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Education, Human Capital and China's Technology Ecosystem

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1 Introduction

In January 2025, DeepSeek, a Chinese Artificial Intelligence (AI) research laboratory, still relatively unknown outside tech circles, released a reasoning model that sent global shockwaves. Trillion dollars were wiped off the US stock markets, and US President Donald Trump called it a "wake-up call" for the American technology industry.[1] Others referred to it as "AI's Sputnik moment".[2] What unnerved onlookers was that DeepSeek's model not only matched the performance benchmarks of leading American companies, but it also claimed to do so "at a joke of a budget" and during a time when China was under the shadow of US export restrictions on advanced semiconductors.[3] Domestically as well, the company's rivals, Alibaba and ByteDance, reportedly either cancelled or heavily curtailed their AI teams' Lunar New Year holidays amid competitive pressure from DeepSeek.[4]

Some of this buzz would come to be explained in the following months. HighFlyer, the hedge fund that is DeepSeek's parent company, was known to have stockpiled chips before the implementation of US export controls, and DeepSeek's models are now widely believed to have been distilled from OpenAI—a process that aids in reverse engineering by using the outputs of one model to train another.[5] But this is only part of the story.

There is no denying the engineering ingenuity DeepSeek's material innovations demanded. Moreover, for the future trajectory of AI, the narrative that language models needed brute-force billions of dollars in compute infrastructure and internet-scale training data, and therefore needed to be concentrated in a handful of companies, was squarely undone.

DeepSeek is emblematic of China's growing innovation prowess and the broader data only reinforces it. According to the World Intellectual Property Organisation's Global Innovation Index for 2025, China ranked 10th out of 139 economies, the only middle-income country to rank in the top 10, a step up from its 11th and 12th positions in 2024 and 2023, respectively. For the third consecutive year, it continues to host the world's largest number of Science and Technology (S&T) clusters (26), with dense networks capable of cross-pollination, research, industry-academia partnerships, and commercialisation. China has now overtaken Switzerland in knowledge and technology outputs and ranks 2nd in R&D expenditure. On patent filings, the figures are equally striking. The number of intellectual property applications submitted by China exceeds the total of all countries combined.[6]

Beyond the indices, China's technological reach is apparent across three distinct domains. The first is material innovation, i.e., the capacity to produce original research and novel technologies that reshape existing industries. China now dominates global production of the technologies needed for energy transition, such

as electric vehicles, batteries and solar panels. While still trailing in frontier AI, Chinese companies lead in industrial automation and what the Chinese call "embodied AI", a term that refers to AI integrated into the hardware stack, such as in humanoid robots.[7]

Second, China has, of late, increasingly shown the ability and willingness to use its dominance in the technology value chain as a tool of economic coercion and strategic retaliation. No longer is China merely a victim of technology denial regimes of the West, but it has now instituted bureaucratic structures that mirror those of the US, such as an Unreliable Entity list and a broader countersanctions toolkit.[8] This has recently come to the forefront in the rare earths sector, where China dominates refining, value-added manufacturing, and recycling of these minerals. This coercive power is evident in that it is an asymmetric leverage point. In other words, restricting the exports of key minerals needed in small quantities, but in very critical applications across several industries, hurts other countries more than it does China.

The third domain pertains to governance norms and standard-setting. China has moved aggressively to internationalise its technical standards and shape the rules governing emerging technologies. This is evident from its active participation in international standards bodies to the export of its standards and AI governance frameworks through the Belt and Road Initiative and the Global AI Governance Initiative, respectively.[9]

Yet, there are also chinks in Beijing's armour, and the picture is more complicated than the headlines suggest. For instance, Chinese COVID-19 vaccines such as Sinovac and Sinopharm, despite China's zeal to mass-produce and export them, were of dubious quality and showed much lower efficacy than their Western counterparts.[10] The country continues to depend on foreign firms for advanced chips, semiconductor manufacturing equipment, and chip design software. And despite investing upwards of $70 billion in Commercial Aircraft Corporation of China (COMAC), its state-backed aircraft manufacturer, China still has not produced an aircraft that can compete with Airbus and Boeing in open markets. The C919, China's flagship narrow-body jet, relies on imported engines, and when the US temporarily suspended the sale of those engines in 2025, the programme's structural vulnerability was exposed.[11]

These contrasts, i.e., dominance in a few sectors alongside dependence in others, point to a complex reality that cannot be explained by a single variable. Intellectual property theft and China's once-notorious image as the producer of cheap, copycat products continue to be cited as reasons to dismiss China's ability to absorb new technologies before adapting and building upon them, as it did by rising up the technology value chains over the past two decades.

China's technological rise is often attributed to the state's industrial policy, its authoritarian capacity to mobilise resources

at scale, and the top-down national planning apparatus. While this captures something real, it doesn't acknowledge the sheer wastage of resources, overcapacity, ruinous competition—often monikered hunger-games capitalism—price wars and consequent deflationary pressures the same model had inflicted on the Chinese economy in the past. A factor that receives comparatively less systematic attention is education and human capital formation, which Beijing has continually invested in.

This chapter examines this dimension and how it feeds into the country's technological power. It explores how China's education policies, skill development programmes and research infrastructure have contributed to its technological ascent. Further, it explores how constraints in the same domain, compounded by a declining economy, an ageing population, and great power competition, are beginning to reshape the contours of this critical ingredient in China's technology ecosystem. The Chapter also offers a forward-looking assessment of the trajectory of China's technological advancement in the coming years.

2 What China Got Right?

In this section, we argue that China's policymakers got three broad things right, which played a key role in enhancing the country's economic and scientific prowess. These are openness, investment in education and infrastructure, and an industrial policy that engendered competition and tolerated failure.

China's technological prowess was not built by being insular. The country benefited immensely from a conducive global environment since its economic reforms, and especially after joining the WTO in 2001. At the turn of the millennium, technology was not as securitised as it is today. Moreover, as globalisation distributed supply chains, Western firms eager to access China's cheap manufacturing base and fast-growing domestic market brought their capital, technical expertise, and production knowledge, helping propel the country's rise. But this was not as straightforward as it may seem. Unlike the East Asian tigers, Taiwan, Singapore and South Korea, which were Cold War allies embedded in the US security architecture and could secure technology transfers easily, China had to rely on foreign direct investment (FDI), a far more complex pathway. Additionally, it built joint venture requirements that mandated technology transfers as a price for market access, a model that has since been called "Trading Market For Technology".[12]

What's unique about China is its motivation and investment in the scientific foundation necessary to "bring in technology, absorb it and then re-innovate" on top of it.[13] For China's political leadership, among other priorities, S&T ranks very high, and it has viewed technological self-sufficiency and indigenous innovation as critical to national security. Technology is considered a key pillar of China's Comprehensive National Power.

A contributing factor to the Chinese success was also that, for a long time, the West grossly and consistently underestimated innovation capability from the Chinese side, prioritising short-term business interests that compromised their long-term competitiveness. This was a "Faustian bargain" that allowed Chinese players to squeeze foreign partners in the Chinese domestic market before they were challenged in international markets.[14] This played out in the high-speed railways sector in the 2000s and is currently unfolding in the automobile sector.[15]

This absorption of foreign technology was only possible because China had massively invested in its human capital, infrastructure and domestic processes. In fact, China's focus on primary education preceded the 'Reform and Opening Up' era that Deng Xiaoping initiated. By the time Deng embarked on the path of openness, the country had a large, literate workforce eager to escape the agrarian economy. Despite the prevalence of cultural norms against women, higher female literacy rates also meant that more women in China were willing to defy patriarchal norms.[16]

The continued focus on education has led to remarkable changes in China. In 1980, approximately 33 per cent of the Chinese population aged 25 or older had no formal schooling. This figure fell to 8.2 per cent by 2010.[17] China's national literacy rate rose from 20% in 1949 to around 97% by 2020.[18] Since 2012, China's national fiscal spending on education has accounted for no less than 4% of its gross domestic product (GDP), a target set in the 'Outline of China's Education Reform and Development' in 1993. China had the highest per-student budgetary spending, wherein, compulsory education accounts for approximately half of China's fiscal education spending, and higher education accounts for about 20% of the total spending.[19] These investments have translated into a notable improvement in the quality of compulsory education and an uptick in Gross Enrolment Ratio (GER) in higher education, from 9.76% in 1998 to over 60.2% in 2023.[20] Similarly, the number of Chinese higher education institutions ranked among the world's top 400 universities has grown from 7 in 2009 to 35 by 2021.[21]

China has been unique in the scale and focus with which it has sought to leverage high-tech talent, both Chinese-origin and foreign, to advance its national goals. Several hundred talent programmes targeting different age groups as well as key technology areas have been initiated by the Chinese government over the years. A popular example is the "Thousand Talents Programme," launched in 2008, which attracted foreign researchers to China with generous packages, startup funds, and internationally competitive salaries. By 2018, the programme had attracted nearly 7,000 experts to work in Chinese institutions.[22]

Such programmes also sought to maintain transnational ties with members of the ethnic Chinese community, and various creative ways, such as "overseas workstations," allowed for contributions to the motherland without needing to return. By 2019, the Chengdu

High-Tech Industrial Zone had 31 offshore centres spread across Japan, Europe, the US, and South Korea.[23]

The Chinese government has also been substantially investing in infrastructure like transportation networks (roads, railways, air transportation), telecom, energy, and industrial materials such as steel. Chinese government investment in telecommunications, transportation, and electricity infrastructure was consistently between 6% and 10% of GDP during the 1980s and 1990s.[24] Through the 2000s, Fixed Assets Investments have played a key role in driving development. This was particularly the case after the 2008-09 financial crisis, which resulted in the government launching an RMB 4 trillion ($586 billion) stimulus package.[25] All of these enabled the growth of greater infrastructure and industrial capacities. In recent years, Beijing has been increasingly focussed on "new infrastructure".[26] In 2020, it defined this concept through three pillars, i.e., information infrastructure, integrated infrastructure such as smart grids and smart transport, and innovative infrastructure, such as Research and Development (R&D) facilities and science parks. All of this has strengthened the country's scientific and technological base.

Apart from an infrastructure build-out, Chinese policymakers and enterprises have repeatedly emphasised the need to expand R&D spending to move up the technological value chain. Gross Expenditure in R&D (GERD) in China has consistently exceeded 2% of GDP.[27] The country's R&D spending has increased from a 4% share of global expenditure in 2000 to 26% in 2023 and is now the second-largest in the world after the US.[28] According to data following the March 2026 legislature meetings, China's cumulative R&D expenditure had hit 2.8% of GDP in 2025, marking a steady year-on-year increase driven by a strategic push towards technological self-reliance and "New Quality Productive Forces" (NQPF), a set of emerging technologies prioritised by central planning and considered politically favourable for local governments to plough investments into.

The 15th Five-Year Plan, for instance, lists new energy, new materials, aviation and aerospace, and the low-altitude economy as "emerging and strategic" industries and instructs the government to focus on establishing dominance in "industries of the future".[29] These include quantum technology, biomanufacturing, hydrogen and nuclear fusion power, brain-computer interfaces, embodied artificial intelligence and 6G mobile communications. Alongside increasing investment in the country's higher education institutions, Beijing has also sought to institute targeted programmes to develop capacities in specific sectors in line with these national priorities. For instance, in 2017, a programme aimed at developing "world-class cybersecurity schools" and allowing government bodies to direct coursework integrated with university's curriculum was launched.[30]

Inherent to the Chinese state's policies is a venture capital model in which multiple bets are placed, accepting that most will fail

while the winners are harvested, modelled, and returns reinvested at scale. In other words, there is a significant risk appetite and willingness to bear the cost of failure. Guidance funds, which channel private and public capital into the government's strategic and priority sectors while generating financial returns for their investors, are a key financing and policy instrument in China. As of 2021, China had 1800+ such funds.[31] A significant recent change in R&D spending has been the source of funding. Businesses, including state-owned enterprises, accounted for 70 per cent of R&D investment in 2016, up from 30 per cent in 1995, when government departments, elite research institutions and other organisations accounted for the bulk of funding.[32]

Despite the risk of mismanagement, corruption, and inefficiency creeping into this model as more capital flows into the system than can be reasonably absorbed, government-guided funds still allow for some market discipline and profit motive in China's industrial policy, which is otherwise dominated by government subsidies.

Essentially, China's domestic policy includes a wide range of measures, such as selective protectionism, joint ventures (JVs) with foreign firms, cheap credit via state bank loans, land policy and infrastructure support, strategic investments in foreign countries, and active and coordinated efforts across multiple levels of government, state-owned universities, military-civil efforts and the private sector. The government's propensity for risk-taking and its willingness to tolerate failure, iterate and adapt help with such an "all-of-the-above" approach. Domestic competition, sometimes even engineered by the government to pit multiple state-owned enterprises against one another, even in traditionally state-owned sectors, is an important feature of this model. Incentive structures are designed to promote exports, so Chinese companies may spar with the best in the world and, in turn, get more competitive.

3 What constrains China?

China's growth story, however, is not without its contradictions. Its unparalleled rise, alongside an increasingly irredentist and aggressive international posturing, has alarmed onlookers. Much of this may be attributed to the rise of Xi Jinping as the General Secretary of the CPC in 2012. When Xi took over, China was a force to reckon with, However, there were some structural vulnerabilities in the system. Corruption was entrenched, the country's growth rate was rapidly slowing down, economic reforms had stalled, and a policy stasis had set in. Increasingly, the political leadership believed that capital needed to be redirected from seeking quick profits to long-term problem solving and capability development.

Under Xi Jinping, China's science and technology policy was imbued with greater strategic salience. At the 19th Party Congress in October 2017, Xi said that he wanted China to become a

"country of innovators."[33] Xi's view of science and technology was that it was critical to address security needs and capture the commanding heights of future strategic competition. For instance, among the first few initiatives launched by Xi was the Innovation-Driven Development Strategy with the stated goal of positioning China as a strong global innovation power by 2050.[34] To enable this, huge capital funding flowed into the system. This was evident in areas like AI, as it was with the Semiconductor Big Fund. The fund is now in its third iteration, with the rate of return on investment being well below par, while corruption and waste have become rampant. This, however, is a structural flaw of the Chinese command innovation approach, which nurtures a political economy that tolerates sub-optimal and even wasteful outcomes in the quest for expanding the scale of industry.

Externally, what started as US export controls in 2018 has today become a broad-based techno-strategic competition between the US and China. Soon after assuming office in January 2017, US President Donald Trump had initially targeted Chinese telecoms giant ZTE and Huawei. The subsequent Joe Biden administration cobbled together a "small yard, high fence" approach to deny Chinese entities access to advanced American technologies. This, however, quickly escalated into a much broader range of controls, targeting a wide range of high-tech products, like high-end AI chips, advanced semiconductor manufacturing equipment, and biotech laboratory equipment. The Biden administration also focussed on domestic capability development, while decoupling American and Western research ecosystems with that of China. For instance, the CHIPS and Science Act of 2022 restricts the National Science Foundation's R&D funding to institutions that host or support Confucius Institutes.[35] Chinese-origin researchers in the US, Japan, and Australia have also since faced higher scrutiny if their work concerned critical technologies. Under Trump 2.0, while strategic competition continues to be an organising principle for America's China policy, there has been some dilution of export controls. Nevertheless, Beijing has remained extremely wary of American policies, preferring to continue down the path of building self-reliance.

These geopolitical tensions and technology denial attempts have promoted renewed science and technology investments, and even retaliatory measures and intimidation from China. Asymmetric advancements, such as in open-source technologies with DeepSeek, and increased efforts toward technological self-reliance have received significant public attention and nationalistic euphoria. But whether China can weather the long-term disruptions to capital flows, technology transfers, and research collaborations remains to be seen, especially since domestic policy shifts have eroded private sector confidence in the country's regulatory environment. China's private sector is still reeling from the effects of regulatory crackdowns it encountered since 2020, starting with the crackdown on Ant Financial.[36] This was followed by a series of investigations under the framework

of tackling monopolies, unfair trade practices, walled gardens and addressing inequalities, which have dampened the private sector's investment appetite. The technology sector has since announced a reduction in R&D spending, along with hiring freezes and universal pay cuts. More significantly, overall private sector investment in China has stagnated and declined since 2022.[37]

Another challenge facing the Chinese economy, since 2020 has been that of capital flight, i.e., low FDI and FII inflows. As of 2025, venture capital funding has been cut in half, and entrepreneurial risk-taking, which is critical to unleashing the 'animal spirits' of the markets, has suffered.[38] While this has marginally improved, it will take longer for the market to recover with momentum.

Additionally, China's trade surplus and its position as the world's manufacturing hub are not being viewed kindly by countries whose domestic industries have been decimated by Chinese industrial overcapacity. Coupled with China's domestic policy shifts, an aging population, high youth unemployment, and stubbornly low domestic consumption, a changing international environment is increasingly constraining the potential for China's private sector, which has traditionally been the engine of its technological growth. The country's propensity for wasteful spending to spur entrepreneurship, competition, and eventually innovation is increasingly difficult to scale, as local governments experience fiscal stress and budgetary constraints. Local governments' revenue share as a percentage of the GDP has been consistently falling, from about 12% in 2015 to 9% in 2022. They are also being spread thin across various expenditure avenues. While they face heavy debt repayment burdens, they are also being asked to spend more across a wide range of policy priorities, such as public healthcare and social systems for China's ageing population.

On the human capital front, too, statistics reveal a more complex picture.

Firstly, China's human capital formation is stifled by the urban-rural divide and socio-economic inequalities. Persistent differences in career opportunities for rural populations, codified in regulations such as the hukou system (i.e., the official household registration system of China), risk limiting economic growth and stifling the development of a modern workforce.[39] According to an OECD report, China has among the lowest high-school graduation rates compared to other middle-income countries.[40] Only about 36.6% of China's workforce aged 25–64 years old had finished high school in 2022 and for those who finish high school, future job opportunities can be limited by their performance in the Gaokao, the country's highly-competitive standardised entrance exam for colleges. This only further deepens the urban-rural divide, with rural youths able to get lower-paying jobs and less stability. The same is true for ethnic minorities. The piecemeal approach by which different regions are attempting to reform the hukou system yields mixed results and slower outcomes.

Secondly, despite a large portion of the new investment going into select high-tech sectors outlined by the NQPFs, China faces an acute shortage of skilled workers in these sectors. Growth in the numbers of PhDs and STEM graduates alone may not capture the vast differences in the calibre of these graduates. While some universities are truly world-class, the quality of original research and patents filed by others may be questionable. The 15th Five-Year Plan diagnoses that China accounts for less than 15% of the world's top 100 universities, that talent shortages exceed 30% in "bottleneck" fields such as semiconductors and that the conversion rate of university research and commercialization is less than 15%, far below the 40-60% level of developed economies.[41]

Thirdly, a declining economy and a tightening job market have led to social movements calling for detachment from the pressures and aspirations of the modern job market, popularly encapsulated in the 'lying flat' movement. At a time of demographic pressures and a shrinking workforce, a younger population that is burnt out, disillusioned, and without optimism for its future can risk a country's economic trajectory.

Finally, geopolitical contestations with the US are limiting China's ability to attract foreign talent.[42] With no avenues for permanent residence for international immigrants, the country struggles to attract high-end talent with no prior connections to its people and mainly draws only ethnic Chinese or Chinese nationals studying abroad. This is further complicated by Beijing's push for self-reliance in recent years, with several businesses reporting localisation of high-skill jobs.

Despite the success of several programmes, China does not rank as an established global talent hub compared to the West, particularly the US. Despite concentrated efforts on immigration reform, the COVID-19 pandemic undid much of the progress, leaving the country with a much-diminished foreign population than it had pre-2019.

4 Conclusion

China's technological trajectory defies simple characterisation. It is a story of a country that has traced a once-in-a-century growth journey in a remarkably short period of time, upending expectations and stunning the world in the process. However, China's model is increasingly coming under pressure in a world that is no longer what it once was. The pressures from a more hostile geopolitical environment, as well as domestic policy choices of the CPC under Xi Jinping, have introduced political, economic and social rigidities that sit uneasily with input factors which are key to breakthrough innovation.

As with other national priorities, the Chinese leadership has acknowledged these challenges and attempted policy initiatives

meant to address them. So far, however, the results have been mixed. A few examples come to mind.

First, the 15th Five-Year Plan explicitly points to the pathological problem of involution, which is widespread in the Chinese domestic market and endemic across sectors such as electric vehicles (EVs), semiconductors, batteries, humanoid robots, and satellites. This is structural to China's investment-led export-oriented economic model and has contributed to stubborn deflationary tendencies.[43] The country's manufacturing sector, for instance, had profit margins hovering around 4.5% last year, less than half the levels seen in the US.[44] However, by doubling down on the NQPFs, the system deploys the very instruments that unleash and exacerbate the consequences the state is trying hard to rein in. Seen previously in the EV sector, the same is now playing out in AI. The AI+ initiative, introduced in 2024, seeks to integrate AI across sectors of the economy, with several local governments already competing to develop AI economies in their jurisdictions.[45]

This is because local officials, still bound by growth targets, now have fewer avenues to unlock that growth. The property sector is still struggling, and consumption remains lukewarm, leaving investment, in line with China's economic model, as the main avenue. The logic of NQPFs designates a few sectors as politically favourable and amenable to such investment, and is likely to crowd in capital.

Second, in May 2021, China announced a three-child policy that allows couples to have up to three children, replacing the previous 'two-child' limit.[46] With measures such as educational support and tax incentives, the policy aims to address a rapidly ageing population and plummeting birth rates, but has seen limited uptake due to high living costs and career pressures. There is recognition in China that the pressure-cooker model of education, defined by the tyranny of the Gaokao, is extracting huge financial and emotional costs from families. The Chinese government has emphasised the need to ease students' burdens and establish education as a public good. The 2021 regulatory crackdown on private tutoring and ed-tech platforms was the most far-reaching expression of this instinct. But the paradoxes inherent here are evident. The heavy-handedness of Beijing's actions has sent macroeconomic ripples that have constrained the very system it was trying to support.

Third, against the backdrop of unemployment pressures, vocational education and skilling are becoming increasingly important as means to cultivate technical talent and bridge practical skill gaps. However, a small share of total national education spending is currently directed here. As in other areas of national priorities, Beijing is likely to act with speed and focus, mobilising institutional resources to bridge these gaps like no other system can. It is this tussle, so structurally difficult to paper over and far from resolved, that will define China's future

trajectory. How China navigates these domestic tensions and geopolitical pressures will define the technological order and global power structures in the coming decades.

In all likelihood, Beijing will muddle through the next decade, making progress towards its stated goals. In the technology domain, what one is likely to witness is significant breakthroughs in areas of strategic interests. However, scaling these breakthroughs will remain a challenge. In other words, breakthroughs at the commanding heights will likely co-exist with compounding underperformance in the wider economy, which will adversely impact areas in which success depends on decentralised initiative and private risk-taking.

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