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Understanding the global chip shortages

Why and how the semiconductor value chain was disrupted

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Executive Summary

The global chip shortages and the resulting severe spillover damages in many sectors put the spotlight on questions of the health of the semiconductor supply chain. The struggle to cope with skyrocketing demand, natural disasters and lock-downs—all happening concurrently—reveals the supply chains fragility. Governments ask themselves what their role should and could be to strengthen the resilience of this vital supply chain, beyond mulling substantial subsidies to strengthen their domestic chip manufacturing.

From talks within the EU-US Trade and Technology Council (TTC), to US and South Korea exploring the idea of a joint supply chain task force and the US Bureau of Industry and Security asking chip companies a host of questions about their supply chains. These and many more strategies and initiatives are well-intentioned and understandable first steps to better understand to what extend governments can help in strengthening the resilience of this critical value chain. But to identify the root causes of these shortages, policy makers need to understand the dynamics within semiconductor manufacturing.

What customers and markets are currently experiencing as *the* semiconductor shortage is, in fact, multiple shortages happening concurrently in different process steps and supplier markets based on a multitude of dynamics and dependencies. The interplay between the underlying dynamics, such as high market entry barriers, high geographic concentration, high fab utilization and long manufacturing cycles, is the reason why skyrocketing demand and external shocks, from natural disasters and human error to COVID-19-related lock-downs, disrupted the value chain since 2020. Consequently, none of the shortages in semiconductor manufacturing can be explained by one reason alone. Most importantly, some of the underlying dynamics are unlikely to change in the future because they are rooted in fundamental characteristics of semiconductor manufacturing.

This paper provides an analysis of the root causes of the global chip shortages by identifying key characteristics of semiconductor manufacturing. It shows how these characteristics result in first and second order effects that explain the lack of resilience within this vital value chain. Some dynamics, such as high market entry barriers, the challenge of limited sources and long manufacturing cycle times, will not change any time soon. There is no short-term solution to this problem, it needs to be addressed by long-term strategic decisions. Thus, governments need to understand that strengthening the resilience of the global semiconductor value chain is a complex task for years to come—requiring structural changes, new business models and supplier relationships.

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Introduction

Many industries worldwide, from automotive to farming and healthcare, are affected by the current chip shortages. Some forecasts estimate that automakers will produce between 6.3 and 7.1 million fewer units in 2021 due to chip supply constraints.[1] Medical device makers are struggling to keep up with the demand for ultrasound equipment, pacemakers, ventilators and countless other medical devices that rely on chips.[2] As almost every industry is dependent on semiconductors to some extent, Goldman Sachs estimates that around 169 industries globally are impacted by these chip shortages.[3] The recent lack of semiconductors and their spillover damage to many other industries also explain governments' increased interest in the semiconductor industry. From roundtables with industry to consultation processes, trade talks and joint supply chain task forces, governments are trying to get more involved in strengthening the resilience of this critical value chain—beyond simple subsidies.

The first step in this process of getting more involved is understanding the different dynamics, including different actors' economic incentives, more deeply within the global semiconductor value chain. Understanding key characteristics of the semiconductor manufacturing supply chain, from the high division of labor to high capital intensity, long manufacturing cycle times and strong lock-in effects, to name a few, is critically important to assess how and why the value chain was disrupted. It is not by chance that this value chain struggled to cope with skyrocketing demand and external shocks, such as natural disasters and lock-downs. The global semiconductor value chain is highly efficient and innovative but neither agile nor resilient to external shocks.

This paper provides an overview of and introduction to the root causes of the global chip shortages. It argues that rather than one distinct shortage, we are currently facing multiple shortages at different processing steps and inputs within the supply chain. To that end, the first section explains which factors (skyrocketing demand and external shocks) led to the disruption of the value chain. The second section explains six characteristics of the semiconductor manufacturing supply chain that play a critical role in the value chain's lack of resilience. The third section then elaborates how the interplay of these six characteristics in combination with (a) skyrocketing demand and (b) external shocks led to the disruption of the global semiconductor value chain. The third section then provides some exemplary cases to illustrate the variety of shortages at different process steps. The last section then provides some background on the challenges of strengthening the resilience of the global semiconductor value chain.

This paper builds on SNV's previous analysis of the global semiconductor value chain. To get the most out of this paper, it is highly recommended to read some of our previous analyses, a list of which you can find at the end of this paper.

What disrupted the global semiconductor value chain?

Historically, the semiconductor market has been through several boom-and-bust cycles[4] where periods of double-digit market growth are quickly followed by stagnation or decline.[5] One reason is that consumer electronics, such as laptops, smartphones and tablets, and PCs for home or office use make up the lion's share of global semiconductor demand. Demand for these goods depends heavily on the general economic situation. The first and most important factor that disrupted the global semiconductor value chain was the **skyrocketing demand for chips due to COVID-19** and **the US-China technology rivalry.**

One reason for the quickly increasing demand for chips was **COVID-19**. Since the second half of 2020, working from home and home schooling were the new normal in many countries. As many companies lacked the necessary equipment and infrastructure to enable work from home, many PCs and laptops were bought.[6] With remote work, video calls became the "new normal"; thus, data center and server equipment was in high demand. Staying at home due to curfews and lock-downs meant that many people invested in gaming consoles and other gadgets.

Another reason for the increasing demand seems to be the **US-China technology rivalry**. When the US placed export bans on Huawei in 2019, some Chinese companies started hoarding chips out of fear of facing similar challenges if being put on the U.S. Entity List.[7] U.S. export restrictions on Chinese companies can be highly disruptive because of China's reliance on foreign (US) chips.[8] Thus, it is understandable that Chinese companies started stockpiling chips, but by doing so they contributed to skyrocketing demand.[9]

Thus, COVID-19 and hoarding due to geopolitical tensions led to **skyrocketing demand** for chips. Global semiconductor sales were 18% higher in 1Q21 than in 1Q20, 29% higher in 2Q21 than in 2Q20 and 28% higher in 3Q21 than in 3Q20.[10] Of course, this huge increase in sales can be partly explained by the supply constraints that significantly increased prices. However, forecasts also predict that 21% more semiconductor units are expected to be sold in 2021 than in 2020.[11] All this despite severe supply constraints throughout the entire value chain.

In addition to the steep increases in demand for semiconductors, many **external shocks** have further strained the global semiconductor value chain in the last two years. Government-mandated lock-downs forced several fabs to shut down temporarily. Earthquakes, fires, snowstorms leading to power outages, droughts and human error have brought further disruptions to an already strained supply chain.[12] See the annex for a list of external shocks to the semiconductor value chain since 2020.

Characteristics of the value chain

Before assessing how and why skyrocketing demand and external shocks disrupted the global semiconductor value chain, it is imperative to understand the underlying characteristics that make this value chain work. Six characteristics define the inner workings of the semiconductor manufacturing industry: a high division of labor, high capital intensity, high knowledge intensity, long manufacturing cycle times, transnationality and strong lock-in effects.

High division of labor: The semiconductor industry's high levels of innovation and efficiency are rooted in a highly specialized and interdependent ecosystem. A high division of labor is distinctive across not only the three main process steps (design, wafer fabrication and assembly, test, packaging) but also in the supplier markets. Modern chip production involves thousands of highly specialized companies. The first process step, chip design, relies on access to third-party intellectual property (IP) vendors and electronic design automation (EDA) tools. The two process steps that follow, front-end and back-end manufacturing, depend on a variety of chemical suppliers, manufacturing equipment vendors, cleanrooms, and process automation, to name just a few. There is a reason large semiconductor manufacturer such as Intel and TSMC recognize outstanding suppliers each year—the high division of labor is a result of the economic pressure to constantly innovate.[13]

High capital intensity: Semiconductor manufacturing is highly capital intensive, especially cutting-edge wafer fabrication. Building a modern fab (5nm) requires USD 20 billion in capital expenditure,[14] and a single cutting-edge lithography machine from ASML costs USD 175 million. Large fabs need around 20 of them.[15] These extremely high capital expenditures for cutting-edge manufacturing are one reason the market has been heavily consolidated over the past 20 years.[16] The only three companies that still operate cutting-edge fabs (TSMC, Samsung and Intel) accounted for more than 50% (USD 59.4 billion) of global semiconductor capital spending in 2020.[17]

High knowledge intensity: Across all industries, semiconductor companies have one of the highest research and development (R&D) expenditures. In 2020, the semiconductor industry spent more than 14% of revenues on R&D.[18] Chip design (fabless) companies that out-source manufacturing, such as Nvidia, AMD and MediaTek, typically invest around 20–25% of their revenue in R&D. However, semiconductor manufacturing also relies on extensive process knowledge based on decades of experience and skilled workers.[19] To develop future manufacturing processes, foundries and integrated device manufacturers (IDMs) have R&D collaborations with research and technology organizations (RTOs), equipment and chemical suppliers and their fabless customers. Historically, U.S. companies and institutions have the highest share of global semiconductor R&D, but South Korean, Taiwanese and Chinese companies have become important R&D partners in recent years.[20]

Long manufacturing cycle times: Producing a single chip requires up to 1500 steps, each based on hundreds of variables.[21] Some process steps during wafer fabrication, such as oxidation and coating, lithography, etching and doping, are repeated hundreds of times, depending on the specific chip.[22] Thus, wafer fabrication from start to finish (cycle time) takes, on average, 12 weeks but can take up to 20 weeks.[23] Then, the wafers are delivered to back-end manufacturers (assembly, test and packaging).[24] In total, producing a semiconductor can take more than 6 months.[25] Consequently, the industry is characterized by long-term planning with customers placing their orders well in advance.

Transnationality: The United States, Japan, South Korea, Taiwan, the European Union, China and several Southeast Asian countries play critical roles within the semiconductor value chain. No region is able to source all necessary inputs and perform every process step domestically.[26]

Strong Lock-in effects: In this transnational value chain, having close connections within the ecosystem is essential to develop competitive products. However, this, in turn, creates strong lock-in effects between companies, making it harder to switch suppliers or manufacturers. One example is the close business relationships between chip design companies and foundries for contract manufacturing. Choosing a foundry's process node for a new chip design is a long-term, strategic decision as chip design companies cannot simply switch nodes once the chip has been developed (i.e., from Samsung's 5nm process to TSMC's 5nm process). A chip design, especially for cutting-edge chips, is always designed for and thus dependent on a fab's specific process node. Another example is lock-ins between fabs, manufacturing equipment and chemicals. Manufacturing equipment might work best with chemicals from a specific vendor because of an R&D collaboration, making it unlikely that fabs will switch equipment vendors for fear of disrupting the production process. These functional interactions create strong lock-in effects across the entire value chain.

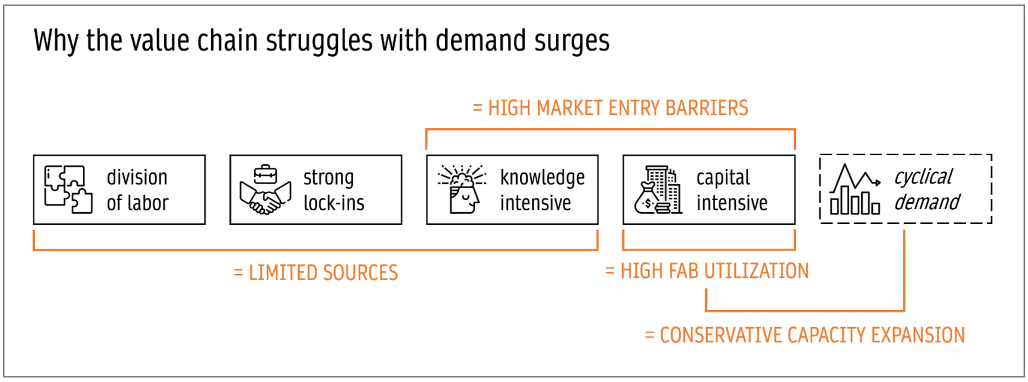
The interplay of these **six characteristics** of the global semiconductor manufacturing industry—**high division of labor, high capital intensity, high knowledge intensity, long manufacturing cycle times, transnationality and strong lock-in effects**—led to further dynamics within the value chain over the past decades. These dynamics are increasingly **high market entry barriers**, the need for **high fab utilization** due to economic pressure that, in turn, leads to **conservative capacity investments**, dependence on **limited sources** for inputs and manufacturing and a **high geographic concentration** for certain production steps. The following section elaborates why these dynamics were the reason the global semiconductor value chain was disrupted by skyrocketing demand and external shocks.

Skyrocketing demand and external shocks

The semiconductor value chain has very limited agility and resilience, which is why sudden demand surges and certain types of external shocks, such as natural disasters or COVID-19 lock-downs, have potentially highly disruptive effects with huge spillover damages. The reasons for that lack of agility and resilience are specific **dynamics that stem from the interplay of the value chain's characteristics.**

Why did skyrocketing demand disrupt the value chain?

Sudden increases in demand threw the semiconductor value chain off balance because of **high market entry barriers**, **high fab utilization** and **limited sources.**



High market entry barriers
The value chain did not cope well with the explosion of demand because the high market entry barriers in semiconductor manufacturing make it impossible for any company from outside the ecosystem to fill in if demand exceeds supply. The high market entry barriers result from the **high capital intensity** and **high knowledge intensity.** As an example, in 2020 many distilleries quickly set up production of hand sanitizers—an equivalent would be unimaginable in the semiconductor ecosystem. The high market entry barriers of semiconductor manufacturing (including supplier markets such as manufacturing equipment and chemicals) mean that even in the mid-term, the value chain can rely only on existing companies.

High fab utilization
Another reason skyrocketing demand can be highly disruptive to the value chain is the need for constant high fab utilization rates in semiconductor manufacturing. As fab owners need to invest substantial amounts of money in equipping their fabs, these huge capital investments are profitable only if the fabs operate 24/7 with utilization rates at or above 80%.[27] Thus, the operational goal of high fab utilization

is a direct result of the **high capital intensity** of semiconductor manufacturing. Operating close to full capacity is the only way to amortize the high investment costs. However, this, in turn, means that the market has very limited “spare” fabrication capacity, and fabs are quickly booked out if there is a sudden increase in demand. In 3Q20, when shortages started to materialize, the average fab utilization rate was already at 95%.[28] TSMC’s CEO said in spring 2021 that their fabs had been “running at over 100% utilization over the past 12 months.”[29]

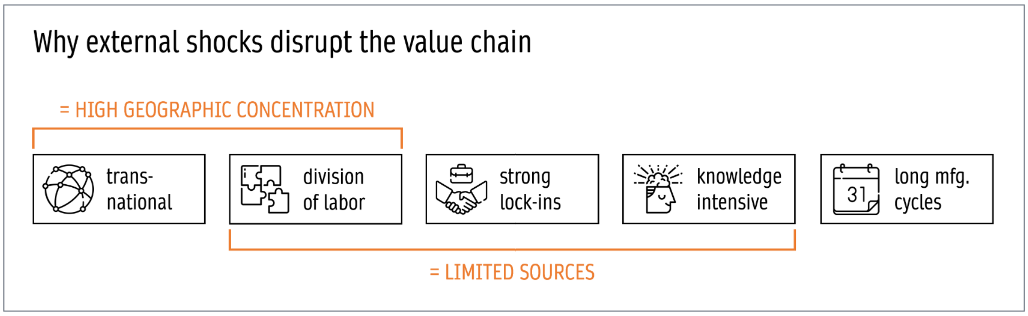
The business objective of **high fab utilization rates** in a market with fluctuating demand leads to another second-order effect: **conservative capacity investments.** Even as fab owners such as Samsung, TSMC, Intel and many others announced substantial capacity investments in the coming years, they want to avoid overcapacity at all costs.[30] In the future, semiconductor manufacturing will also be defined by periods of oversupply and undersupply. Fab owners have a strong economic incentive to utilize as much existing capacity as possible before investing in new fabs that cost up to USD 20 billion at the cutting-edge.[31]

Limited sources

Another contributing factor to why quickly increasing demand led to supply constraints within the value chain is the reliance on limited (or single) sources. There is no abundance of suppliers for a particular process step, type of equipment or chemical because of the industry’s **high knowledge intensity**, **high division of labor** and **strong lock-in effects.** The interplay of these three characteristics means that quasi-monopolies are very common throughout the value chain because companies have to specialize to stay competitive. TSMC and Samsung are the only cutting-edge foundries, ASML is the only supplier for the most advanced lithography equipment, Japan’s Tokyo Electron has 90% of the global market for another type of equipment (coater/developer), and specialty chemicals and wafers are also regularly single-sourced, simply because of lack of competition or highly customized processes.[32]

Why did external shocks disrupt the value chain?

The semiconductor value chain was disrupted not only by skyrocketing demand but also by a series of natural disasters, human error and COVID-19-related lock-downs often resulting in (temporary) production loss. The global semiconductor value chain is susceptible to these types of external shocks not only because of the **long manufacturing cycle times** but also because of two additional dynamics—**high geographic concentration** and **limited sources**.



Long manufacturing cycle times

Because wafer fabrication alone takes 12 weeks or more, a single power outage in a fab can potentially lead to 12 weeks of lost production.

High geographic concentration

The semiconductor value chain is spread across several geographic regions and jurisdictions. However, chip manufacturing, especially cutting-edge wafer fabrication and back-end capacity (assembly, test and packaging), is relatively concentrated. There are several reasons, including government incentives and out-sourcing of labor-intensive production steps (back-end manufacturing), and they stem from decades of specialization through **high division of labor** in a **transnational** value chain. For example, South Korea (Samsung) and Taiwan (TSMC) account for 75% of the global foundry production capacity.[33] East Asia is also the most important region for back-end manufacturing (assembly, test and packaging).[34] This high geographic concentration increases the risk of supply chain disruptions in the event of a natural disaster (earthquake, tsunami, flood, droughts, etc.) or lock-downs due to a pandemic.[35]

Limited sources

The inability to quickly switch to second or third sources is a challenge not only during periods of skyrocketing demand but also in the event of an external shock. The **high knowledge intensity**, **high division of labor** and **strong lock-in effects** created specialized companies that may be indispensable in their niche. That is why external shocks can be especially disruptive for fabs (front-end and back-end), chemicals and wafer suppliers.

In summary, skyrocketing demand and external shocks were highly disruptive because of the underlying dynamics within the semiconductor value chain. **High market entry barriers**, the economic need for **high fab utilization rates** and **limited sources** throughout the value chain resulted in the sudden increase in demand that substantially disrupted the value chain. In addition, external shocks throughout 2020 and 2021—from natural disasters to human error and lock-downs—further disrupted the value chain because of its **long manufacturing cycle times**, **high geograph-**

ic concentration and **limited sources** or inability to (quickly) switch to a second or third source. Thus, what customers and markets are currently experiencing as *the* semiconductor shortage is, in fact, multiple shortages happening concurrently in different process steps and supplier markets based on a multitude of dynamics and dependencies. Most importantly, some of these underlying dynamics are unlikely to change in the future because they are inherent characteristics of this value chain. The next section discusses several cases to illustrate how diverse the reasons for shortages in different production steps can be.

Examples:
Different shortages for different reasons

Case 1: Automotive semiconductor shortages

Automakers decided to cancel chip orders during 1Q20 and 2Q20 because of pessimistic demand prospects due to COVID-19.[36] This "freed up" wafer capacity at foundries and IDMs was quickly filled with orders from consumer electronics companies as demand in this sector skyrocketed. When automotive demand increased sooner than expected, car manufacturers quickly ran out of chips because of their just-in-time supply chain model, which generally tries to avoid inventories. At that time, three dynamics kept carmakers from quickly receiving the necessary chips: high fab utilization, long manufacturing cycle times and limited sources.

High fab utilization: Foundries and IDMs were almost fully booked in 4Q20 when automotive suppliers ran out of chips. The existing wafer capacity was completely utilized by other customers, and there was simply no overcapacity available to accommodate carmakers (or any other customer). Additionally, with a global market share of less than 12%, automotive semiconductors play a smaller role in the market compared to consumer electronics or telecommunication.[37] At the end of 2020, lead times for automotive microcontrollers already extended to 14 weeks and continued to rise constantly.[38]

Long manufacturing cycle times: When the supply is stable, it takes four to six months to manufacture a chip. These long production times are incompatible with a highly complex and non-transparent just-in-time automotive supply chain.[39]

Limited sources: Automotive chips have stringent safety requirements (weather resistance, fault tolerance, redundancy, etc.) that must be certified, including the production process. This limits the number of fabs that automotive chip suppliers can rely on, putting further stress on an already strained supply chain during times of scarcity.[40]

Case 2: Chemical shortages

Front-end and back-end manufacturing relies on hundreds of different chemicals and materials. The lack of one type of chemical can have domino effects through the entire value chain and can interrupt the whole manufacturing process—as was the case with Ajinomoto Build-up Film (ABF) substrates.[41] ABF substrates are essential for every chip that uses laminated packaging.[42] Functioning as a layer that connects different components within a chip, ABF substrates are widely used in chips for graphics cards, servers, smartphones and laptops, to name just a few.[43]

In addition to the ABF substrate supply constraints due to **skyrocketing demand** for gaming consoles and graphic cards, two fires at a major substrate supplier, Unimicron (October 2020 and February 2021), and problems with low yield (less than 70%) at three different suppliers (Unimicron, Nan Ya, Kinsus) led to further shortages.[44] In March 2021, it was estimated that supply would fall short by at least 25%, with delivery times extending to more than one year and price increases.[45] The shortage is estimated to worsen (33% short of supply in 2022)[46] and is expected to last until at least 2023, although some sources predict it will ease not before 2025.[47] Large customers such as AMD, TSMC, Samsung and Intel are planning strategic investments and partnerships with suppliers such as Unimicron and Ibiden to secure their ABF substrate supplies.[48] Three dynamics led to the ABF substrate shortages: conservative capacity investments, limited sources and geographic concentration.

Conservative capacity investments: As substrates are a low-margin business, substrate suppliers have been hesitant to expand their production capacity. This, in turn, led to many years of underinvestment in additional capacities.[49] When the market was exposed to **external shocks** and **skyrocketing demand** at the same time, suppliers had no room to produce more, as they were already operating at full capacity.

Limited sources and **external shocks:** ABF substrate supplier Unimicron experienced two fires[50] at its plants, which led some customers to switch to a smaller supplier, Nan Ya (6% global market share). Consequently, Nan Ya could not compensate for the demand of all the customers that usually source their ABF substrates from Unimicron.[51] In reaction to the tight supply, many customers, such as Nvidia, now plan to diversify their supplier network for ABF substrates.[52]

Geographic concentration: The leading ABF substrate suppliers are based in Taiwan (Unimicron Technology, Kinsus Interconnect Technology, Na Ya) and Japan (Ibiden, Shinko Electric).[53] This high geographic concentration poses risks during natural disasters or pandemic-related lock-downs in these regions.

Case 3: (Back-end) equipment shortages

Expanding (back-end or front-end) capacity in existing fabs can be done much quicker than building new fabs (18 months instead of 3 years). However, supply constraints for certain types of manufacturing equipment pose a challenge to short-term capacity expansions. One example (of many) is wire-bonders, often used for packaging (one process step in back-end manufacturing) of trailing-edge components such as microcontrollers. ASE Group, the largest chip packaging company, reported that wire-bonding accounts for 80% of their chip packaging processes and that lead times for wire bond equipment, for example, from market leader Kulicke & Soffa,[54] rose to 40–50 weeks (in 1Q21).[55] Thus, short-term back-end capacity expansion will take longer due to equipment shortages stemming from the interplay of two dynamics: limited sources and conservative capacity investments.

Limited sources: As the demand for trailing-edge chips gained traction during the beginning of the shortage, Kulicke & Soffa was already running at full capacity. Consequently, chip packaging companies such as ASE Technology experienced that their wire-bonding capacity is 30–40% below demand.[56] Packaging companies and their equipment suppliers maintain close relationships (**strong lock-in effects**), making it unfeasible to quickly source equipment elsewhere.

Conservative capacity investments: Mature nodes (front-end and back-end) have seen very limited capacity investments in recent years. Thus, equipment suppliers have increasingly focused on equipment for modern fabs (300mm wafers) instead of equipment for older fabs (200mm wafers). The sudden demand for mature nodes cannot be met because of a lack of mature node equipment.[57] As long as equipment suppliers are not able to meet the demand for chipmaking machines, foundries and packaging companies cannot expand their capacity.[58]

Case 4: Disruptions in wafer fabrication

In February 2021, Samsung, NXP and Infineon had to temporarily suspend plant operations for several weeks due to power failures in Austin, Texas, caused by major snowstorms, resulting in lost production[59] and hundreds of millions of U.S. dollars in lost revenue.[60] The power outage damaged not only manufacturing equipment but also components in the facilities' infrastructure that had been expected to last the life of the facility.[61] The power outage exacerbated disruptions in an already strained supply chain. External shocks, such as power outages, disrupt not just wafer fabrication but also the entire value chain mainly because of two dynamics: limited sources and long manufacturing cycle times.

Limited sources: Customers of the Samsung foundry weren't able to simply move their production to a different foundry because a chip design is always based on a process node from a specific company.

Long manufacturing cycle times: As wafer fabrication, on average, takes three months, a considerable amount of production is lost during such an external shock, and lead times quickly increase.

Why strengthening the resilience of the semiconductor value chain is difficult

Challenges of adapting to fluctuating demand

The four exemplary cases illustrate the interplay of the many dynamics that led to a variety of shortages at different process steps and inputs. The global semiconductor value chain cannot quickly adapt to sudden increases in demand mainly because of the interplay of three dynamics all rooted in fundamental characteristics of semiconductor manufacturing: **high market entry barriers**, **high fab utilization** and **limited sources**.

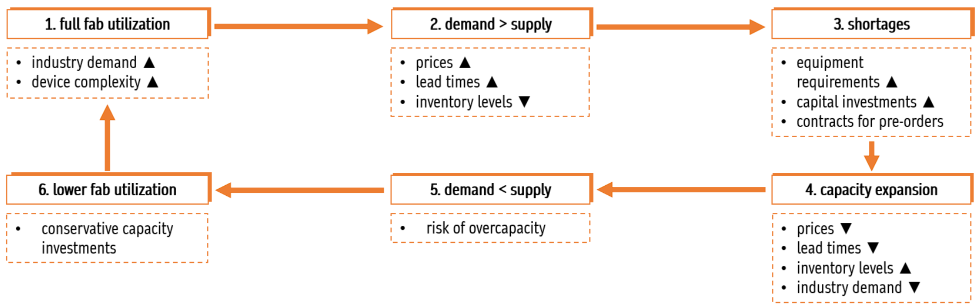
The high market entry barriers (**high capital intensity** + **high knowledge intensity**) and the challenge of limited sources (**high knowledge intensity** + **high division of labor** + **strong lock-in effects**) throughout the value chain will not change any time soon.

However, the operational goal of high fab utilization (because of **high capital intensity**) and the resulting **conservative capacity expansions** due to fluctuating and uncertain demand are not set in stone—but they are hard to change. The conflicting priorities between high fab utilization and the ability to cope with quickly changing demand have led to many boom-and-bust cycles in the semiconductor market: Investments in additional capacity or a new fab are made only if such an expansion is economically viable—when high utilization rates can be achieved quickly. Thus, new fabs are built when demand for chips is larger than supply (fab capacity), and shortages and stockpiling are already occurring. Fabs make more money in times of scarcity (high fab utilization), and their customers thus far have not had incentives to pay for spare capacity. Government subsidies and simply building more fabs will not fundamentally change this dynamic because future fabs will also have economic pressure to achieve high utilization rates.[62]

Because it takes at least a year to expand an existing fab and around three years to build and ramp up a new fab, demand visibility is crucial for semiconductor manufacturing. The current shortages have the potential to change the business relationships between fabs and their customers to improve demand visibility and make the value chain more resilient. Some foundries are negotiating long-term agreements and prepayments from their customers for future fabs in exchange for guaranteed wafer capacity per customer.[63] Another development is non-cancellable non-refundable chip orders.[64]

The inherent characteristics and dynamics of the semiconductor value chain show that adding capacity alone is not a successful strategy for making the supply chain more resilient and agile in view of sudden demand increases. Achieving more resilience is deeply rooted in the question of how to incentivize overcapacity.

The cycle of demand and supply in semiconductor manufacturing



Resilience against external shocks

The exemplary cases show that the global semiconductor value chain struggles to cope with external shocks, such as natural disasters, human error and lock-downs, mainly due to **single or limited sources**, the **high geographic concentration** and the **long manufacturing cycle times.**

Long manufacturing cycle times are a structural feature of the complex process of semiconductor manufacturing, and nothing can be done to change that. The same is not necessarily true regarding the high geographic concentration (**high division of labor** in a **transnational** value chain) and single or limited sources throughout the value chain. Both can and should be addressed through diversification, especially as natural disasters are occurring more often due to global warming.[65] As pointed out in the section on back-end equipment shortages (Case 3), external shocks cannot only be narrowed down to disruptions in manufacturing processes. One incident at a chemical provider can lead to severe shortages throughout the whole value chain.

Identifying bottlenecks in the value chain where companies are indispensable due to the high division of labor and lock-in effects, leaving customers dependent on single or limited sources, can be a first step. Consequently, possibilities of alternative sources (at least in the long term) can be explored, or diversification of those “quasi-monopolies” can be incentivized. Similarly, if a region accounts for the major share of a certain production step (Taiwan for cutting-edge wafer fabrication) or the provision of a critical input, it is highly likely that most companies based in that region will have production outages when external shocks occur. The winter storm in the United States, the lock-down measures in Malaysia and the earthquake in Taiwan already demonstrated the disruptive potential of the interplay of external shocks and geographic concentration. (See the table “External Shocks”)

As diversification is not always possible, even in the long term, semiconductor customers, such as automobile manufacturers, must prepare better for chip supply disruptions. A first step is increased transparency of the value chain but also closer relationships with suppliers and strategic inventories for production-critical chips—measures that seem to have helped Toyota keep its car production running much longer than most of its competitors despite chip shortages.[66]

Conclusion

The global semiconductor value chain is not in good health. It is highly efficient and innovative but prone to be disrupted by external shocks, and it does not adapt well to skyrocketing demand due to diverging long-term business interests of fabs and their customers. This is nothing new to the semiconductor market; in fact, this is neither the first nor the last boom-and-bust cycle.

However, chips play a much more critical role in almost every sector of today's industry than 10 or 20 years ago. Thus, it is understandable that governments ask questions[67] and wonder what role they could play to strengthen the resilience of the semiconductor value chain.[68] To that end it is crucial to recognize that merely subsidizing fabs and increasing supply chain transparency will ultimately have very little positive impact on its resilience to demand surges and external shocks.

To better cope with demand surges fabs need an economic incentive for overcapacity—not striving for 85% and higher fab utilization rates. Who pays for that if not their customers? Similarly, making the semiconductor value chain more resilient to external shocks certainly involves more transparency in a first step. But any supply chain that depends on chips, such as the automotive supply chain, will also need to invest in substantial inventory on their own and better supplier relationships.

Governments can certainly provide the right incentives to lessen the high geographic concentration, for example in cutting-edge wafer fabrication and back-end manufacturing, at least to some extent in the long term. They may also be able to push industry toward increased supply chain transparency, a better flow of information and strategic inventories. But some of the key challenges within the global semiconductor value chain come down to business models and supplier relationships that are hard to change from the outside.

External Shocks (Table)

Year	Country / City	Incident	Process step	Affect. Corp.
2020	Japan (Sakurashimo)	fire[69, 70]	Chemicals	Nittobo (ABF)
2020	Taiwan (Taoyuan City)	fire[71]	Chemicals	Unimicron
2020	Japan (Nobeoka City)	fire (3 days)[72, 73]	Fab	AKM
2020	Taiwan	one hour power outage[74, 75]	Fab	Micron
2021	Taiwan	second fire[76]	Chemicals	Unimicron
2021	Japan (Tokyo, Fukushima, Shirakawa)	earthquake & power outage[77]	Fab, Chemicals	Renesas; Shin-Etsu
2021	US / Texas	winter storm, power failure[78, 79]	Fab	Samsung, NXP, Infineon
2021	Japan (Hitachinaka)	fire[80, 81]	Fab	Renesas Naka factory
2021	Taiwan	drought, freshwater reservoir shortage[82, 83]	Fab	TSMC, UMC
2021	Taiwan	temporary power outage at Tainan Science Park plant (7 hours)[84, 85]	Fab	TSMC
2021	Malayisa	lockdown measures[86, 87]	Back-end Fab	Infineon Technologies, NXP Semiconductors, STMicroelectronics, Intel, Texas Instruments, ASE, Amkor, TFME, Hua Tian, etc.
2021	Taiwan	lockdown measures[88]	Back-end Fab	King Yuan Electronics Co

Year	Country / City	Incident	Process step	Affect. Corp.
2021	Vietnam	lockdown measures (Saigon Hi-Tech Park)[89]	Back-end Fab	Intel, Samsung
2021	China	power rationing	Front-end/ Back-end Fab[90, 91, 92]	Suzhou Keyang Semiconductor, Pegatron, Chang Wah Technology, Eson Precision Engineering, Unimicron, etc.
2021	Germany (Dresden)	power outage	Fab	Bosch, Infineon[93]
2021	Japan (Hitachinaka)	earthquake	Fab	Renesas[94]

SNV's previous publications on the semiconductor value chain

The Global Semiconductor Value Chain: A Technology Primer for Policy Makers
Jan-Peter Kleinhans and Dr. Nurzat Baisakova, October 2020

→ Our first publication on semiconductors gives an overview of the global semiconductor value chain, its interdependencies, market concentrations and choke points. The different process steps, their characteristics and the major players are depicted to understand why this value chain is highly innovative and transnational but at the same time very fragile and thus not resilient.

The lack of semiconductor manufacturing in Europe
Jan-Peter Kleinhans, April 2021

→ The lack of semiconductor manufacturing in Europe—and which conclusions to draw from this—is much discussed since the beginning of 2021 to date. Establishing cutting-edge semiconductor manufacturing is targeted in the 2030 Digital Compass decadal plan and the recently announced EU Chips Act. The paper explains why there is no business case for a 2nm fab in Europe, which in turn means that there is a real risk of wasting billions of Euros in public and private money.

Who is developing the chips of the future?
Jan-Peter Kleinhans, Pegah Maham, Julia Hess und Anna Semenova, June 2021

→ While a lot of public attention is currently focused on semiconductor manufacturing, our third analysis dives into the national research and development (R&D) power to better understand who is developing the chips of the future and where R&D cooperation already is in place. Teaming up with SNV's Data science Unit, the publication offers interactive charts combined with 5 key insights from the quantitative analysis of paper contributions to three of the leading academic semiconductor conferences (IEDM, ISSCC, VLSI) over the last 25 years.

Mapping China's semiconductor ecosystem in global context: Strategic Dimensions and Conclusions
John Lee, Mercator Institute for China Studies (MERICS) and Jan-Peter Kleinhans, June 2021

→ As the semiconductor ecosystem consists of strong interdependencies between different regions around the globe, many governments start to reassess their strategic dependencies along the value chain. A special focus in these considerations lies on China's capabilities to be competitive by their recent efforts to strongly support and innovate their local ecosystem. To better understand China's position in the value chain, the report provides an analysis by drawing conclusions across three strategic dimensions: industry competitiveness, national security and resilience. This is a joint publication with the Mercator Institute for China Studies (MERICS).

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About the Stiftung Neue Verantwortung

The Stiftung Neue Verantwortung (SNV) is an independent, non-profit think tank working at the intersection of technology and society. SNV's core method is collaborative policy development, involving experts from government, tech companies, civil society and academia to test and develop analyses with the aim of generating ideas on how governments can positively shape the technological transformation. To guarantee the independence of its work, the organization has adopted a concept of mixed funding sources that include foundations, public funds and corporate donations.

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