EconoFact Chats: Are Semiconductors the New Oil?

Chris Miller, The Fletcher School, Tufts University

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Michael Klein:

I'm Michael Klein, executive editor of EconoFact, a nonpartisan web-based publication of the Fletcher School at Tufts University. At EconoFact, we bring key facts and incisive analysis to the national debate on economic and social policies publishing work from leading economists across the country. You can learn more about us and see our work at www.econofact.org.

Michael Klein:

In a blurb written for the new book Chip War by my Fletcher colleague, Professor Christopher Miller, Larry Summers writes, "Semiconductors may be to the 21st century, what oil was to the 20th. If so, the history of semiconductors will be the history of the 21st century." In the 20th century, oil affected the economic fortunes of countries, the outcomes of wars, and the everyday life of individuals. If we look around us today, we see that in fact, semiconductors are having the same pervasive effect, whether through the dominance of Taiwan in the manufacturing of microchips, the success of smart weapons in wars, or through our use of -- no dependence -- on smartphones, personal computers, and microchips in a wide array of products, everything from cars to watches, to medical devices.

Michael Klein:

Indeed, this summer, GM had almost 100,000 vehicles sitting on a storage lot waiting for parts due to the global chip shortage. More recently, top US lawmakers were urging the Biden administration to put a Chinese semiconductor company, Yangtze Memory Technologies on a blacklist for allegedly violating export controls by supplying Huawei. I'm very pleased to welcome Chris Miller back to EconoFact Chats to discuss his newly published book Chip War. Chris, thanks for joining me once again on EconoFact Chats.

Chris Miller :

Thanks for having me, Michael.

Michael Klein:

Chris, as I mentioned, you've been a guest on a EconoFact Chats before, and each time, we've discussed Russia. You're a historian of international politics and economics, and you focus on Russia and you've published books on this topic, including 'The Struggle to Save the Soviet Economy: Mikhail Gorbachev and the Collapse of the USSR,' and also 'Putinomics: Power and Money in a Resurgent Russia'. Chris, what made you research and then write a book on semiconductors?

Chris Miller :

I got interested in the question of technological development in Russian history, and in particular, the question why was it that the Soviet Union could make its own atomic weapons, which were pretty complicated to make. They could shoot the first person into space, as well as the first satellite. So they had some technological capabilities, but they could never master computing power, and indeed fell behind in economic terms and military terms because of that. And so I started digging into the history of this failure and came to realize that making computer chips is one of the greatest engineering challenges of our time. And it was a story that hadn't really been told outside of a very specialist literature. And the average person, myself included when I started this research, didn't really realize how complicated or important this was.

Michael Klein:

I got an advanced copy of the book and I enjoyed it really very much, and I learned a lot about microchips and semiconductors, the history of their development, the interesting personalities involved in the advancement of this technology and its commercialization, and the political, economic, and technological implications of this high tech story. Also, why Russia fell behind. So Chris, to begin with, for our listeners, can you describe what a semiconductor is?

Chris Miller :

There's a couple words that are used interchangeably to refer roughly to the same thing. A chip, a semiconductor or an integrated circuit, all generally refer to a piece of usually silicon with lots and lots of transistors etched into it. And so today, advanced chip of the type that you'll have in your iPhone for example, could have a billion or more transistors inside of it. A transistors is an electrical circuit turns on or off. And when it's on, it creates a one and when it's off it creates a zero. And these ones and zeros undergird all of the digital computing we rely on. And we often think of computing as something that happens in a computer on the cloud or in software, but in fact it's lots of little circuits flipping on and off that actually make the ones and zeros of computing possible.

Michael Klein:

So you said one of these chips could have a billion transistors on it. When it started off, there are many, many fewer and this advance is called Moore's law. Can you explain what Moore's law is, when it was first proposed, and whether it's actually proven to be true? And finally, why is it so important?

Chris Miller :

So Gordon Moore was one of the early figures in the semiconductor industry. He founded a company called Fairchild Semiconductor and later co-founded Intel. And he noticed in 1965 that the number of transistors per chip that produced the lowest cost per transistor was doubling annually. And what that meant is that it was becoming cost effective to produce far more transistors on each chip every year. And as a result, each chip could have more and more computing power at a rate that grew exponentially. And Moore's Law is not a law, it's actually a prediction. And so it's changed somewhat over time. Gordon Moore first articulated it in 1965 to have a doubling of computing power annually. In more recent years, the rate has been around a doubling every two years. But the basic trend of exponential growth and computing power has persisted to this day, which is why the cost of computing or remembering a single piece of data has fallen by something around a billionfold since 1960.

Michael Klein:

One of the important themes in your book is the difference between the development of semiconductors and their large scale production. You write that fabricating and miniaturizing semiconductors is one of the greatest engineering challenges of our time. And you alluded to that earlier. Can you say a few words about that?

Chris Miller :

Well, if you think about what it takes to put a billion or more tiny transistors on a silicon chip that's often just one square inch or so in size, you have to have very, very small transistors. And today, the most advanced, and therefore the smallest transistors are absolutely tiny -- measuring a couple dozen nanometers or even smaller in size. That's around the size of a coronavirus, if not, even smaller. And the fact is we manufacture these by the billions every single day. We've manufactured more transistors than every other manufactured good in human history combined. And the scale is just extraordinary. And making this actually possible has been a very, very expensive and time consuming process. And today, it requires a very complex supply chain, from designers to people who write the software tools needed to lay out transistors as to where each transistor goes on the chip, to machine toolmakers, to the actual process of fabricating them. And so there's a large number of companies that produce relevant intellectual property or tools or materials and several thousand steps required to make each chip that we rely on today.

Michael Klein:

So you describe how these chips are etched using light and now they use extreme ultraviolet light, right?

Chris Miller :

That's right, yeah. So to make a chip, you take a piece of silicon, you layer some chemicals on top of the piece of silicon, and then you shine patterns of light at the chemicals on top of the silicon, and the light and the chemicals will react in certain ways that let you create holes, for example, etch holes in the silicon. And that's how you actually form transistors is by etching the tiny indents of sorts in the silicon. And to do this with the precision needed has required not only using normal light, which is how the industry started, but today we use extreme ultraviolet light -- light With a smaller wavelength than visible light, which is extraordinarily difficult and expensive to produce.

Michael Klein:

Yeah, actually I started laughing at one point in the book because you described how producing enough extreme ultraviolet light requires shooting a ball of 10, that's 30 millionths of a meter wide, moving through a vacuum at 200 miles an hour, and its struck twice with a laser that's blasted to half a million degrees. And this is done 50,000 times per second to produce enough extreme ultraviolet light to fabricate chips. Basically this is magic, right?

Chris Miller :

It's extraordinary that it works. And making the machines that can do this on a regular basis, basically constantly in a chip fab, they're producing UV light took three or four decades and each of these machines cost $150 million a piece. So these are the most expensive mass produced machine tools in human history. And you can understand why given the complexity involved. If you start taking apart, the machines needed to produce UV light, they themselves have components that are on their own extraordinarily complex. The flattest mirrors, for example, humans have ever produced are in these machines. Some of the most powerful lasers commercially used are in these machines. So it's really sort of an engineering marvel, just this one step of the production process. And when you consider that the production process has 2,000 steps, you can begin to get a sense of just all of the engineering and physics and material science expertise that's required to make the chips we use today.

Michael Klein:

Well, you can get some idea, but it's still incredibly mind-boggling.

Chris Miller :

That's right.

Michael Klein:

In the introduction I mentioned Yangtze Memory Technologies, which now US lawmakers want to put on a blacklist, but the biggest chip manufacturer in the world is across the straits from that. It's the Taiwan Semiconductor Manufacturing Company, which is better known as TSMC. I guess this illustrates the global nature of this industry, right?

Chris Miller :

Well, I like to use the word international rather than global because although the supply chain is international and stretches between many different countries, it's not a technology that is globally available in the sense that a small number of countries really control access to the technology. But certainly to create an advanced chip, you need to access intellectual property, materials, and tools from a number of different countries. And if you think, for example, of a chip in an iPhone, there'll be designers in the US, and the UK, and Israel working to design that chip. It'll be sent to Taiwan to TSMC for fabrication. But Taiwan will use...this Taiwanese firm, TSMC will use machine tools from several different countries, the US, Japan, and Netherlands to actually produce the chip. It'll import specialized chemicals often from Japan as well. And then once the chip is done, it will be sent, often to Malaysia, for example, for packaging into a ceramic or a plastic package. So there is certainly a very complicated international supply chain that is required to make a chip, but it's a international supply chain that gives certain companies and certain countries a lot of outsized influence in terms of their ability to shape what the chip making process looks like.

Michael Klein:

Right. So point taken that global is really a misnomer here because there are, as you mentioned very few countries that actually are deeply engaged in this, and one of them is Taiwan. The story of how Taiwan became a leading chip manufacturer offers some insights into the important role of government, and how governments have played a role in the creation of this industry. Sometimes they're direct government subsidies and other times, as was a case with the United States, the support is a little bit less direct. In the case of the US, the support came through the defense department.

Chris Miller :

That's right. We've seen since the earliest days [of] the chip industry, governments being very interested in trying to support the development of the industry, and also shape it in ways that suits their political, and often their foreign policy aims. So in the US, the industry emerged out of defense funding and it was the Defense Department's desire to miniaturize computing power and put it in the nose of missile systems, that really led to the industry's first emergence. But when other countries looked at the chip industry, in Taiwan for example, or South Korea, they saw a source of jobs in assembly operations, and then eventually a way to climb the technological ladder and climb the value chain; and so began funding their own chip industries with that goal in mind. And today, those two competing interests: governments' focus on the international political ramifications and the strategic ramifications, as well as a focus on jobs and technological innovation shape how different governments try to interact with the chip industry. And one of, I think the challenges that companies have always faced is that because every government that has a chip industry in their country is involved in some capacity in subsidizing it, there's been a constant challenge to delineate what's the responsibility of market competition and where our government's involved? Because the reality has been that governments have always been involved to some capacity.

Michael Klein:

Well, in the United States, the role of the Defense Department in fostering the semiconductor industry reflects the important role that smart weapons are now playing. You write about how the Gulf War was one of the first things that illustrated this, and I suppose the western weapons and intelligence provided to Ukraine are more current examples.

Chris Miller :

Yeah, that's right. And this is again, something that's been central to the industry's entire history. The first major procurement order for semiconductors was for the Apollo spacecraft's guidance computer. And the second major order was for the guides computer on a intercontinental ballistic missile called the Minuteman II. And there's been a deep interrelationship between Defense Department technological demands, and the ways [the] chip industry has developed since then. And if you look at the future of military power today, like we see it used on battlefields in Ukraine, the military's needs to sense information to communicate it, to interpret it, and then to guide munitions toward their target, all depend very intensely on semiconductors. And if you think forward to the next generation of military technologies that are...involve systems that are more autonomous or more advanced electronic warfare systems, this question of who's got access to the best semiconductors, and who's best able to use them to improve the military systems is going to be crucial to the future of military power as well.

Michael Klein:

Well, in terms of access, there were supply chain disruptions from COVID and they've illustrated how vital this semiconductor industry is for a wide range of products. For example, what I cited at the outset about GM having cars stalled on their lots because there's a shortage of chips. Also, the fact that Taiwan is a center of chip fabrication makes the tensions between that country and China really important well beyond the sovereignty of a country, even though of course, that too is very important. What does the recent COVID experience and also the limited set of countries where chips are produced, say about the vulnerability of the world economy with respect to semiconductors?

Chris Miller :

I think the extraordinary thing about the semiconductor shortage of the last two years has been that although there's been a shortage, it's been a shortage driven by a huge increase in demand rather than a decrease in supply. And in fact, the world produced more chips in 2020 than it did in 2019, and had double digit growth in the number of chips produced in 2021. And yet nevertheless, there was still a shortage, which shows us a) just how substantial demand growth is, as we rely on computing power in ever more parts of our society and economy. But b), shows us how damaging it would be if we ever had a reduction in the supply of chips, which is something we haven't had to deal with for some time. And you're right, I think to point to the fact that there's really substantial concentration of chip making in a number of geopolitical hotspots. 44% of the world's memory chips are produced in the Korean peninsula, and 90% of the world's most advanced processor chips are built on Taiwan. And that does leave not only the semiconductor industry, but every industry that relies on semiconductors, which is basically every industry, hugely dependent on peace in both those hotspots because any sort of disruption, not even an all out war, just disruption to trade, would have dramatic effects on the rest of the economy because our ability to acquire computer chips would be called into question.

Michael Klein:

Of course, as you're indicating it's not only the United States that's vulnerable, you point out in your book that China spends more money importing chips than it does importing oil.

Chris Miller :

That's right. And this has been a source of concern for Chinese leaders over the past decade, as they began to examine where they were vulnerable to external pressure. Chinese leaders have focused on the fact that they import so many chips. And the chips that China imports are partly from the US, but also from Taiwan and South Korea. But most of the chips that China imports are subject to US export restrictions because they're either designed with US-based software, or produced with US-based machine tools. And as a result, China is very sensitive about the security implications of this for China. And the response has been a vast domestic subsidy program probably adding up to the low hundreds of billions of dollars over the past decade to build a domestic chip industry that is less reliant on American technology.

Michael Klein:

So like Yangtze Memory Technology, that's an example of it?

Chris Miller :

That's right. They received a pretty dramatic initial investment both from the Chinese government's own fund, which is called the Big Fund or the National Integrated Circuit Investment Fund, but also from a number of ostensibly private corporations that in reality were deeply tied to the Chinese government like Tsinghua Unigroup, which has been a major investor in Chinese semiconductor corporations. And so part of the controversy over Yangtze Memory is that it's very clearly been a beneficiary of Chinese government subsidies. And so even if you set aside the question of is it violating sanctions law, is it in the interest of a market based global economy to have a company whose origins is in pretty substantial subsidies, begin to take meaningful market share.

Michael Klein:

So this raises a question of what are reasonable government policies to reduce that kind of vulnerability? Do we need to have onshoring of chip production? And does this make economic sense given what you talked about in terms of the huge investment required for chip fabricating plans?

Chris Miller :

Well, if you look at the semiconductor supply chain, in a lot of parts of the supply chain, there's not that much vulnerability, because there's some geographic dispersion as to where production's happening. But when it comes to fabrication of chips, there's extraordinary concentration, and above all in Taiwan. And so this is a question that's come to the fore over the past couple of years is, is this dangerous? And I think answering this question depends on the likelihood you think there is, of some sort of military escalation or even war in the Taiwan straits over the coming years. But if you think there's even a relatively small chance of that, given the magnitude of disruption this could have, the expected value is actually pretty large. And so given that context, the US Congress and now the Biden administration are trying to find ways to incentivize the fabrication more chips in the United States by promoting their own sets of incentives for manufacturing in the US.

Michael Klein:

Given the centrality of Taiwan and the dependence of China on semiconductors, would China be shooting itself in the foot if it invades Taiwan and disrupts the production of semiconductors from there?

Chris Miller :

Well, in pure economic terms, the answer is yes. The question is whether you think China's leaders will be guided by a desire to maximize GDP or maximize their population's living standards, or whether they'll be guided by something else. And I think the lesson of 2022 is that we shouldn't necessarily assume that autocratic leaders with opaque decision making processes and conspiratorial minded intelligence agencies always make decisions with GDP maximization in mind. And I do worry that the more we've learned about China's leaders and Xi Jinping's personal preferences over the past couple of years, GDP maximization has fallen away relative to questions of national pride or geopolitical influence. And that's the type of...sets of interests that might lead a leader to be less focused on the economic costs of an attack, and more interested in rolling the dice and seeing what they might be able to get.

Michael Klein:

Well, that's ending the interview on a sort of very sober note, but I do want to congratulate you, Chris, on the publication of Chip Wars. Not only really informative and instructive, but it's also a real fun read, and I enjoyed it very much. So thanks for joining me once again on EconoFact Chats.

Chris Miller :

Thanks for having me, Michael.

Michael Klein:

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