Chip War: The Fight for the World's Most Critical Technology

Tom Slater & Chris Miller
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Capital at risk.

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Tom Slater (TS): Semiconductors are critical to progress. The apps you use, vehicles you travel in and medical care you receive all depend on the computation, sensors and power management that chips make possible. They're arguably humankind's highest achievement. But further advances in artificial intelligence, space travel and the energy transition all require even more complex designs and elaborate manufacturing processes.

As many of you know, Scottish Mortgage has long sought out exceptional semiconductor companies. Over 10 per cent of our portfolio is currently invested in these innovation enablers. And this pursuit of future growth can be informed by the past. So to set the scene for our first session, let me take you back four decades.

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In 1985, Taiwan asked an American businessman of Chinese birth to help it establish a chip industry. Morris Chang had quit an American semiconductor firm that picked a rival over him as CEO. As the book, Chip War, describes, Taiwan effectively gave Chang a blank cheque, and he bet on a revolutionary idea, a business dedicated to building others' chips, not its own.

Today, TSMC is one of the world's most valuable firms and a Scottish Mortgage holding. Moreover, several of our other portfolio companies, including NVIDIA, Tesla and Amazon, depend on it, while another investment, ASML, is one of its closest partners.

Chip War author, Chris Miller, describes TSMC as indispensable and the world's most important chipmaker. Chang has returned the compliment, describing Chip War as the book he wished he'd written himself. To discuss the topic further, I'm delighted to welcome Associate Professor of International History at The Fletcher School of Law and Diplomacy at Tufts University near Boston, Chris Miller. Welcome, Chris.

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Chris Miller (CM): Thank you, Tom.

TS: Could you start by giving us an idea of how critical Morris Chang and TSMC were to creating today's world?

CM: Well, as you alluded to, before TSMC was founded, every chip that was made, with only a tiny number of exceptions, was both designed and manufactured by the same company. And that was a natural place for the industry to begin, but it meant that there were limits to specialisation. And Morris Chang realised that specialisation was key both to optimising economic efficiency, but also to improving technological capabilities.

And so TSMC, after he founded it, focused only on manufacturing chips. It's never designed a single semiconductor. But as a result of that, it's been able to scale up far beyond its competitors because it produces chips for many different companies, for Apple, for NVIDIA, for Qualcomm and for others.

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And this has let it pour dollars into research and development and improve its technological capabilities above all of its rivals. And so many of the advances that we have today, the chips in our smartphones, for example, almost all of the chips training AI systems, they are produced by TSMC. And the fact that they're so relatively inexpensive and so technologically capable is due in no small part to this extraordinary business model innovation that Morris Chang pioneered.

TS: And I think you've compared Morris Chang and TSMC to Gutenberg and his printing press. Gutenberg didn't write the books he printed, but it made it much more economical for others. Can you tell us how that's worked to TSMC's advantage?

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CM: Well, that's right. And it's given TSMC the ability to work with a very wide variety of customers, because it doesn't compete with any of them. Right now, TSMC has multiple customers in the smartphone space, multiple customers in the AI space, and it's trusted by its customers with their most valuable intellectual property. They have to turn it all over to TSMC as part of the manufacturing process.

And they wouldn't be willing to turn that IP over to almost any other company. But they've worked with TSMC, in some cases for decades. And the fact that it's just a platform for printing chips, just like Gutenberg provided a platform for printing Bibles, meant that there were no reasons for customers to see it as competitive.

And so that has enabled the scale that TSMC has benefited from. And it's been an innovation that TSMC is fairly rare actually in being able to capitalise on.

There's only a small number of companies today that have this same business model, in part because TSMC has the lion's share of the market, and because customers trust it with their most critical products.

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TS: And why do you think that is? TSMC obviously pioneered this model. But why have others been unable to achieve the same scale?

CM: Well, I think it fundamentally gets down to trust. Put yourself in the shoes of Apple's CEO, for example. Every year, you have to sign a contract for a new processor chip which will enable the next generation of iPhone, your most important product. If this chip is delayed, your iPhones are delayed. And the economic implications for a company like this are tremendous.

And so when you look for a foundry partner to produce your chips, you're looking for cost, of course, you're looking for technology, but ultimately, the most important factor is you're looking for someone who can get the job done on time, with no delays and no unexpected manufacturing hiccups.

And that's what TSMC, above all, provides for its customers. It's this reliability, this trustworthiness, that they can trust TSMC for manufacturing that their business really depends on. And that is why you've seen companies like Apple or like NVIDIA return to TSMC year after year for the production of their most important semiconductors.

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TS: And I think I probably would add to that with saying they haven't exploited that dominant position by hiking prices. You get that reliability, but you build those enduring relationships by not being overly exploitative or pushing too hard on price as you move through the different generations of chips.

CM: I think that's right. If you look at the production of AI accelerators, TSMC recently stated that it produces 99 per cent of the world's AI accelerators, chips called GPUs, which is about as close to the definition of monopoly as you can get. But it's, I think, striking that some of the commentary from Wall Street was confusion as to why TSMC hadn't hiked prices more, which is the response you might expect from a company with 99 per cent market share.

But I think TSMC's leadership would say they're not thinking about this contract or the next contract. They're thinking in terms of relationships that have already lasted decades and that they hope will last decades into the future. And that requires a level of trust in manufacturing, but also, I think, trust in pricing with their customers.

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TS: Switching gears a little bit, given your background, I think your specialism was in Russian history, how did you come to write Chip War?

CM: I first got interested in semiconductors not primarily due to their role in competition between businesses, but due to the central position they played in competition between countries for national power. I learned early on in the course of this research that the first chips that were invented were created for use in the guidance systems that were used to direct nuclear missiles during the Cold War. And so all of the chip technology that we benefit from today stems from those early use cases.

And just as today there's an extraordinary race between NVIDIA and AMD, for example, to produce the best GPU AI accelerator, so too there's a race between countries for a leadership position or even a dominant position in this industry, both because they realise that economic implications are extraordinarily vast, with trillion-dollar companies at stake, but also because they believe that chip technology will have strategic ramifications, be relevant for intelligence and defence applications.

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And so you've got both companies and governments having played a major role in shaping the industry from its early days in the Cold War all the way up to the present.

TS: Yes, and maybe to push a bit on that, if Chip War's origins relate to the struggle between US and Russia, one of the things in making sense of what you describe as today's struggle for supremacy or for control over the future of computing is between China and the US. Can you give us a sense of what is at risk there?

CM: Well, both China and the US have identified artificial intelligence as a key priority, as a general-purpose technology that each government believes will have broad economic, technological, but also strategic ramifications. And indeed, we already see both governments beginning to use AI, for example, to sift through intelligence that their spy satellites are collecting, for example, or to guide drones more accurately as they fly through the air.

And both governments as well have realised that of the key ingredients to AI, such as data, such as talent, such as algorithms, computing power is in many ways the most contested. Everyone has access to algorithms that are largely open-sourced. Talent disperses widely across the world. But computing power is produced by a tiny number of companies.

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And if you look at the entire supply chain that's necessary to manufacture the most advanced semiconductors, you find that there are a couple of companies, TSMC being one, that have outsized market share and fairly unique technological capabilities. And so both the US and China have been trying to increase their ability to shape and even control the industry, and both realise that they can't do it on their own.

They'd like to be able to produce all of the most advanced ships all by themselves. But the supply chain is so complex, stretching from the Netherlands through Taiwan, using ultra-precise chemicals manufactured in Japan, that no one can do it on their own. And so you've seen both China and the US jockeying for influence in the chip industry, but having to do so by negotiating with companies and other countries to get access to the technologies that they need.

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TS: It is a striking feature of the industry that it is a global supply chain, that you see these attempts at semiconductor nationalism, but as you suggest, it's a pretty vain hope. And it's also one of the reasons why Taiwan has become such an area of focus. Yes, it's geopolitics, but also, it's semiconductors.

CM: Well, that's right. And Taiwan is, of course, the world's most important producer of chips, producing the vast majority of advanced processor chips at TSMC in just a tiny handful of factories in Taiwan. Today, TSMC produces all of its most advanced ships in Taiwan, although it's beginning to diversify that production a bit. And that makes Taiwan critically important for both the US and the Chinese tech sector.

There was a moment in 2020 where TSMC's two biggest customers were, first, Apple, and second, Huawei, which illustrates the extent that both the Chinese and the US tech sectors have become dependent on chips made in Taiwan. And the US has been trying to take advantage of that by pushing TSMC to limit sales to Chinese customers. But that only underscores the extent to which TSMC is this company with unique capabilities that no one, either in China or really at this point anywhere else in the world, can match.

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TS: And from the point of view of an investor, we do take seriously the threat that Taiwan could become a flashpoint. But it's important to stress that that would be a pretty disastrous outcome, yes, for TSMC, but actually for so many companies around the world. As your comments illustrate, this technology is so fundamental that it is a risk, but it's not a TSMC risk, actually. That's a broader economic and broader set of company risks.

CM: Well, that's exactly right. And if you look, for example, at the largest companies in the world by market cap, you'll find TSMC customers very well represented in the top ten, Microsoft, Apple, NVIDIA, for example. And the same thing is true for China. China is, of course, the largest importer of semiconductors in the world.

China, for most years in the last decade, has spent more money each year importing chips than it spends importing oil.

And TSMC is a large producer of many of the chips that go into China, and then, in turn, make it possible for Chinese workers to assemble the smartphones and servers that are then shipped worldwide. So there are networks of mutual interdependence that I think do act as stabilising factors, even as governments try to jockey for influence in the midst of this.

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TS: I've got a topic that's been of interest in the questions from our audience, which is ChatGPT, which, of course, launched, I think, about a month after Chip War's publication. It has led to a surge in demand for NVIDIA's graphics chips, which are used to build and train advanced AI models.

Now, we've been an investor in that company since back in 2016. And part of the attraction was Jensen Huang, the Chief Executive's, high tolerance for risk. And as your book documents, I think NVIDIA's success today directly links to a bet-the-farm decision that Huang took. So could you tell us about that?

CM: Well, as you say, NVIDIA was founded to produce graphics chips, but it was realised, over a decade ago, that the same math that undergirds the representation of graphics on a screen is pretty similar to the math that you use for training AI systems. And so NVIDIA began exploring whether it could repurpose graphics chips and build a software ecosystem around them that would enable their use for artificial intelligence.

And it started this in the late 2000s, at a time when AI was seen as something far out and implausible, at least as a relevant business for NVIDIA. And Jensen invested pretty large sums of money in building both the chips and the software ecosystem that the chips would require if they were to become the standard in AI processing.

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And he gave the software away for free, which led to a fair number of questions on Wall Street as to what was he doing, first, building chips for an industry that didn't exist, second, giving away software for free, when surely it seemed like the right thing to do was to charge a price for the pretty expensive software you were developing.

And NVIDIA, I think today it's obviously to its credit, more or less ignored those complaints because it realised that if it could find a way to repurpose its chips efficiently, they would be vastly more efficient than the existing class of processors called CPUs, which at the time were used in small numbers for AI, but AI wasn't used in a wide fashion because CPUs were so bad at AI.

NVIDIA bet that if it could make its chips efficient to use in AI, it would drive down the costs of AI and therefore blow up in a much larger market than anyone else foresaw. And that's exactly what has happened over the past couple of years. I think ChatGPT was the consumer product that made it obvious just how capable AI systems would be, but it was really a vision that Jensen had been betting on for well over a decade at that point.

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I think, a final point here, that this speaks to the importance of leadership in the semiconductor industry. Jensen is one of the Fortune 500's longest serving CEOs. There's an extraordinary, I think, sense in which he himself deserves a lot of the credit for the decisions that NVIDIA has made. And if you were to look at the company's development, you'll find, as you say, major bets that were taken, not on the basis of short-term profit, but rather on the basis of long-term technological shifts that, it's now quite clear, NVIDIA bet correctly.

TS: Yes. And I think it's one of the things I was talking about in my introduction to the conference, is just actually these individuals that are able to take advantage of these long-term trends. And Jensen's a great example of that, because it's been a single-minded pursuit for more than 20 years. It's not so much as a moment of brilliance as just the tenacity to keep going with this technology when others were passing on it.

CM: Yes, that's absolutely right. And it's striking as well to look at the number of other companies that dipped their toes in AI acceleration and then decided not to invest because they couldn't perceive the market that would eventually emerge.

The best example of this probably is Intel, which, of course, was the world's largest chipmaker for some time, still plays a dominant role in the design and manufacture of the CPU chips that for a long time were the backbone of data centres. And it has explored artificial intelligence in a variety of different formats, bought at least one AI accelerator startup, but could never really convince itself to dive in in a way that Jensen bet the company on AI as being its future.

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TS: I want to come back to Intel, because I think it's a really interesting example. But there was another audience question that I wanted to touch on. Now, I realise you're a historian, not a futurist, but are there lessons from how computing has developed that might help us anticipate AI's coming impact?

CM: Well, I would say a couple of things from the history of computing stand out. I think the first is that even revolutionary technologies take a long time to develop. If you look at the history of computing, from the invention of the first transistor to the first integrated circuit, that took a decade. It took a decade more for mainframe computers to become widespread in large corporations, two decades after that, the first personal computer, another decade or so for the first smartphone.

And there's no denying that each of these steps in the computing revolution has been transformative. They've each produced companies that were among the most valuable in the world in their day. But it also I think, speaks to the fact that these revolutions take long periods of time to fully play out. And there are ups and downs in the dissemination of these technologies as we try to find out the right form factor, for example, for enterprise and consumer uses. And I think AI will be the same.

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And we shouldn't expect that we're going to know exactly how AI will be used or monetised in ten years' time, because it will require experimentation. But I think you can, nevertheless... Just like if you were sitting there when the first integrated circuits were invented, you could see this was an extraordinary new technology for providing compute. It had much lower energy use. It ran a manufacturing process that could allow further miniaturisation. And you could see, as many people did see at the time in Silicon Valley, the ways in which this would spread.

I think AI is similar. We don't exactly know all of the ways that it will be used in five- or ten-years' time. But I think there's no doubt that it will be used in many different ways. And one of the challenges that we all face and that companies face is finding out what's the right use case, what's the right form factor, and what's the right business model around providing that.

TS: And I think, for me, it's really important to think about not just the challenges this presents, but the opportunities. I had the opportunity to speak to Ethan Mollick last week, who is a Wharton professor. And we were talking about the impact of AI and ChatGPT in education. And, of course, thus far, we've seen that it's allowed students to cheat at their homework and get it to write their essays. And I thought he would have quite a downbeat take on the impact of these systems on education.

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But actually, he was, first of all, upfront in saying, yes, it's chaotic at the moment, but actually, in a year or two's time, he thinks this technology will just be a huge advance in the way we deliver education, that they will look back on the idea of somebody standing up in front of a huge room full of people delivering a lecture, as opposed to having an individual AI tutor, as completely archaic. And yes, this presents challenges, but also, there are all sorts of exciting possibilities that come from it.

CM: Well, I think that's absolutely right. I remember when I was in middle school and high school, we were taught never to cite the internet while doing research, because it was an untrustworthy source, better to rely on books instead. And today, the idea of not using the internet for research seems 18th century in terms of its technological sophistication.

I think that's exactly right in terms of the impact of AI on education. And I think there are many spheres where we haven't even begun to conceptualise what the application will be, because we're in the midst of, I think, the very earliest stages of what will be a technological shift that will take decades to play out.

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TS: So I want to come back to... You touched on Intel before. And I think your book does a great job of charting the challenges and the decline that we've seen at Intel. And my read of it was that you blame that, to some extent, on the short-term thinking by managers within Intel, that they had become focused on quarterly earnings. So the question is, how important do you think long termism is in this sector, both in terms of the companies, but also in terms of the regulators and lawmakers that are setting the rules?

CM: Well, I think it really is fundamentally important. If you look at NVIDIA, I've argued that their success today is in large part the result of decisions that were made a decade ago to invest in AI. And I think, at Intel, the reverse is true. The challenges that Intel has faced over the past couple of years are due not to recent decisions. They're due to decisions made many years ago.

The problem that Intel faced is that it was too successful for too long. And in the last decade, the management began to take for granted its market position and its key markets for PC processors and for providing these CPU chips for data centres. It was extraordinarily profitable when it lasted, but it meant that the leadership didn't take risks on new products.

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And there's a number of new products that they missed over the last ten or 15 years. Perhaps my favourite anecdote is when Steve Jobs came to them and asked if they'd be willing to produce a processor for a new computerised phone he was developing. And they said, no, that sounds like a low-volume, low-margin product. And of course, today, that's one of the highest-volume, highest-margin products for TSMC, which took the business instead.

But that speaks to the fact that if you've got a very successful business, it's hard to take a risk on something new, because something new will not look likely to be as successful and as large as your existing businesses. And that drove, I think, a decade of underinvestment at Intel, a decade in which risks were not taken, and a decade in which management became overly focused on finetuning each quarter's financial results rather than investing in the next generation of technology.

And indeed, you had a shift in which some of the leadership tended to have more of a financial background rather than a technological background. And that, I think, set the stage for putting technology second and financial results, at least short-term financial results, first. And I think, in the last couple of years, Intel's got a new leadership team trying to change this. But it shows how difficult it is to change in the short run, when decisions made over the long run really structure the types of products and capabilities that you have.

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And just as for NVIDIA, its decisions a decade ago that explain its success, Intel is struggling to break out of a funk that its old management team set itself in. And even under the newer leadership over the past couple of years, which does have more of a technical background, has, I think, correctly diagnosed some of the challenges that Intel faces, it just takes a long time to turn such a big enterprise when it was making, I think, overly cautious decisions for so many years prior to that.

TS: I have found myself wondering, as I've looked at Intel, that the US government has clearly woken up to the challenges, clearly is thinking about the strategic importance of having a domestic semiconductor champion and is throwing lots of money at the problem. And I do find myself wondering.

One of the lessons I took from your book is that it's almost impossible for a single country to actually sustain competitiveness in the semiconductor industry. On the other hand, this is the US, and they have such enormous firepower, that maybe, just maybe, they have enough to throw at it to keep Intel competitive.

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CM: Well, I think there's a belief in the US government that it would be very much in US interests if Intel were to succeed in its turnaround. But I think we've also seen that the US is not betting solely on Intel. If you look at the CHIPS Act, which is providing billions of dollars in subsidies for companies that build manufacturing capacity in the US, they've given a handful of big grants to chipmakers.

Intel received the biggest, but only slightly behind Intel was TSMC of Taiwan and Samsung of South Korea. So in some ways, I think the US government is making a portfolio approach in terms of its bets on manufacturing. And it's not saying it's solely going to support Intel. It's also subsidising both other US firms and also non-US firms to build manufacturing capacity in the US.

But it speaks to another challenge, which is that in the chip industry, manufacturing has extraordinary economies of scale, as we've discussed with TSMC. And Taiwan, followed closely behind by Korea, has more chipmaking more densely packed than anywhere else in the world.

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And that enables economies of scale both in terms of individual factories, but also in terms of the network of suppliers and chemical producers and material manufacturers and repair experts, if a machine breaks down, that you just can't replicate overnight anywhere else. It doesn't exist today in the US, doesn't exist in China, doesn't exist in Europe. And if you don't have that ecosystem, your costs are inevitably higher.

And so, ballpark, it's 20-30 per cent more expensive to produce a chip in the US versus in Taiwan, not related to labour costs. There's not actually a whole lot of labour cost differential anyway. These facilities are highly automated. It's due to the ecosystem that Taiwan has, that Korea has, and that it's going to take a very long time for the US or any other country to build up.

TS: So talking of geography, many people think of the chipmaking industry as being dominated by Asia. And you highlight Taiwan and Korea there. But in the book, you do touch on Europe's role, and in particular, the Dutch company, ASML. Now, it makes the machines that carve chips, intricate patterns into silicon. It's one where we've been investors since the 1990s. So we obviously think it's quite an important company. But I'd be fascinated to hear why you think it's so special.

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CM: Well, as chips have gotten more complex, it's required creating smaller and smaller components on each piece of silicon. And so today, if you pop open your smartphone, for example, and look at the primary processor chip, it'll have 10 billion or 15 billion tiny transistors, which are little switches that turn on and off.

And each of those transistors, in order to fit 10 billion of them on the chip, will be roughly the size of a coronavirus. And so the machines that are capable of manufacturing at that level of precision are critically important in the chipmaking process. And so whether you're Intel or TSMC, you have to spend billions of dollars for every single factory, buying these ultra-precise chipmaking machines.

And there's a couple of different categories of machines. Some lay down thin films and materials, a couple of atoms thick. Some inspect chips once they're manufactured to make sure there aren't any errors. And if you're inspecting coronavirus-sized transistors, you can understand the complexity of the inspection.

But the most complex of the chip making tools are called photolithography machines. And today, the most advanced photolithography machines are produced by a single company, ASML, which has 100 per cent market share in the manufacture of these tools.

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And I think, like NVIDIA, which took a decade-long risky bet on a new technology, ASML was in a similar position in the 90s and 2000s, when it took a bet on producing the next-generation lithography tool that today is central for advanced chipmaking.

For a long time, this type of lithography, called EUV, extreme ultraviolet lithography, was seen as harder than bringing a man to the moon. These machines cost several hundred million dollars apiece. They require the flattest mirrors humans have ever made, one of the strongest lasers ever deployed in a commercial device.

And I think the most extraordinary fact is that inside of every one of these machines, there's an explosion happening as a tiny ball of tin is pulverised into a plasma. And the temperature of this explosion is 40 times hotter than the surface of the sun.

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So there's no tools that humans have made that are more complex than these ones. And you can understand why for a long time, it seemed just highly implausible that a machine with an explosion happening like this inside of it would be usable in a factory context. But ASML bet on this technology over years.

For some time, especially in the late 2000s and early 2010s, a lot of people in the industry thought it just couldn't succeed. It could never be viable in mass manufacturing. But ASML made it viable. They made it work. And although the price point of each machine is high, the newest ones cost over $300 million per machine, their capabilities provide unparalleled precision in chip manufacturing. And if you want more computing power on your chip, you need more transistors on your chip. If you want more transistors, you need smaller transistors.

And so this is why the next-generation chips from everyone from Apple to NVIDIA will already require, and will in the future require, the most advanced lithography systems from ASML. And so it's made it this absolutely critical firm. It doesn't produce any chips, but it produces the machines without which advanced chips simply can't be made in an efficient manner.

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TS: And to pick up on a topic from our audience's questions, if you look at Chinese semiconductor maker, SMIC, it uses ASML's products but is blocked from buying its most advanced machines. And that gives an incentive to Huawei and others to build competing products. But you suggest they're doomed to playing catch-up. So why is that?

CM: Well, it's been since 2018 that the Dutch government has declined to allow the sale of these most advanced lithography tools to China. And they've, over the course of the last couple of years, tightened the control somewhat to catch the second-generation most advanced tools as well. And in those six years since the first ban was put in place, we haven't really seen any tangible evidence of progress in replicating ASML's tools.

And I think the reason is because these are the most complex tools that have literally ever been made by humans. I mentioned some of the components, like the flattest mirrors humans have ever made. There's one company in Germany that produces these mirrors, and no one else knows how to do it. And that's just one of the components. ASML's tools have hundreds of thousands of components in them. And each of these components has to be extraordinarily reliable and precise.

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If you have a tool with hundreds of thousands of components, and each one breaks down once a year, your tool never works. So you need reliability that stretches into the decades, on average. And to make manufacturing work at the nanometre scale, that's billionths of a metre, where misplacing a single atom can at times cause disruptions to your manufacturing process, the precision involved is really mind-boggling.

And for the same reason that ASML faces no competitors in the West, I think it will not face significant competitors in China for some time, just because this is the most complex tool that exists today. And if you want to replicate it, it's going to take years and, I think, billions of dollars in investment. And by the time you've learned to replicate it, ASML will have already produced their next generation tool, and so you'll still be behind.

TS: But I think the Chinese are making some progress at the trailing edge or foundational chips. So can you tell us what they are and why they matter?

CM: Well, inside of every electronic device, you've got a couple of leading-edge chips, which are the most advanced semiconductors, with the smallest transistors, most densely packed. If you think of the primary processor in your smartphone or the chips that are training AI systems, these require the most complex manufacturing.

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But around these advanced chips, we find more and more trailing edge or foundational semiconductors, which are used to send data to the central processor, to acquire sensory information, to communicate with the outside world.

And so one useful, I think, heuristic for thinking about the interrelationship between leading-edge and trailing-edge chips is your car. If you buy a new car today, it could have several hundred, even 1,000 semiconductors inside. And if it has any sort of semi-autonomous driving features, it'll probably have a couple of high-end semiconductors that are undertaking some of the calculations that are needed for autonomous driving.

But in order to make autonomous driving work, you need a whole lot of sensory information about the world around you, either optical sensors or LiDAR sensors. And all of that's collected by trailing-edge chips and processed and brought to the central processor by trailing-edge chips.

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And the trend that we've seen is that the more leading-edge chips we have, the more high-end processors we use, the more sensory data and communications capabilities we need, the more trailing-edge capabilities that we require. And so we actually use more and more of these trailing-edge chips. But their production is, in most cases, fairly straightforward, because it was worked out years or even decades ago.

And so we've seen, in addition to the existing manufacturing capacity that exists for trailing-edge chips, Chinese firms have been investing very heavily in new capacity, because it's a type of technology they know how to produce. It's already been worked out. And so there's pretty vast capacity expansions coming online in China to produce these lagging-edge chips, which will go in Chinese-made autos and in dishwashers and in microwaves and household devices.

And it's led actually to a boom in the procurement of chipmaking tools from companies like ASML, which have had a very good last couple of years, selling the tools that make chips into the factories that produce lower-end chips, with China being the key growth market.

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TS: So I guess that it speaks to the idea that whilst the West continues to dominate the cutting-edge chips, actually there still is a lot of supply chain interdependency, because you also need access to that capacity in lagging-edge chips to actually make systems functional.

CM: Well, that's absolutely right. If you think of a system like an NVIDIA server, NVIDIA recently stated that their most advanced servers have 35,000 components in them, electronic components of all sorts of different types, some of them extraordinarily complex, like the GPUs that TSMC manufactures with a high-bandwidth memory, but a lot of them are much more simple, components on the printed circuit boards that can be manufactured by many different countries.

And for those, cost really matters. And so companies have a strong incentive to find the most efficient producer of those. And if the level of technology isn't that sophisticated, you'll often find that manufacturing happening not at a place like TSMC, which tends to focus on more sophisticated, higher-margin manufacturing, but in facilities that are producing simpler types of electronic components.

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TS: Maybe one last question. If you're a Western policymaker or company, what would you be thinking about as the key issues today?

CM: Well, I think for Western companies, the key issue is technology leadership, because ultimately in the industry, the only way you've got a defensible market position is by having better technology than your competitors. That's what has made TSMC the primary provider of manufacturing services. It's got better capabilities than its competitors.

That's what's led NVIDIA to this position with this extraordinary market share in AI computing. It's got a better offering than its many competitors that would like to take a share of its market. And when it comes to ASML, it has no competitors in the production of chipmaking tools because it's got 100 per cent market share, and it wants to make sure it keeps advancing its lithography technology to keep it that way.

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And I think governments are beginning to realise that this is critical, not just for their companies, but also for their economies too, because if you want businesses that can charge a margin over their competitors, that margin is only sustainable in the long run by technological differentiation. And we see that in the most valuable chipmakers today. They're valuable because they've got capabilities that their competitors don't.

TS: Well, Chris, that's been a fascinating conversation, and I always learn something by listening to you. So thank you very much for taking the time to join us today.

CM: Well, thank you again for having me.

00:40:59

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