China Briefing

How Semiconductors Will Drive the Next Decade of Geopolitics

by Ryan Manuel, Chief Asia Strategist

Executive Summary

- *The US is now applying a constantly-increasing range of sanctions on China-bound semiconductors and Chinese industries to degrade its technological capabilities.*
- *In this piece, we will look at whether or not this will work. The vast technical and capital needs of semiconductors cannot be easily reduced into single silos. Rather, there are three things to consider: process knowledge; supply chain access versus in-house creation; and the price and availability of capital. China, as a newcomer, is a long way behind being self-sufficient.*
- *To show this, we discuss how chip industries are created, show the fundamental need for capital and IP transfer across borders, look at where China is on this path, and assess how likely US sanctions are to succeed in blocking Chinese progress. Some large American advantages in its IP across the entire supply chain can be very quickly chipped away at in China, whereas other advantages are more structural. The impact will be very grave.*
- *China will, therefore, need to play very nicely with others. The remarkable thing is that when one considers how the chips are made, semiconductors may be the thing that brings Asia together rather than pulling it apart. But US-China relations are likely to suffer a further downturn.*

China Briefing

Today, deep tech is perhaps the hottest thing in investing. It uses advanced technology to change, or "disrupt", progress in a sector and spark rapid growth. The promise of improvements in these, and many other fields, is what fuels ambitious founders and their teams through the long nights necessary to find a breakthrough. But there is one thing that is behind all of these things: silicon chips, known also as semiconductors.

What is a semiconductor? It is a chip of silicon that transistors can be crammed onto — with microscopic tunnels bored into the material such that light can travel along it. The light can be switched on and off, allowing information to travel in binary form ("01011"), taking advantage of silicon's ability to conduct the energy so that these "chips" can talk to each other. This chatter powers the world.

One often hears about Moore's Law. It is the theory of famed Silicon Valley engineer Gordon Moore, the father of Intel, that the number of transistors that can be packed onto a microchip of silicon would double about every two years. Sixty years ago, four transistors could fit on a chip. In 2020, that became some 11.8 billion transistors on each chip, flowing information. This is an extraordinarily complex set of operations, though, involving more than 100 processes and inputs from suppliers based around the world.

With complexity of end product comes specialisation of input, and perhaps unsurprisingly therefore most of the major inputs in semiconductors are dominated by either one or two companies, or nations. The Taiwan Semiconductor Manufacturing Corporation (TSMC) produces more than one-third of the world's chips. Korea produces nearly one-half of all storage chips. The Netherlands has the world's only extreme ultraviolet (EUV) lithography tools (these use rare parts of light to etch more and more paths into the chips, helping them become smaller).

Silicon chips are the very bedrock of things being made digital, they fuel the engine of 21st century economic growth. Unsurprisingly, they are often looked upon as a source of conflict. As China and the US grow further apart and threaten to decouple, the long and intertwined global supply chains that give both the chips they crave to grow are subject to things other than market forces. This means much speculation about what China, in particular, might do to ensure its access to semiconductors. If data is the new oil, the theory goes, then what might China do to make sure it can access such a vital resource?

This piece takes the opposite view. Semiconductors are the very reverse of oil — they must be manufactured, and not dug out of the ground — and that requires process knowledge and humans instead of raw materials. Put simply, you can't take a chip plant by force. But you will need an extraordinary amount of capital to make one. That might yet bring the world together. Or, as the events of October 2022 seem to indicate, it may also lead to multiple worlds being made.

Who Can Make Chips?

Semiconductors are extremely capital intensive, and process-knowledge intensive. There are some 111 steps in the total manufacturing process[1], each with a staggering specific set of needs. To give an example, a tool used in manufacturing the smallest chips is said to have 515,000 different processes[2].

Put broadly, there are three major parts of this lengthy supply chain: designing chips; making chips; and assembling, testing, and packaging chips. Originally, this all occurred within an individual firm. But as supply chains have become more complex, firms specialised. Manufacturers did nothing but produce the physical chips themselves. To put into context how hard this is, a thunderstorm can destroy a chip batch by changing the air pressure semiconductors are made in. The capital required to prevent these and many other forms of distortions is ridiculous. That's why it is dominated by large manufacturers, with the best being Samsung and the TSMC.

So the modern semiconductor supply chain designs the chip you want and then sends it off to the manufacturers overseas. There are large advantages to this — easier to do, less capital expenditure, smaller chips. But it also creates another market, which is for the software and the know-how necessary to make

[1] This is based on China's date. Similar statistics from Western data is not available.
[2] Source: Dutch semiconductor giant ASML. Data from *Clip Wars*, Chris Miller, 2022.

a chip. And it means that every step along the way is vital. Put differently, I might have access to a kitchen but I don't have the recipes of a famous chef and, more importantly, if there are any ingredients missing, I can't make their dish. The pieces include software to design chips; existing intellectual property that is used as part of chip making processes; a vast array of R&D licensing arrangements; materials such as silicon wafers and masks; manufacturing equipment; and, finally, assembly, testing, and packaging to check that chips work by connecting the chips to logic boards and preparing them to be installed. These vital component steps are often located in the US, because the industry was invented there.

One way to show this is to look at an approximation of the ownership of each step of the process. Of these, as the chart below shows, only one nation has access to the whole value chain, which is the US. This includes some full in-house chip makers such as Intel and Texas Instruments. So if everything went wrong for the US, it would still have semiconductors available to it.

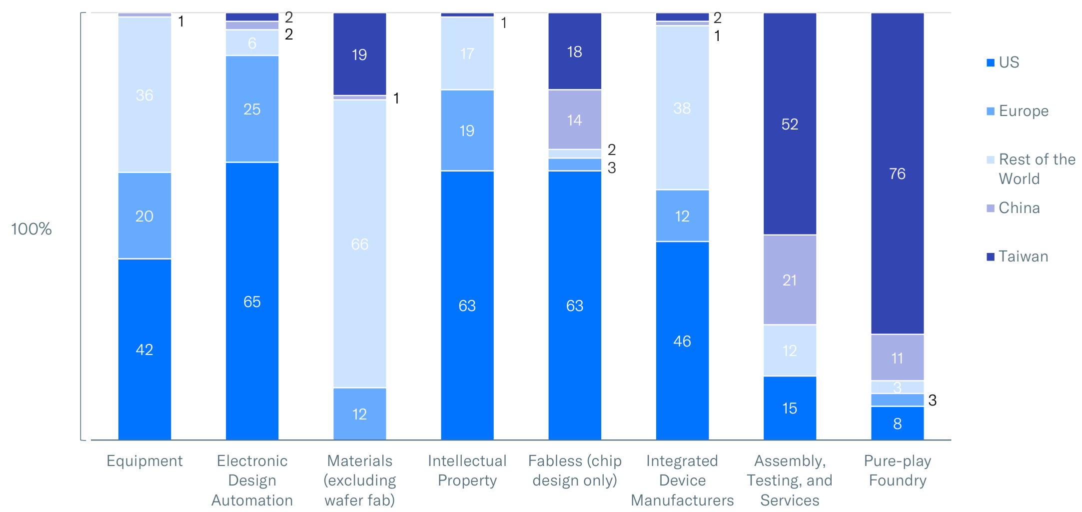
Moreover, as the chart also shows, the US dominates some steps. Texas Instruments and Intel hold leading market shares in their respective fields while manufacturing their own chips. Qualcomm, Broadcom, and Nvidia are all US companies that own a sub-branch of the semiconductor market. (You can't make a call without Qualcomm chips, for example, while Nvidia provides 95% of China's AI semiconductors). Design tools come from companies including Cadence and Synopsys, and even European companies such as Mentor get most of their IP from American patents. Finally, US companies such as Applied Materials, Lam Research, and KLA-Tencor all provide equipment that is unable to be secured anywhere else in the world.

The final US advantage is that perhaps the most critical of all the steps is the production of the chip ("pure-play foundry" in the chart). The foundries develop many of the tools needed to make the smallest chips in-house; one can design the chip, but figuring out how to make it that small is always harder in practice. And the US has the longest and closest relationships with Taiwan and its giant manufacturer TSMC. Let us now turn our attention to this part of the relationship.

Which Are the Biggest Companies?

At present, none of the world's largest semiconductor companies (by revenue) are Chinese. As mentioned above, there are only two major companies that can produce the smallest chips, TSMC and Samsung, and of those, TSMC is the clear leader. 92% of the world's chips with a process of 10nm and below are provided by TSMC. As a specialist manufacturer, TSMC makes the majority of US chips for the biggest companies (think Apple, AMD, Qualcomm, Nvidia, and Intel).

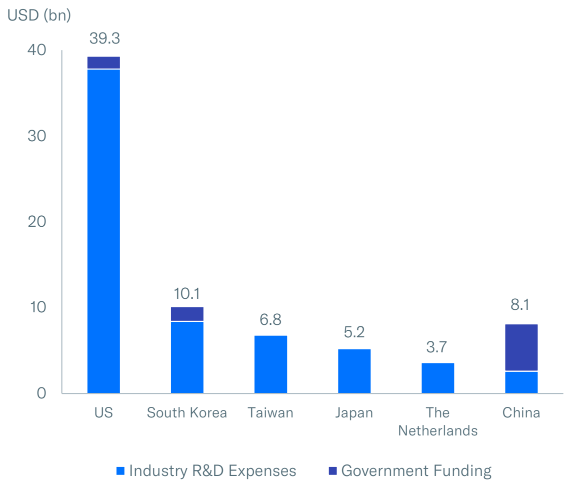
2020 Semiconductor sales along the value chain



Source: McKinsey 2022

Why? As noted in the previous section, the US started ahead. Yet the best manufacturers are offshore. Semiconductor factories (or fabs) are extraordinarily capital- and process-intensive. Chips also involve a very cyclical industry, prone to boom and bust. As such, a large amount of capital is needed upfront, and preferably one needs to know that one's credit will not be called in during bad times. On capital, the US, Korea, and Taiwan have all been very strong, because they either have a strong private enterprise (US) or large savings rates and state funding (Korea and Taiwan).

The US spends the most on semiconductor R&D



Source: Bart van Hezewijk, Holland Innovation Network China

Within these three countries, the biggest rivalry for the most advanced technology is actually between South Korea and Taiwan.[3] Why is that? Somewhat simplified, it is because they adopted the most advanced technology by taking a risk on a new method (described in the box below), and when that method succeeded, they left behind the major US rival chipmaker. By taking on these new, advanced steps, TSMC and Samsung were able to leap ahead of all other competition.

There are a few reasons for that success that are not merely a classic tale of an innovator's dilemma. First, as noted above, there is a constant need for capital and patience. Why? Because making chips is like making software: the money is all upfront, but once the thing is made, marginal cost of reproduction is very cheap indeed. Silicon is not an expensive input. A factory using the machines described above (among many others), on the other hand, most definitely will be very expensive. So firms need to make hard decisions: should they stick with old technology that has already been paid for, or should they invest in a factory with extremely uncertain returns?

Why Chipmaking is So Hard

To give a concrete example of what goes into the many processes discussed above, this is how the Brookings Institute describes the method used for etching chips:

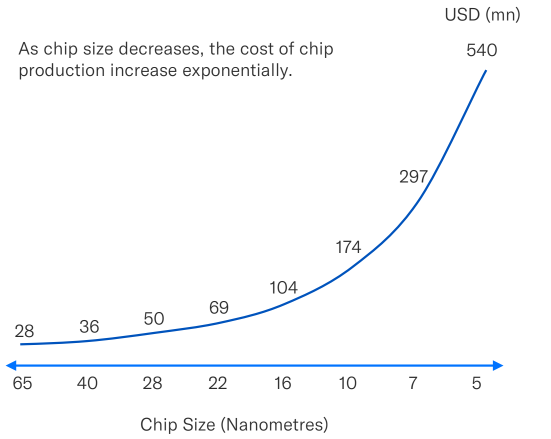
A generator ejects 50,000 tiny droplets of molten tin per second. A high-powered laser blasts each droplet twice. The first shapes the tiny tin, so the second can vaporise it into plasma. The plasma emits extreme ultraviolet (EUV) radiation that is focused into a beam and bounced through a series of mirrors. The mirrors are so smooth that if expanded to the size of Germany they would not have a bump higher than a millimeter. Finally, the EUV beam hits a silicon wafer — itself a marvel of materials science — with a precision equivalent to shooting an arrow from Earth to hit an apple placed on the moon. This allows the EUV machine to draw transistors into the wafer with features measuring only five nanometers — approximately the length your fingernail grows in five seconds. This wafer with billions or trillions of transistors is eventually made into computer chips.[4]

These machines have around 100,000 parts, 515,000 internal processes, cost approximately USD 120mn, and require two years of on-site technician access and to be shipped by 40 freight containers. Less than a hundred of them have ever been made, and yet there are already approximately two years' worth of back orders for more.

[3] See Kevin Xu's translation of this judgement made by Morris Chang, TSMC Founder - interconnected Morris Chang's speech.
[4] Source: Brookings

Secondly, once you reach a certain size, the moat is not just capital but the ability to integrate all 111 parts of the supply chain. This is because the complexity of producing a chip increases exponentially at the smallest sizes, rather than linearly.

Average chip design cost by chip size



Source: McKinsey 2022

So to be a major chipmaker, one not only needs capital, but patient capital; one also needs very solid revenue streams — not just a partner, but an extremely large and voracious consumer as a partner.

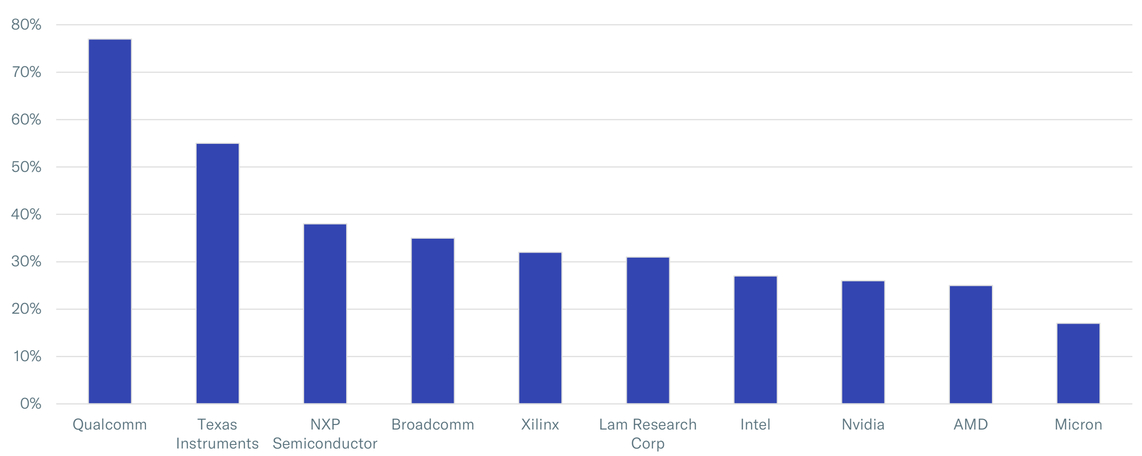
Where does China sit here? Previously, it was sitting pretty. First, it provided much of the world's growth in demand (and for other voracious consumers such as Apple, it provided the manufacturing to put everything together, chips and all). It could buy everything it needed around the world and rely on low-cost high-quality labour to put it all together. Chipmakers are among the most dependent on China for their sales among US multinationals that disclose their regional revenue breakdowns.

And this matching of demand and supply meant that everyone along the supply chain could specialise. When progress depends on large capital outlays, years in R&D, and the readiness of partners to take a risk, it simply makes the most sense to specialise, i.e. for one company to do lithography, and another to lead the world in fabrication[5]. So the US, Germany, the Netherlands, Japan, and Taiwan invested in specialisation, and that provided the very high end chips China needed to return manufactured goods. In a world of highly effective supply chains, China had no chip problems.

But China wants to be better at hard tech and not soft. All of the tech relies on chips from other places. As China's leader Xi Jinping once said: "If a tech company is dependent on others for components, then the 'vital gate' of the supply chain is grasped in the hands of others."[6] And other nations wanted China not to be good at making its own things. As the next section will show, this gate is now shut.

How is China going in building its own semiconductor firms? It has some advantages. First, it has a clear path to success, as long as it does not seek to be a first mover. There is plenty to be gained through technology transfer and process knowledge learning, as the

US Chip Companies' Share of Annual Revenue from China in 2021



Source: CSET

[5] Stratchery
[6] Xi, 2016

regular streams of Taiwanese chip designers moving to China will testify. There is also a very strong domestic market that can buy chips and give plants feedback and designs. Huawei was to HiSilicon what Apple was to TSMC. The nation has been extraordinarily good at creating its own software industry, which now is concentrating on AI, and that will drive a lot of competition.

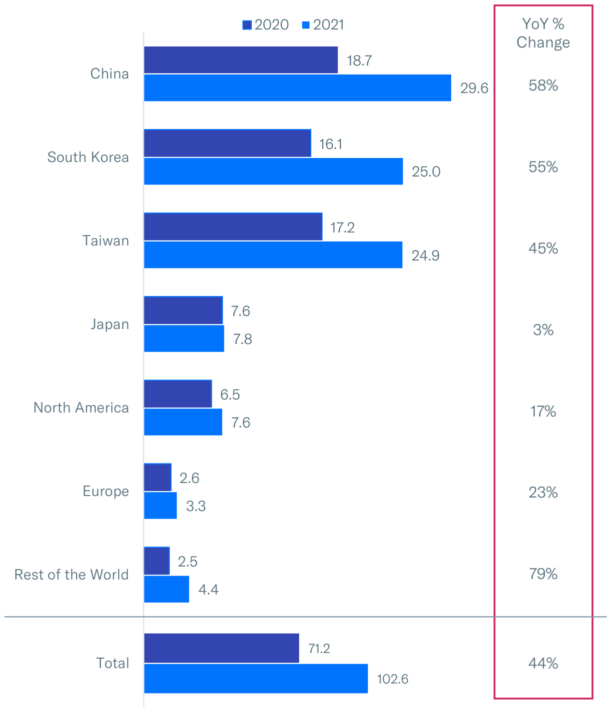
Secondly, there is some advantage in leading from behind. Microprocessors don't always need the most modern chips, and China's advantages are in circuit design, which means they can get quite a lot out of trailing edge technology. (Chip giant Nvidia seems to follow a similar line, recently arguing in an investor call that the firm can meet the needs of the "vast majority" of its Chinese customers using less advanced alternatives).[7]

Finally, China is spending a lot of money. It launched a so-called "Big Fund"[8] to try and get to 40% domestic production by 2025.[9] The table on the right shows total semiconductor wafer fabrication equipment spending by region. China's main advantage is in being able to throw money at new startups, going as far as offering a tax holiday for up to a decade to domestic semiconductor companies.[10]

Trying to become autonomous is very expensive but it does give you plenty of process knowledge. Building an autonomous semiconductor industry takes a long time — decades, really — as China will need to go through failure after failure in order to develop the IP and tacit knowledge necessary to go alone. And at the moment, China's domestic fab capacity is still far from the leading edge. China has recently made significant advances; its best fab is shipping some 7nm chips, only two generations behind TSMC and Samsung, and one behind Intel, the US leader. But producing these at the scale necessary to be self-sufficient seems a long way away.

Why? Because along the supply chain there are too many chokepoints, as Chinese official statements regularly point out.[11] China's intermediate processes are behind. On tools, it lacks wafer fabrication equipment, and electronic design automation tools. Moreover, the internal systems for plants have many and varied inputs, all of which take time to build up. These range from HVAC systems, which China can produce; to precursor chemicals where there are many quality issues; to advanced robotics and manufacturing, where China is making rapid progress.

Annual Semiconductor Wafer Fabrication Equipment by Region in USD (bn)



Source: SEMI Organisation

So what will China do? Almost certainly, focus on what can be built: the less advanced chips that are still, for the most part, perfectly viable for commercial production. For chips that are 4 or 5 generations behind (i.e. 16nm), China is theoretically self-sufficient. Its share of the global market for bigger chips is roughly equal to its total demand.[12] These chips still make up most of the volume for the industry as a whole.

[7] Caixin Global (2022)
[8] More formally, China Integrated Circuit Industry Investment Fund
[9] Made in China 2025 Plan (2015)
[10] SCMP (2021)
[11] A regular theme of Xi Jinping speeches; for an example, see https://paper.cnii.com.cn/article/rmydb_16257_313400.html
[12] Estimates from Ben Thompson, Stratchery: "China's share of >45 nanometer chips was 23% in 2019, and probably over 35% today; its share of 28-45 nanometer chips was 19% in 2019 and is probably approaching 30% today."

China will then lean on its market power and internal coordination to try and ensure the goods. There are a range of areas where this will happen. Electric vehicles, for example, will be dominated by China.[13] These chips need to be more rugged and more stable, but may not always need to be at the cutting edge. Software and other improvements could also make Chinese chips usable, if not as advanced.

Access Denied

The reason that we need to discuss full self-sufficiency is the persistent efforts to block China's access to the global semiconductor supply chain. Successive US administrations have argued that China is an adversary and that the close links between the commercial sector and military mean that China's semiconductor industry should be curtailed. This will also hurt China's AI industry.

Anxiety began in March 2018 with the US blocking ZTE from importing electronics material. In May 2019, sanctions were first applied to Huawei. Without access to the newest chips or the latest software, its mobile phone business collapsed. But these were all actions aimed at stopping Chinese companies, rather than killing the industry.

In August 2020, the scope expanded. The target became companies that were supplying chips to Huawei using American technology (which consists of all major companies, with the US being the inventor of semiconductors and the holder of nearly all technology used to make chips). In other words, sanctions became extra-territorial. Any company who supplied Huawei could also be sanctioned. To reiterate the point made earlier: making a semiconductor alone requires more than 100 steps, and some of them will be using US technology.

Having blocked off individual companies, the focus shifted to preventing the entire industry from developing. South Korean companies that used Dutch technology to make things in a Chinese factory were not allowed permission do so in fear that the technology might leak. Finally, in October, all pretences were dropped and the US Department of Commerce Bureau of Industry and Security (BIS) released a new range of measures to restrict Chinese companies' ability to build or obtain advanced chips, including those used for supercomputing and AI training.

Now, any chip manufacturer — Chinese or otherwise — that seeks to make Chinese chip designs puts its own access to US semiconductor manufacturing equipment at stake. With the new rules, Chinese chip design companies will no longer be allowed to outsource manufacturing abroad for advanced AI and supercomputing chips. Chinese organisations on the BIS Entity List will be blocked from outsourcing the manufacturing of all types of chips.[14]

In other words, this is aimed at quelling an entire industry. There are tremendous difficulties in interpretating and executing the October 7 sanctions globally. The ban came in as a 139-page-long document — the most complex regulations one can imagine. The implication for this is that it will take the major players a reasonably long time to understand the degree of damage or threat to their businesses, and implementing such regulations across the global production chain will be very challenging. Key players in the EU, Japan, South Korea, and Taiwan may find a way to obtain certificates and continue carrying on their business. For example, leading Chinese GPU (graphics processing units) specialist Biren took a weekend to realise it was one of the biggest victims for such ban, while TSMC is still uncertain of the extent to which the ban impacted its business.[15]

Previously, the US focused on merely shutting off China's access. Now, its goal is more actively to shut down server labs that can build AI models. The new regulations block GPUs that can be linked into clusters and can conduct what is called unsupervised machine learning, which simplistically speaking is where a computer plays games against itself a million times until it figures out the most efficient method.

[13] "In terms of NEVs, China's production and sales both exceeded 3.5 million from January to June, about 1.6 times higher than that of last year. We thus predict that the figure will reach 5.5 million at the end of 2022, up 56 percent year on year. Previously, our mid- and long-term goal for the industry was to reach a penetration of 20 percent by 2025. Now, it seems that this target will be achieved this year, three years in advance." Miao Wei, former head of Ministry of Industry and Information Technology, translated by Ginger River.
[14] Center for Strategic & International Studies
[15] TechArp (2022)

This was pre-warned in September by US national security adviser Jake Sullivan, who argued that the US would no longer try and "run faster" on technology, but rather also act to prevent others from catching up.

The new rules also stop US citizens and companies from supporting advanced chip development or production at Chinese companies without licenses. This means that anyone living in China or working for these companies will have to go.

To state it bluntly, these recent actions are designed to put the major Chinese chip design and supercomputing firms out of business. To stop them from making AI chips, Chinese firms are banned from the best chip design software — all of which are American. The US has also blocked chip manufacturing plants from taking any Chinese orders in attempt to degrade the quality of the AI chips China currently makes. Finally, to stop China from developing its own capabilities, the US has tried to ban anyone from providing China with equipment.

Why has the US done this? In their own words, to stop China from becoming a military rival. The policies are said to block what is called "civil-military fusion", or the use of the private sector for military gain. As this itself is not anything new, and indeed, helped the US end up with Silicon Valley today, the issue is more about China's ideology and government as making sure that the army doesn't get the latest kit. As a former official said recently, the actions were in response to "China's technology acquisition policies, including acquiring commercial technologies in order to help modernise its military, the use of a state policy of achieving strategic economic dominance in key sectors for the economy that are also critical for the modernisation of a military, [and] the use of commercial items to commit human rights abuses."[16]

What will end up happening?

Whatever one thinks of these recent actions, their impact will be significant.

In the short term, China will need to respond. While this response is not yet clear, we can make predictions based on prior behaviour and public statements. First, expect China to develop a kind of rocks-and-diamonds approach to its semiconductors — as it is largely self-sufficient in the larger chips, and these affect most of its industrial sectors, it will continue to funnel capital into the sector to make sure that it is self-sufficient in larger chips. (These, it must be said, are also more than capable of working for military purposes).

This will allow China to work on a moon-shot type of breakthrough, which will be the development of semiconductors made using completely different processes. For example, all of the chips discussed above act as switches that transmit binary code by stimulating electrons. This requires the incredibly difficult ultraviolet etching processes described above (because electrons start to behave unusually at such microscopic levels). China is behind the 8 ball when it comes to catching up to these methods, as nearly all of the intellectual property is held by American firms. So instead, the focus in China will be to make circuit boards that use light ("photonics") to transmit information faster, hence one's chips do not need to be as small.[17] Another option is to change the material used to make semiconductors from silicon to graphene, which will be much cooler. By forcing China's hand, the US is betting that it can't come up with something new. That is always a risk.

Secondly, China's AI industry is perhaps the most fundamentally affected area and will now need to develop in a different way. China's software giants — Tencent, Alibaba, Baidu, and JD.com all come to mind — will be able to develop software improvements that can gain roughly 30%.[18] That will help. Moreover, China will find creative ways to make chips for AI. Modern artificial intelligence models for neural networks require millions of GPUs tied together to run computations.[19] There are plenty of ways to get around the US sanctions to make these chains of chips.

[16] ChinaTalk (2022)
[17] This, for example, is the method proposed by Alibaba.
[18] Interview, semiconductor plant manager. Thanks to Simon Ogus for arranging.
[19] Graphics cards work for artificial intelligence because they solve lots of problems at once, as you have to do to show images, as opposed to normal computers which solve millions of problems one-by-one at the speed of light. Hence, modern AI took a large step forward by having these sorts of chips; 95% of the chips used in China's AI industry come from one US company, nVidia. It is already shipping new chips to China after the sanctions. Thanks to Lixi Yuan for a number of conversations on this theme.

That does not mean everything will automatically be fine for the Chinese AI industry. The lack of availability of chips will reduce the use of unsupervised machine learning models, such as deep neural networks, and more likely see the use of greater amounts of labelled data and supervised machine learning. This is not, ceteris paribus, arguing for one form over another. We still don't know how efficient each model may be. However, it is undoubted that the greatest breakthroughs in artificial intelligence in recent years, such as protein folding, have come mainly from unsupervised models using vast computational power, fired by massive numbers of GPUs.

China’s industry will need to work very hard to catch up with these models. Or it may invent its own. In any case, the global collaboration that has driven the large advances in artificial intelligence we have seen over recent years will be hindered.

Secondly, it will change the global semiconductor market. As we showed in the above, TSMC and other manufacturers constantly need capital. China is the world’s second largest market, one that is growing much faster than anywhere else, and cutting them off from the most advanced chips will lose every semiconductor firm a fortune, making it harder to raise and innovate further. It is hard to compete without access to China’s massive market; this ban is in that sense a test of how loyal allies are to the US market and to US requests.

Part of the difficulty is that it is very hard to argue that the sanctions are related to the military. Military systems such as missiles and ‘smart’ munitions need a fair amount of semis for advanced guidance, but the total quantity of chips is measured in millions, a drop in the bucket of the billions of chips produced every quarter. Procuring these chips in the sprawling semis supply chain may get a bit more cumbersome for the People's Liberation Army, but there are enough loopholes and grey markets that will allow them to get close to the quantities they want.

Companies will not like the new restrictions, complying up to and no further than the letter of the law, which their lawyers are already parsing very closely. And open source software, such as RISC-V, may prove extremely valuable to China. Blocking chip flow is also difficult due to China’s integration with international supply chains. To give an example, say a US company wants to ship a bunch of GPUs. They could buy a million dollars’ worth of chips, but then would need to ship them to a Taiwanese company to put the motherboard together, mainly in mainland-based factories. These same factories are banned from buying those chips directly. Would that violate the sanctions?

A similar range of difficult decisions and judgments face the many scientists and engineers with US citizenship or permanent residency who have some kind of connection to China’s semiconductor industry. They must now choose between giving up their US citizenship or quitting their jobs. Many Chinese Americans with US citizenship hold key technical positions at Chinese chip companies.

So what is most likely is that the world will send China older equipment, China will use this and its own advantages — skilled labour, software, a large number of STEM graduates — to try and make its own systems, and the world will cleave further.

But this cleavage does not suit Asia. Major Japanese and South Korean firms have already made clear that they do not wish to choose and they will provide for both Chinese and US markets. Other Asian states such as Malaysia and Singapore similarly have stated that they do not wish to choose. This shows how even a world divided can help others unite. That is probably lucky at the moment, because the US and China systems appear destined to spin further apart for at least the next half-decade.

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