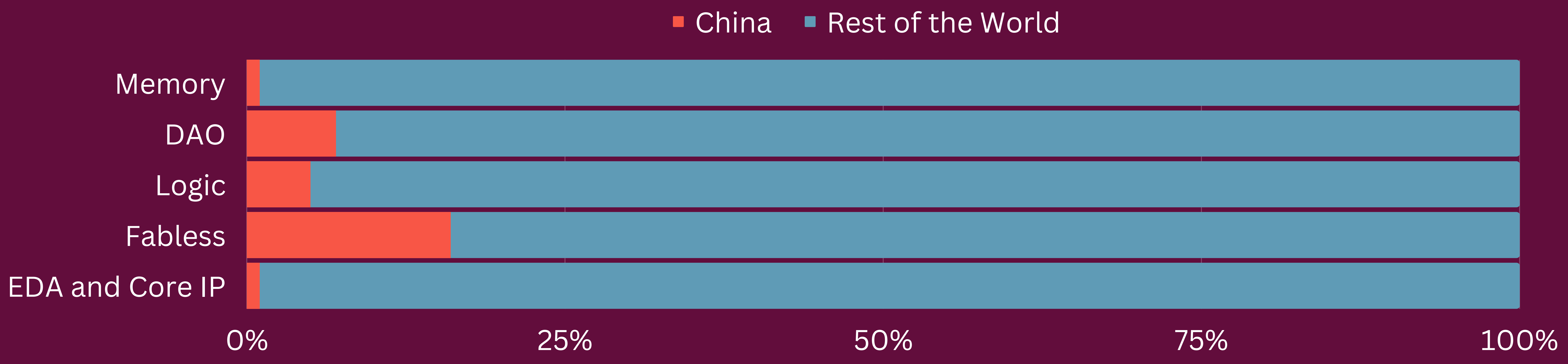
- China produces 36% of the world's electronics [29] and is world's second-largest consumer market.
- Domestically produced chips are able to fulfil only 16% of the domestic demand for semiconductor chips. This is significantly lower than the target of 40% by 2020 set under the "Made in China" initiative. [30]
- China accounts for only 7.6% of global semiconductor sales. [31]



Chinese Share in Global Semiconductor Supply Chain in Equipment and Manufacturing Segment (Source: SIA)

CURRENT STATUS OF CHINA'S SEMICONDUCTOR SECTOR

- China is a world leader in semiconductor assembly, supplying around 38% of global demand. [32]
- It has been able to catch up in semiconductor design in a limited way. China accounts for only 16% of global fabless market. It primarily designs mid-tier mobile processors and basebands, CPUs, network processors, sensors, and power management ICs. [33]



Chinese Share in Global Semiconductor Supply Chain in EDA/Design Segment (Source: SIA)

POLICY INSTRUMENTS ADOPTED BY CHINA TO DEVELOP R&D ECOSYSTEM IN SEMICONDUCTOR AND INTEGRATED CHIPS DOMAIN

Among various policy instruments described above, almost all of them have been adopted in some way or the other over last several decades, albeit with varied degree of success. For example, in integrated chips, and later in the semiconductor sector, China started with a completely state-led approach in 1950s to a combined state and private sector led innovation.

1 TARGETED INDIGENOUS DEVELOPMENT

China identified semiconductor technology as one of the priority areas under its "Outline for Science and Technology Development, 1956–1967." Consequently, Chinese universities started awarding degrees in semiconductor related fields and in 1960, one of China's then most notable semiconductor factories, Huajing Group's Wuxi Factory No. 742 started production. [34] By 1965, China's research in this field was far ahead of Taiwan and South Korea and perhaps similar to Japan. [35] However, this venture had limited success due to ineffective technology transfer from state labs to factories. Moreover, Cultural Revolution squandered even limited gains from this initiative. [36]

2 BUYING IT OUTRIGHT

During the reform and opening period under Deng Xiaoping, China created a "Computer and Large Scale IC Lead Group" to modernise the domestic semiconductor industry. [37] By 1985, state-owned factories had imported 24 secondhand semiconductor manufacturing lines at a cost of 1.3 billion RMB to facilitate technical upgradation of their semiconductor industry. [38] However, these efforts were not as successful. One American researcher visiting a Shanghai factory in the mid-1980s found it was producing chips that were 10–15 years out of date on wafers with yields as low as 20 to 40 percent. [39]

3 BARGAINING APPROACH

China tried a hybrid model of industrial development by facilitating joint ventures (TVs) with foreign companies. For example, JVs with Nortel (Canada), Philips (Netherlands), NEC (Japan), and ITT (Belgium) all began in the late 1980s and early 1990s. [40] Furthermore, China also attempted to develop Huajing (operator of Wuxi Factory No. 742) into a leading integrated-device manufacturer. It negotiated technology transfer and a JV with Lucent Technologies (USA) and endowed it with additional funding. [41] However, this plan took long to be implemented and led to a JV which used outdated equipment and produced chips that lagged behind the industry's leaders.

4 STEAL IT

In 2018, the US Department of Justice's indicted Fujian Jinhua Integrated Circuit Company (JHICC was founded in 2016 based on the Chinese government's and Fujian Province's US$5.6 billion investment) for economic espionage. [42] The indictment charged it for conspiring to steal Micron Technology's sophisticated dynamic random-access memory (DRAM) technology to aid in development of its own DRAM technology. Micron is a leading player globally with 20–25 percent market share for DRAM chips and has established competitive advantage in this field due to its intellectual property. Micron's stolen IP was valued at $8.75 billion.

5 PROVIDING SEED INVESTMENT

In June 2014, China released 'Guidelines to Promote National Integrated Circuit Industry' with the aim of accelerating technology transfer and help make China's semiconductor industry globally competitive. [43] Consequently, a National Integrated Circuit Investment Fund was established with a funding of upto $150 billion from the central and provincial governments. [44] The fund has since served a dual purpose: it funds outbound FDI to acquire foreign companies while providing funds to facilitate inbound FDI such as greenfield investment and joint ventures with foreign companies in semiconductor sector.

6 SUPPORT DOMESTIC ENTREPRENEURSHIP

Under "Made in China 2025" initiative, select manufacturing sectors have been identified with the aim of increasing the market share of Chinese companies to meet domestic and international demand. Targeted funds have been established to facilitate indigenous R&D, acquisition of technology from overseas, and cultivate the technology, intellectual property, and brand identity necessary to achieve this goal. Semiconductors, especially integrated circuits have been identified as one of the priority sectors. By 2030 the roadmap specifies that segments of Chinese IC industry should reach advanced international levels. China's 13th FYP (2016–20) further prioritises the development of DRAM chips (reminiscent of Huahong's Project 909 attempt) to lessen its dependence on memory chips from the United States.

7 OPEN UP TO FOREIGN DIRECT INVESTMENT

Foreign investment has helped China develop its semiconductor industry. Most successful such example is the Semiconductor Manufacturing International Corporation (SMIC) which was founded by a Taiwanese veteran of Texas Instruments (U.S.) and Worldwide Semiconductor Manufacturing Company (Taiwan) as a wholly foreign-owned foundry based in Shanghai. Since starting production in 2002, it has emerged as the largest and most advanced chip maker in China. [45] SMIC has developed partnerships with foreign firms and recruited ethnic Chinese engineers (primarily returnees from the United States, Taiwan, and Singapore) to be placed among the top five foundries globally. [46]

CONCLUSION

China's innovation success has been due to a combination of fundamental and proximate factors. There's no single blueprint for innovation success and different countries have followed different pathways. Even within China, success of policies are different than others. Telecom companies have been more successful at technology upgrading than semiconductor firms. However, the role of education and a capable workforce has been critical.

Some common explanations such as forced technology transfer, industrial espionage, theft or state capitalism do not entirely explain how China has been able to become one of the global innovation powerhouses. Efficiency and autonomy were important factors and pure State-led approaches have not shown much successes. Furthermore, State's focus on innovation has been more important than specific policies. The role of informal social networks can be an "unseen" factor contributing positively to the innovation ecosystem.

Finally, China seems to have jeopardised its major source of innovation strength: a benign geopolitical environment which contributed to conducive to S&T flows. Previously, FDI and free flow of talent across borders played a significant role in promoting innovation, in addition to a favourable geopolitical climate. This is not the case anymore.

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