The global supply chain challenge

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An analysis of global supply chain vulnerabilities and how to resolve them using the example of the semiconductor industry

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- Abstract -

Introduction. In order to resolve the current vulnerabilities in global supply chains policymakers in the United States (US) and European Union (EU) are introducing initiatives and subsidy programs in an effort to partially restructure and near-/reshore supply chains. *Method*. Based on an empirical analysis of literature-based findings and categories derived from guideline-based expert interviews, this paper examines current challenges in global supply chains and how to resolve them on a policy and corporate level. In addition, as part of a case study challenges in the global semiconductor supply and value chain as well as two current legislative initiatives in the US and EU to tackle its existing vulnerabilities are analyzed: The US CHIPS and Science Act and the European Chips Act. *Results*. Among other things, global supply chains are particularly susceptible to disruptions due to a lack of diversification and a high level of geographic concentration of low value-added production and manufacturing in Southeast Asia and China. Policymakers need to incentivize supply chain diversification through near-/reshoring subsidy programs, invest in strategic stockpiling of critical goods/minerals to increase crisis preparedness and promote international collaboration with like-minded partners including in infrastructure and global manufacturing expansion, stockpiling and crisis monitoring and response. The same applies to the semiconductor industry. In general, the two Chips Acts set the right incentives and are expected to have a positive impact on supply chain resilience.

1. The global supply chain challenge

The COVID-19 pandemic revealed severe vulnerabilities in global supply chains. Pandemic-related supply chain disruptions across industries brought the issue of supply chain resilience to broad political attention in countries around the world, fueling the debate on supply dependencies (Grossmann et al. 2021), including in the United States (US) and the European Union (EU). In the second month of his presidency, US President Joe Biden issued an Executive Order on America's Supply Chains, with the goal to foster "resilient, diverse, and secure supply chains to ensure […] economic prosperity and national security" (White House a., 2021). Among other aspects, the Executive Order aimed to "revitalize and rebuild domestic manufacturing capacity," while keeping up international engagements with partners and allies. One section of this directive also specifically requested a detailed risk analysis of the semiconductor supply chain and respective policy recommendations to address these risks. The requested report, conducted by the Department of Commerce (DoC), highlighted the bottlenecks of the semiconductor supply chain. Semiconductors are a key component in the value chain of innovative digitalized and energy efficient technologies (e.g. cars, electronic devices). However, the chip industry and its widely globalized supply chain are particularly vulnerable to supply disruptions resulting from increased geopolitical tensions and/or global crises (US Department of Commerce a., 2022).

This research paper generally reflects on the current global supply chain challenge and as part of a case study examines the semiconductor supply chain issue. While the aforementioned DoC research highlights the complexities of the status quo in the global semiconductor supply chain, policymakers have become increasingly aware of the critical situation in this key industry over the past years and are now coming together with manufacturers to solve the supply chain issue (Grossmann et al. 2021). This is also reflected in previous legislative initiatives in the United States and the European Union: The US CHIPS and Science Act and the proposal for a European Chips Act by the European Commission (currently in the ordinary legislative procedure) (US Senate, 2022; Cota, 2022). Safeguarding supply chains and ensuring resilience in the event of an international conflict or crisis is a core element in both of these initiatives. It is evident that the subject now receives a prominent place on the political agenda on both ends of the Atlantic. While many companies and organizations from the semiconductor industry cherish the political momentum, other observers fear a subsidy race between the regions resulting in overcapacity and a waste of public money. Currently, there is no detailed analysis of the differences, similarities and the expected effectiveness of these programs. Thus, this research also focuses on comparing the US CHIPS and Science Act and the European Chips Act. The paper examines their scopes and aims to identify synergies.

In accordance with the outlined research objectives, the analysis follows four research questions:

RQ_1: Which challenges in global trade are currently impacting global supply chains?
RQ_2: How can the current vulnerabilities in global supply chains be resolved?
RQ_3: How can the current supply chain vulnerabilities in the semiconductor industry be resolved?
RQ_4: What are similarities, differences, and synergies of the US CHIPS and Science Act and the European Chips Act?

The following chapter will focus on challenges in global trade that impact supply chains, followed by an assessment of supply chain resilience-increasing approaches in the political arena and on a corporate level. The third chapter reflects on the semiconductor supply chain and policy initiatives in the US and Europe (the Chips Acts), which aim to strengthen the industry and its manufacturing landscape, thus increasing supply chain resilience. Here the literature-based analysis is being complemented with the results of six expert interviews, which were conducted as part of the research. The paper is concluded with a comparison of both semiconductor subsidy programs followed by a recap of the research findings.

2. Global supply chains: Structure, issues and solutions

This chapter reflects on the evolution of transnational supply chains, followed by a summary of challenges in global trade with an impact on supply networks. It is concluded with an assessment of supply chain resilience-increasing initiatives and strategies in the political arena and on a corporate level.

2.1 The transnationalization of supply chains

In his book "The Wealth of Nations", economist and founder of economic liberalism, Adam Smith (1776) describes free trade and the division of labor as a prerequisite for economic growth and prosperity (Smith, 1776). According to Smith, the specialization principle[1] enables significant efficiency improvements and cost reduction (ibid.). Today, this fundamental concept is rooted in the global economic system (Fengru & Guitang, 2019).

The idea of the liberalization of trade and free market access within a rules-based international order particularly gained momentum in the late 20th century. Since the 1970s a neoliberal order with free markets, cross-border capital flow and trade agreements has manifested in international trade (Moore et al., 2011). While tariff barriers have decreased, subsidies for Foreign Direct Investments (FDIs) have increased (Free & Hecimovic, 2021). Protectionist measures were effectively challenged by transnational institutions such as the World Bank, the World Monetary Fund (IWF), the World Trade Organization (WTO), and the United Nations (UN) (Chorev, 2005). An entangled global trade system built on the international division of labor evolved with transnational corporations sourcing, producing and partnering in countries around the world (Navarro, 2007). Consequently, transnational production networks were quickly established across industries with low value-added production being offshored to the global south – in particular to Southeast Asia and China – to maximize efficiency and minimize cost due to low input and labor costs in the region (Free & Hecimovic, 2021). While most of the high value-added labor (Research & Development (R&D); Design) continued to be conducted in the global north, this resulted in a regional specialization and geographic concentration of low value-added labor (Alicke & Strigel, 2020). The countries of this region developed a comparative advantage in manufacturing and production (Kreps et al., 2022). According to an analysis from 2021 by the Asian Development Bank, from 2000 until 2019 the linkages in global value chains surged, with forward linkages increasing eleven times and backward linkages nine times (Mariasingham et al., 2021). In textiles and textile manufacturing, next to China Bangladesh, Pakistan and Cambodia are among the most frequent manufacturing partners for transnational corporations (World Trade Organization, 2021). In exports of electronics components China is by far in the leading position. Vietnam, Malaysia, Thailand, the Philippines and Indonesia on the other hand are on the rise in assembly and testing (S&P Global, 2021). Since the 1980s, Taiwan[2] and South Korea have also become thriving forces in global manufacturing in particular for the electronics and microelectronics value chain, but unlike their Asian competitors, with a high level of expertise in leading edge technology (ibid.).

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[1] Division of labor and specialization principle: "On a macroeconomic/global level, specialization and the division of labor can enable increased productivity as different parties focus on different steps in the production process. The result is increased output, cost reduction and an absolute advantage" (Littek, 2001, 8221).

[2] The Taiwan Semiconductor Manufacturing Company (TSMC) is considered the leading silicon semiconductor foundry in the world and a key supplier to corporations across the entire electronics industry (TSMC, 2022).

Increased geopolitical (trade) tensions and other global crises in recent years have revealed that these long, complex and geographically concentrated global value and supply chains can be highly susceptible to external shocks and are continuously exposed to disruptions (Grossman et al., 2021). As a result, among policymakers on the political stage, the trend toward the restructuring of supply chains is evolving and reshoring subsidy programs are being introduced (US Chamber of Commerce, 2021).

2.2 Reflecting on challenges in global trade with an impact on supply chains

This section reflects on three main challenges in global trade that affect supply chains and form one overarching supply chain challenge.

(1) Global warming: Climate change is quickly advancing and extreme weather conditions are putting severe strain on livelihoods and businesses around the world. In mitigating global warming decarbonization is key. Therefore, since industrial and trade processes are among the major drivers of CO_2 emissions, the global economy must be transformed into a net-zero economy (International Energy Agency, 2022). Initiatives such as “Race to Zero” with its Climate Ambition Alliance that comprises of 120 member countries – initiated by the UN – have been set up to pursue a cross-border cooperation in decarbonizing the global economy (COP25, 2022).

The decarbonization of supply chains is a core element within this transformation process (Scope 3). This ranges from raw material supply to logistics processes and product delivery (Ho, 2009). According to an analysis by the World Economic Forum (WEF) (2021), eight supply chains – “food, construction, fashion, fast-moving consumer goods, electronics, automotive, professional services and freight”- represent 50 percent of global supply chain emissions (Topping & Munoz, 2021). The WEF study also states that a decarbonized supply chain can multiply a corporation’s climate impact and comes with “limited additional costs” for corporations and even less for end-consumers (ibid.). In order to achieve this corporations must conduct a full assessment of “emissions and climate impact across the supply chain” and the entire supplier network (Herweijer & Loppa, 2020). However, this is a highly complex endeavor due to limited transparency within supply chains. Companies usually lack the necessary data to assess climate impact beyond tier 1 and 2 suppliers (ibid.).

In addition to the need for decarbonization, climate adaptation in the supply chain will be required since the current state of global warming cannot be reversed. Even in the best case scenario, if the world community is able to limit temperature rise to 1.5°C, there will be – and already are – environmental changes. Therefore, based on thorough risk analysis, supply chains must be organized in a more resilient way in order to sustain in an environment of extreme weather conditions (Cameron, 2019).

(2) Increased global conflicts and rising inflation rate: In addition to the economic fallout as a result of the COVID-19 pandemic, the war in Ukraine is putting severe strain on the global economy, resulting in an all-time high of global inflation since 1981 of more than 8 percent in countries across the world, including the United States and the EU (Desilver, 2022). According to the World Bank, global economic growth declined from 5.7 percent in 2021 to 2.2 percent in 2022 year over year (The World Bank, 2022). The war additionally impaired global supply chains, in particular those in the energy and food sector. It also further strained the semiconductor supply chain, which was yet to recover from pandemic-related disruptions and an ongoing imbalance between demand and supply (Clark & Jones, 2022). In a scenario analysis by Accenture, the impact of inflation on supply chains is analyzed for four key commodities (logistics, material shortages, energy prices, labor and skill shortages) (Ollagnier, 2022). Continuous supply chain disruptions in key commodities and energy prices, according to the analysis, are expected to further increase through gas and oil embargos on Russia. Furthermore, when the war carries on into 2023 global inflation will remain on high levels throughout the calendar year, additionally increasing commodity prices, which will negatively affect the global growth rate. The recovery is expected to take up to two years with additional costs being forecasted to mount to a minimum of 920 billion USD (ibid.).

(3) Decoupling tendencies and trade conflicts (with China). Growing unilateralism in global trade, decoupling tendencies and trade tensions with China (in particular with the US) continuously challenge the international trade system. In light of the development of the Chinese economy in recent years, Beijing's ambition and practices have put the economic ties between China and the West increasingly into question. China quickly manifested its dominance in global manufacturing by thoroughly leveraging its economies of scale and becoming a key partner and supplier for transnational corporations. It now accounts for almost 30 percent of the global manufacturing output (United Nations Statistics Division, 2022), which equally accounts for approximately 30 percent of the country's economic output (World Economic Forum, 2020). China is now the second largest economy in the world with a Gross Domestic Product (GDP) of 17.73 billion USD in 2021 and an ascending trend in the mid and late 2020s to become the world's largest economy, replacing the United States on the first rank (The World Bank, 2021). As part of this ascendance, the Chinese market and the markets in North America and Europe have become coupled and strongly intertwined (Aspen Institute, 2021), which is also reflected in the global supply chain system (Chamber of Commerce, 2021).

Beijing, as for instance stated by the US Chamber of Commerce (2021), has been following its economic ambition with an "increasingly coercive use of economic statecraft" (ibid.). By limiting market access for foreign companies and investors through joint venture requirements and by systematically favoring domestic corporations in procurement procedures (Kratz & Oertl, 2021) it is continuously distorting the international rules-based economic order (Chimits, 2021). Chinese investors and firms, on the other hand, benefit from open market conditions, leading to increased Chinese FDIs abroad, while expanding economies of scale at home (ibid.). This provides China with significant resources (for instance, according to a Harvard Business Review analysis, funds up to 500 billion USD) to further pursue its “Made in China 2025”[3] initiative, which aims to install a state-led technological leadership to minimize dependencies on foreign technologies like microelectronics and ultimately achieve self-sufficiency in the long-term (Chimits, 2021; Chan, 2020). This is also reflected in the Chinese government’s dual circulation strategy, which was introduced in early 2020 (Tran, 2022). This policy promotes international market engagement (capital, financial, and technological) where beneficial to China, while at the same time strengthening domestic capabilities to avoid dependencies in international trade due to macroeconomic and geopolitical uncertainties (Blanchette & Polk, 2020). The concept of dual circulation was embedded in the Constitution of the People’s Republic of China with the goal to ensure prosperity for all Chinese people (Tran, 2022).

In addition, Western partners have continuously raised security concerns about China’s increased “predatory lending and business practices, systematic theft of intellectual property, and brazen cyber intrusions” (Federal Bureau of Investigation, 2022). Another concern is the issue of supply chain resilience and security (ibid.); particularly in light of the zero-COVID-19 policy imposed by the Chinese government, which continuously impaired the functionality of global supply chains (Morrison et al., 2022).

The security threats and the lack of reciprocity have been intensively deteriorating the US-China relationship and fueling trade tensions between both countries (US Chamber of Commerce, 2021) since the mid/late 2010s. In addition to the introduction of export control regimes, which in early 2020 amounted to 335 billion USD on Chinese goods[4] (Reyes-Heroles et al., 2021), the idea of a “large-scale US-China decoupling” has manifested in the political debate (US Chamber of Commerce, 2021). However, at this high level of market engagement, a hard decoupling scenario would come at a high cost due to China’s central position in global value and supply chains and end-markets. According to an analysis by the US Chamber of Commerce, for the US, this would result in an unprecedented loss in output of up to 1 trillion USD within the next ten years (US Chamber of Commerce, 2021), which in general calls into question the feasibility of a hard decoupling scenario (ibid.).

The Center for Strategic & International Studies (CSIS) Economics Program states in a report that, within these new geopolitical and economic realities in which China is considered “as a strategic competitor […], certain sensitive activities” (Segal et al., 2021) should be implemented in response to Chinese market distortions and to counter potential risks/threats (e.g. increased (cyber-)security efforts

[3] At the same time, the country is further strengthening its position in global logistics chains with its *Belt and Road Initiative* (BIR), which aims to re-establish the Silk Road (Organisation for Economic Cooperation and Development, 2018).
[4] These were countered by China through 120 billion USD tariffs on US goods (Reyes-Heroles et al., 2021).

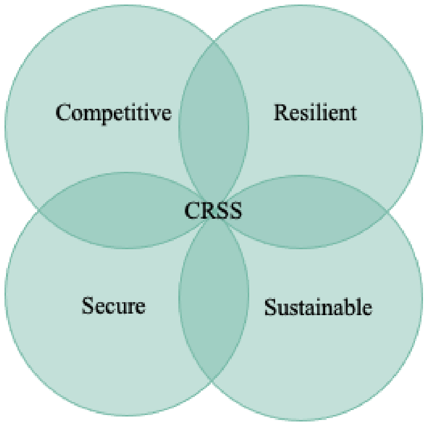
to counter IP theft; increased supply chain security/resilience through supply; and value chain diversification to reduce asymmetric supply dependencies on Chinese goods). This, however, must follow a detailed analytical decision framework, which allows for a holistic risk analysis (e.g. political, economic, security), including the definition of objectives and the assessment of effectiveness and compliance/compatibility with domestic and international laws and rules. In general, such measures should not curb market engagement, but increase security (ibid.).

These three major challenges all – in one way or another – affect global supply and value chains (Knizek, 2022). The transnationalization of the supply chain system has led to wide-ranging efficiency improvements (Free & Hecimovic, 2021). However, as singular regions (China and Southeast Asia) turned into production hubs through regional specialization and thus also major global logistics and supply chain anchors (Richter, 2020), supply chains are easily exposed to single points of failure, resulting in a lack of robustness and increased susceptibility to (aggregate) shocks (Jiang et al., 2022).

2.3 What global supply chains need

Both businesses and policymakers need to take action and collaborate closely to tackle vulnerabilities in global supply chains. According to Tyson and Zysman (2021) futureproof supply chains have to be competitive, resilient, secure, and sustainable (CRSS) (see *Illustration 1.*):

Illustration 1. CRSS[5] supply chains concept



Source: Own illustration in accordance with Tyson & Zysman (2021)

The authors highlight that these four elements – competitiveness, resilience, security, and sustainability – must form the basis for a multifaceted supply chain policy strategy. In order to increase resilience and

[5] Tyson and Zysman (2021) developed the CRSS concept using the example of the semiconductor industry. However, it can also be applied to other industries and corresponds to the major challenges in global trade with an impact on global supply chains. Therefore, it is being used as the conceptual basis for this analysis.

security, policymakers need to provide trade and investment subsidies to support the private sector in balancing the high costs connected to supply chain diversification and restructuring. At the same time, competitive market conditions must be maintained to avoid unnatural imbalances and excessive market power of singular industries/market segments. In addition, "the supply needs to be sustainable," considering the required environmental and energy costs. In order to fulfill these four dimensions, international (bilateral and multilateral) cooperation with like-minded partners but also industries is required to create an appropriate global framework for CRSS supply chains (Tyson & Zysman, 2021).

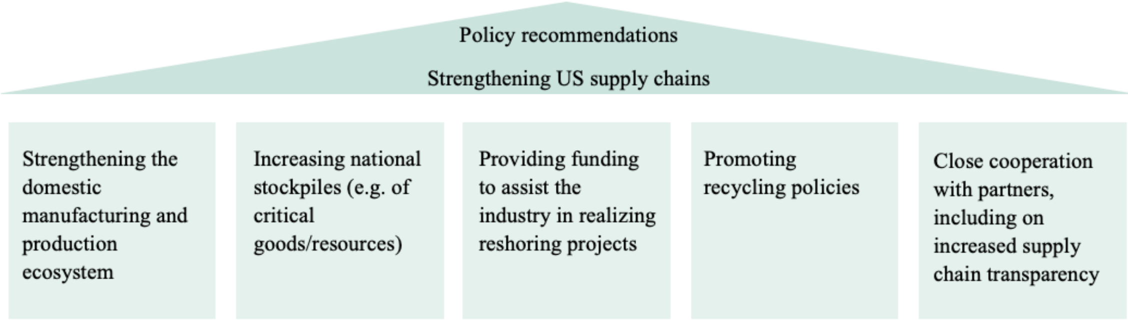
2.3.1 The supply chain challenge on the political agenda: Solutions and initiatives in the US and EU

In light of recent challenges, policymakers in the US and Europe are increasingly recognizing the need for action to secure critical supply in case of a crisis by partially restructuring the current supply chain system (White House, 2021). The following section of this paper discusses options to mitigate supply chain vulnerabilities through policy initiatives. The focus of this study lies on the analytical comparison of legislative initiatives for supply chain resilience in the United States and the European Union. In both regions these efforts were specifically initially triggered by the COVID-19 pandemic, which revealed vulnerabilities in global supply chains.

(1) United States: In the United States several legislative initiatives were released throughout the pandemic to strengthen the economy and particularly vulnerable supply chains. This included the CARES Act from March 2020, a funding program and a bipartisan COVID-19 relief bill of 2 trillion USD, which also targeted medical supply chains and air cargo (Forde, 2020). In January 2021, one week into his presidency, President Joe Biden signed an Executive Order to address vulnerabilities in US supply chains and to increase resilience to maintain "economic prosperity and national security" (White House a., 2021). Among other things, the Executive Order declared the intention to promote reshoring activities and the strengthening of domestic production (ibid.).

In addition, a 100-Day report by several governmental agencies in cooperation with the private sector was launched to investigate the status, vulnerabilities and risks of US supply chains in four key industries (semiconductors, large capacity batteries, pharmaceuticals, critical minerals and materials) (White House b., 2021). The report was issued in June 2021, and identified that US supply chains are particularly intertwined with China and the EU. It also derived a list of policy recommendations to decrease supply chain vulnerabilities in affected industries (see *Illustration 2.*):

Illustration 2. 100-Day report policy recommendations in the US for more CRSS supply chains



Source: Own illustration in accordance with White House b. (2021)

Following this analysis, Congress passed the Innovation and Competition Act, which alongside strengthening technological development and securing economic prosperity was also specifically aimed at introducing a supply chain resiliency and crisis response program across industries and in collaboration with transatlantic allies (US Congress, 2021). Furthermore, the Biden administration installed a Supply Chain Disruption Task Force, which is now working on a government level to increase supply chain resilience based on the findings of the 100-Day report (White House b., 2021). In addition, the administration plans to launch a supply chain resiliency forum with key partners and representatives of the private sector for a collective assessment of current fragilities within the global supply chain system and the identification of respective remedies (ibid.).

(2) European Union: In the European Union, the COVID-19 pandemic also led to increased political attention on supply chain vulnerabilities. In 2020 the European Commission launched a Trade Policy Review in light of the pandemic and also analyzed the current state of supply chains in the EU (European Parliament a., 2021). In the analysis, the Commission defined supply chains as a fundamental strategic pillar for Europe's Open Strategic Autonomy (OSA), which constitutes the compass of European Foreign Policy and is rooted in the overarching European Union Global Strategy from 2016 (Borrell, 2020). OSA entails three key principles (see *Illustration 3.*) (European Commission a., 2021):

Illustration 3. Key principles of the EU's Open Strategic Autonomy concept

Source: Own illustration in accordance with European Commission a. (2021)

The goal is to be able to pursue the EU's own course independently, but under the umbrella of multilateralism. It is about "accepting and managing […] interdependence in the best possible way," while acting and partnering in a multilateral environment (ibid.). This also applies to global supply chains: The OSA framework aims to maintain transnational supply chain networks within the globalized economic world order, while increasing capacity to strengthen autonomy where necessary (Dame, 2022).

Following this principle, as part of a report on strategic dependencies and capabilities, the Commission formulated a proposal for tackling the current fragilities in supply chains. The analysis revealed that out of 5,000 import products, 137 – especially raw and processed materials as well as chemicals – are part of a sensitive ecosystem with a high level of dependency in particular on China, Vietnam and Brazil (European Commission b., 2021). It also identified dependencies in the technological realm in the case of both semiconductors and cloud and edge technologies (ibid.). In general, to overcome the resulting vulnerabilities, the Commission pointed out the need for increased transparency and called for more sustainable supply chains as they "have proven to be more resilient" (European Commission c., 2021). Furthermore, it aims to diversify import sources to avoid single points of failure in light of increasing geopolitical tensions. However, the Commission also stated that the execution of sourcing diversification must be conducted on the corporate level (ibid.).

In order to support this, the EU aims to apply policy tools to obtain access to new and existing global markets as well as "ensuring an undistorted functioning of existing supply chains, based on a stable rules-based trading framework" (European Commission b., 2021). At the same time, it aims to reduce strategic dependencies by increasing domestic production to ensure critical supply and strengthen crisis preparedness at home. As this is not feasible in all areas, the Commission recommends to additionally invest in strategic stockpiling of critical goods (Bencharif, 2022). This approach is also reflected in the Commission's update of the New Industrial Strategy for Europe and a corresponding resolution of the European Parliament from November 2020. In the resolution the Parliament called upon corporations to increase sustainability in their value and supply chains and where possible, decrease their length to enhance resilience. This aims for a shift in supply chain concentration and a diversification by bringing them to the European continent (European Parliament b., 2020).

Lastly, the Commission highlighted the importance of fostering partnerships with like-minded partners and of promoting global market engagement (European Commission b., 2021). At the same time, it pointed out the necessity to enhance international trade cooperation and enforce existing trade agreements to overcome distortions and level the playing field to strengthen fair competition across markets. In the matter of critical supply chains, according to the EU Commission, a coordination mechanism for a common risk management approach should be introduced (ibid.).

(3) Creating CRSS supply chains together: The policy approaches in the US and the EU to increase supply chain resilience reflect a common understanding in terms of actions to overcome current vulnerabilities. On both sides of the Atlantic, policymakers see the need for increased diversification and transparency along supply chains for which close cooperation with trade partners is essential, as well as the benefits of strategic stockpiling of critical goods to secure supply in case of disruptions.

In 2021, the US and EU established a new transatlantic platform with the Trade and Technology Council (TTC). The council was introduced to foster transatlantic trade and technology cooperation between the US and EU[6] and to jointly resolve current trade challenges. This includes dealing with issues in the global supply chain and how to tackle them as key strategic partners (US Department of State, 2021) for the green and digital transition (European Commission d., 2021). It aims to increase supply chain transparency, map sectoral capabilities and enhance information exchange with a focus on the semiconductor, energy, pharmaceutical and critical materials industries (ibid.). In this regard, one of the Council's 10 dedicated working groups collaborates on areas of supply chain cooperation (see *Table1.*):

Table 1. Areas of collaboration TTC supply chain working group

TTC Supply Chain Working Group	Promoting reliable sources in supply chain cooperation
	Mitigating the impact of supply chain disruptions, e.g. through external shocks
	Implementing joint actions to recognize and mitigate risks across critical supply chains/industries, including recognizing the importance of addressing security risks from high-risk vendors and increasing predictability
	Avoiding unnecessary trade barriers
	Cooperating in supply chain diversification, including the launch of a dedicated taskforce on public financing for secure and resilient connectivity as well as information and communication technology and services (ICTS) supply chains in third countries, to promote trusting suppliers

Source: US Department of Commerce b. (2022)

In addition to the bilateral transatlantic cooperation, the creation of "open, fair, resilient and sustainable supply chains" also became a major target on the multilateral stage within the G7 format. According to an analysis by Chatham House, since the G7 account for 33 percent of global exports and 36 percent of global imports, increased supply chain cooperation could already be beneficial for enhancing resilience as it would provide opportunity for action in initiating a joint coordination and early warning mechanism which could later be contemplated with other measures including joint strategic stockpiling chains (Schneider-Petsinger, 2022). G7 policymakers should also concentrate on strategically relevant sectors in the long-term (critical minerals and raw materials, renewable energy,

[6] e.g. "increasing transatlantic trade and investment in products and services of emerging technology, strengthening technological and industrial leadership, boosting innovation, and protecting and promoting critical and emerging technologies and infrastructure." (United States Trade Representative, 2022)

solar panels and semiconductors). As part of these efforts, a close collaboration with the private sector is needed, since corporations are executing resilience-increasing measures and benefit from analytical synergies; e.g. funding for increased domestic production (Handfield, 2022). Furthermore, the launch of the G7 initiative “Partnership for Global Infrastructure and Investment (PGII),” which aims to not only strengthen the global economy by supporting infrastructure projects in developing economies, but also to diversify and enhance the current supply chain system and to make it more sustainable, is a step in the right direction (Schneider-Petsinger, 2022).

However, in order to sustainably improve resilience in the global supply chain system, partnerships need to extend beyond the G7 group. Due to the intensification of geopolitical trade tensions, additional efforts must focus on attracting other key allies, for instance the countries of the Indo-Pacific Economic Framework for Prosperity (IPEF), e.g. India, South Korea, Australia and New Zealand (ibid.). In addition, current distortions of the international rules-based order e.g. through (non)-tariff trade barriers and export regimes or other unfair market restrictions, coupled with the dysfunctionality of the WTO Dispute Settlement Mechanism (DSM), also increase the fragility of global supply chains and must be tackled on the multilateral stage through a holistic reform of the WTO and its processes (Alicke & Strigel, 2020).

2.3.2 Supply chain management in business: Resilience vs. efficiency

The execution of supply chain resilience-increasing measures is carried out on the corporate level. Therefore, policymakers can provide the appropriate framework and support with subsidy programs, but the strategic implementation lies within the scope of individual businesses. Improvements are needed in three key areas to counter supply chain vulnerabilities:

(1) Production network – Geographic concentration of low value-added production: As outlined in Chapter 2.1, offshoring of mass production to China and Southeast Asia led to a geographic concentration, which left global supply chains vulnerable to one singular point of failure. Businesses should maintain their activities in the region, but must take action to diversify their production landscape beyond this regional focus by (Iakovou & White, 2020):

- expanding their network of production partners or their own production facilities to other parts of the world.
- establishing facilities in their home region and/or in partner countries to ensure critical supply (which will require governmental funding/subsidies due to higher cost levels).

(2) Supply chain management – Lack of agility, flexibility, sustainability and resilience: In order to be able to respond to the volatile market environment with fluctuations and uncertainty, including reduced production cycles or total lead times and changes in delivery, flexible and agile supply chains are needed (Bui et al., 2021). However, flexibility and agility have been decreasing since the 1990s, when

transnational corporations were increasingly driving supply chain optimization by pushing for price minimization in input factors to maximize cost-effectiveness (Simmons et al., 2022). This is reflected in the implementation of the "Just-in-Time" (JIT) strategy, which became a common practice by keeping inventories at low levels and focusing on a small set of suppliers (Ye et al., 2021). The JIT approach "facilitates delivering the right product at the right time in the right quantity" (ibid.), which allows for a high level of efficacy. It is in particular frequently used in the automotive industry. However, these zero-inventory approaches leave supply chains susceptible to disruptions, since the limited available inventory buffer is quickly depleted in case of interruptions or a sudden rise in demand (Althaf & Babbitt, 2020). Instead, sourcing flexibility through a diversified supplier base, operating system/production flexibility, and distribution flexibility (including through sufficient inventory buffers and a diversified supplier and logistics network) are needed to ensure supply to customers even in the case of unforeseen events or errors (ibid.; Jiang et al., 2021). In addition, businesses must take action to increase supply chain sustainability to mitigate global warming, which can also increase resilience (Cameron, 2019). According to a WEF analysis from 2021, such sustainability efforts would come with limited additional costs that would be outweighed by the long-term benefit of increased resilience through responsible business practices and shortened supply chains (Topping & Munoz, 2021).

This illustrates that agility and flexibility, but also sustainability, are closely connected to a resilient supply chain. The supply chain recovery speed in case of disruptions is a key aspect in the assessment of resilience. According to Iakovou and White (2020), resilience consists of five fundamental elements: "plan, detect, respond, recover to the pre-disruption state and overarching continual learning" (Iakovou & White, 2020). This requires a high level of agility, sourcing, operating and distribution flexibility, supply chain end-to-end visibility, and transparency along the supply network, which can at least partially be achieved through smart data analytics (including real-time-data) and continuous exchange between the private and public sector (ibid.).

In general, the challenge is to avoid inefficiencies and overly large investments in stock, while organizing the supply chain in a way to be able to secure supply even in case of disruptions (West, 2022). According to Iakovou and White, only a data-driven approach (e.g. data-driven rebalancing of inventories based on real-time data) can make a combination of efficiency and resilience possible (Iakovou & White, 2020). Corporations need innovative solutions and (predictive) data analytics methods (machine learning, mathematics, statistics) for various use cases to better monitor, plan and manage their supply chains (Menden, 2022). In addition, in order to enhance existing supply chain data structures, Bechtsis et al. (2021) propose an "all-encompassing industry-agnostic generalized framework based on data sharing and data monetization." (ibid) The authors suggest a systematic collection of supply chain and supply chain ecosystem data (public-, governmental-, inter-organizational-, supply chain stakeholder-data), transferred and secured through blockchain technology, processed through artificial intelligence (AI) analytics and shared/acquired based on a data monetization approach (ibid.). While this may provide the basis for a thorough monitoring mechanism, for companies it bears the threat of trade and supply chain confidentiality violations. Therefore, if such corporate data is shared, clear boundary conditions need to be defined in advance (BDI, 2022).

3. Case study: The supply chain challenge in the semiconductor industry

In 2020 as a result of the COVID-19 pandemic, demand for semiconductor solutions accelerated, particularly in the electronics and power sectors, when global lockdowns required new remote/home working concepts and thus additional equipment. According to McKinsey Research, this resulted in a surge in shipments by 40 percent from approx. 73 billion in the first quarter of calendar year 2020 to about 102 billion in the third quarter of calendar year 2021 (Badlam et al., 2022).

However, in light of this steep surge in demand coupled with demand forecast errors[7] (bullwhip effect) and order cancellations by user industries (in particular from OEMs[8]) which initially predicted that demand would drop, low inventory levels and insufficient manufacturing capacity made it impossible for chip makers to quickly adapt to the changing market environment (JP Morgan, 2022). A perfect storm of pandemic-related supply chain disruptions, extreme weather conditions and increasing geopolitical tensions further strained global supply chains and also put additional pressure on the semiconductor supply capability. Once the limited inventory was depleted and lead times for components increased from around "10 weeks to 20 weeks for microprocessors, memory chips, power management and analogue chips" (European Commission, 2022), the imbalance between supply and demand manifested. Since semiconductors are a key component in the value chain of digitalized technologies (e.g. cars, electronic devices), the shortage also severely impacted user industries (US Department of Commerce, 2022).

In general, the semiconductor industry is characterized by its regional specialization and division of labor. Its long and complex value chain is based on inter- and intra-regional collaboration; this enables high efficiency levels, but lacks resilience due to geographic concentration (European Commission, 2022). According to an analysis by the US Semiconductor Industry Association and the Boston Consulting Group, the semiconductor manufacturing process bears the main risk potential within the value chain. Leading chip producers in the US and Europe often outsource manufacturing capacity including for key materials such as silicon wafers to China and East Asia. Seventy-five percent

[7] Triggered by aggregate shocks such as the COVID-19 pandemic, demand forecast errors on the retailer side can occur, which impact order books along entire supply chains since inventory and production plans are adjusted accordingly. The lack of supply chain transparency is one major root cause of the bullwhip effect, which continuously poses a challenge to businesses across industries as it impairs the entire supply chain and can lead to either long-term shortages or overcapacity (European Commission, 2022).
[8] Original Equipment Manufacturer = Car manufacturers

of global chip manufacturing including front-end (silicon wafer foundries) and back-end production (assembly & testing) takes place in this region. In the case of front-end manufacturing for instance, the leading edge fabrication of nodes below 10 nanometers in wafer manufacturing can only be provided by manufacturing companies in Taiwan (92 percent) and South Korea (8 percent). The region is, however, particularly exposed to seismic disruptions and therefore susceptible to supply chain interruptions. In addition, it is subject to geopolitical tensions due to China's claim over Taiwan, which leads to a high level of uncertainty (Varas et al., 2021).

Due to the importance of semiconductors for digital and energy-efficient technologies, the vulnerabilities in the semiconductor supply chain system are continuously receiving broad attention from policymakers in the US and EU. As a result, US President Joe Biden specifically requested a detailed risk analysis of the semiconductor supply chain by the Department of Commerce (DoC) in his Executive Order on the state of US supply chains which was issued in January 2022 (see Chapter 2.3.1). The report highlighted the chip bottlenecks (US Department of Commerce a., 2022) and that economic growth in the United States was curbed nearly by a quarter of a trillion USD in 2021 due to the shortage (Badlam et al., 2022). On the European side, in November 2021, the European Parliament issued the aforementioned analysis of the status of European supply chains, also addressing the semiconductor shortage and need for increased resilience (see Chapter 2.3.1) (Szczepański, 2021). On both sides of the Atlantic, this led to legislative initiatives in an effort to tackle the semiconductor supply chain issue, The US CHIPS and Science Act and the European Chips Act, both of which are subjects of this analysis.

(1) US CHIPS and Science Act: On 9 August 2022, the US CHIPS and Science Act was signed into law after passing through Congress with bipartisan support. The legislation provides 280 billion USD in investment over the next ten years[9] (US Senate, 2022) and consists of two parts (see *Illustration 4.*):

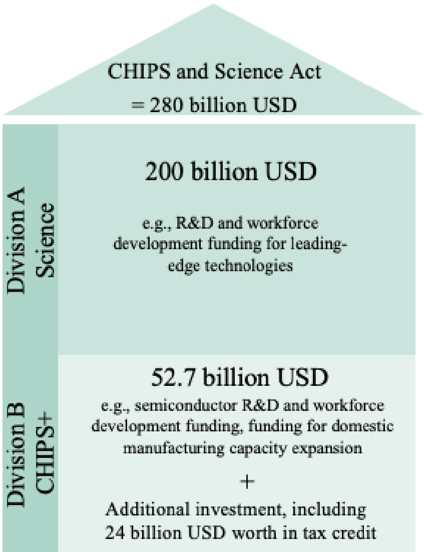
1) The CHIPS+ section (Division A) specifically focuses on the US semiconductor industry and aims to "bolster US leadership in semiconductors," as stated by the White House (White House c., 2022). Therefore, the act provides funding to diminish US dependency on foreign-manufactured chips and thus increase supply chain resilience. It creates incentives for chip makers to further develop the semiconductor manufacturing landscape in the United States and to broaden capacity domestically (US Senate, 2022). At the same time, the legislation supports semiconductor R&D and workforce development.

To this end, 52.7 billion USD are being allocated for the CHIPS+ section. Thirty-nine billion USD will be provided as manufacturing incentives, including 2 billion USD for legacy chips for automobile and defense systems. For R&D and workforce development, 13.2 billion USD will be

[9] The deployment criteria of the funding are currently still being defined.

deployed. An additional 500 million USD are being allocated for semiconductor supply chain activities and international information communications technology security (ibid.; White House c., 2022). In addition to the 52.7 billion USD, chip makers can receive a 25 percent advanced manufacturing investment tax credit for investments in semiconductor manufacturing and processing equipment[10] (worth 24 billion USD in tax credits for chip production) (Kersten et al., 2022).

Illustration 4. Overview of the US CHIPS and Science Act Divisions



Source: Own illustration in accordance with US Senate (2022)

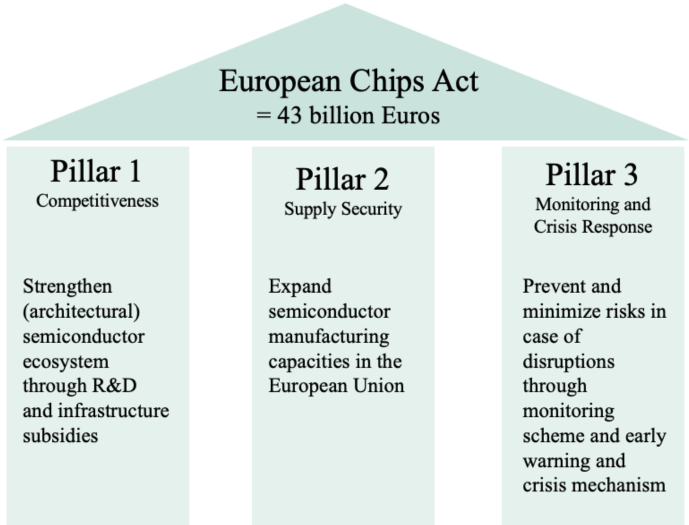
2) The second and bigger part of the bill supports research and development (R&D) in the US and pushes for innovation in the fields of leading-edge technologies, such as quantum computing, AI, energy efficiency, and nanotechnology (ibid.). In addition, it aims to attract STEM-talent, both to ensure US competitiveness and protect national security in the long run (US Senate, 2022). Therefore, 200 billion USD and thus the majority of the funding of the program will be allocated for R&D and commercialization to ensure future global US technological leadership (ibid.).

(3) European Chips Act: On 8 February 2022, the European Commission published its proposal for a European Chips Act. The subsidy program targets the microelectronics industry with a public investment volume of 43 billion Euros for (see *Illustration 5.*) support of R&D in microelectronics and increased attractiveness for STEM talent, an expansion of the European semiconductor manufacturing landscape to decrease outsourcing dependency on China and Southeast Asia, and a strengthened European semiconductor ecosystem and thus increased supply chain resilience (Harvard Kennedy

[10] Building new semiconductor factories can take up to 20 billion USD, for which the allocated governmental funding would not be sufficient and is therefore complemented with tax credits (Kersten et al., 2022).

School, 2022). The European Chips Act focuses on three key strategic pillars that, according to the European Commission, require governmental support:

Illustration 5. Overview of the European Chips Act and its three strategic pillars



Source: Own illustration in accordance with European Commission e. (2022)

1) Competitiveness: Pillar 1 of the European Chips Act focuses on strengthening the European semiconductor (architecture) ecosystem through coordinated research and development efforts and by fostering "advanced large-scale design capacities" to support innovation in leading edge semiconductor technology (Pioch, 2022). Therefore, an additional investment of 3.3 billion Euros will be provided for two current European subsidy programs; 1.65 billion Euros for the "Horizon Europe[11]" program and 1.65 billion Euros for the "Digital Europe[12]" program. Furthermore, the legislation will allocate 2 billion Euros for smaller innovative companies and start-ups to increase the EU's attractiveness for these players, and at the same time to address the current skill/labor shortage (European Commission e., 2022).

2) Supply Security: Pillar 2 focuses on strengthening the European semiconductor manufacturing landscape to secure supply and foster the semiconductor ecosystem by attracting internationally leading semiconductor corporations. Therefore, the European Chips Act provides funding for chip makers to

[11] Horizon Europe is the EU's key funding program for research and innovation with an investment volume of 95.5 billion Euros (European Commission b., 2022).
[12] "The Digital Europe Programme provides funding for projects in five crucial areas: supercomputing; artificial intelligence Cybersecurity; advanced digital skills; ensuring the wide use of digital technologies across the economy and society. The program is designed to bridge the gap between digital technology research and market deployment." The program is set up until 2027 with a total budget of 7.59 billion Euros (European Commission c., 2022)

establish "first of a kind"[13] production facilities. This implies (a) Integrated Production Facilities for the design and front-end and/or back-end manufacturing of semiconductor components for the European market and (b) Open EU Foundries for manufacturing of semiconductor components that are (at least partially) designed by other companies (European Commission e., 2022). When building a new factory, funding recipients would receive either the Integrated Production Facility or Open EU Foundries label. By creating this incentive, the EU aims to increase its current manufacturing capacity of nine percent global production share to 20 percent by 2030 (ibid.) and to create the manufacturing basis to bring "the next generation of chips[14]" to Europe (Pioch, 2022).

3) Monitoring and crisis response: Pillar 3 focuses on crisis response and increased disruption resilience through monitoring. The EU Commission plans to establish a coordination mechanism among member states and the semiconductor industry in case of "serious disruptions." According to the Commission, this would allow for a joint assessment of the seriousness of disruptions in the supply of semiconductors and whether it can result in significant shortages in the EU which would impact critical sectors. Upon the activation of the crisis stage, emergency measures would be implemented, which are defined as part of an "emergency toolbox" in the bill proposal (European Commission e., 2022). This includes (see *Table 2.*):

Table 2. Proposed static measures in the European Chips Act emergency toolbox (pillar 3)

Emergency toolbox	(Mandatory) Information requests about production, capacities, current primary disruptions, and other data to assess the seriousness of the disruption
	Priority rated orders[15], which would imply "enforceable obligation to accept and prioritize an order of crisis-relevant products"
	Common purchasing of crisis-relevant products to ensure the allocation of resources to critical sectors for companies along the semiconductor value chain
	Export authorizations to increase transparency of production, deliveries and supply chains, and to secure supply to the EU

Source: European Commission e. (2022)

[13] Definition of first-of-a-kind facility: "The Chips Act provides for a definition of such a "first-of-a-kind" facility. According to Article 2 (10), this would be defined as "an industrial facility capable of semiconductor manufacturing, including front-end or back-end, or both, that is not substantively already present or committed to be built within the Union, for instance with regard to the technology node, substrate material such as silicon carbide and gallium nitride and other product innovation that can offer better performance, process innovation or energy and environmental performance. In essence, to be recognised as first-of-a-kind, a facility would need to offer a dimension of innovation that is not yet present in the EU." (European Commission, 2020)

[14] According to the Commission, this is not limited to node size or specific materials, but also implies innovation in power semiconductor applications including the use of new wide bandgap technology (the use of silicon carbide (SiC) and gallium nitride (GaN)), which "allow for greater power efficiency, smaller size, lighter weight, lower overall cost – or all of these together" (Infineon Technologies AG, 2022). The European semiconductor industry welcomes this broad definition of "next generation of chips" (Pioch, 2022).

[15] "Under Article 21, Integrated Production Facilities and Open EU Foundries, as well as semiconductor undertakings which have accepted such possibility in the context of receiving public support, could receive a priority rated order. This would be possible where necessary and proportionate to ensure the operation of all or certain critical sectors." (European Commission d., 2022)

Furthermore, EU companies that operate internationally would need to inform the Commission if information requests have been triggered in third countries in light of disruptions that may result in semiconductor shortages which have not yet reached the EU. According to the Commission, in this case, the EU can react in a timely manner to prevent and/or minimize potential impacts by implementing mitigation measures (BDI, 2022).

At the same time, the Commission proposes increased cooperation with international partners like the US for enhanced (end-to-end) supply chain visibility in order to better mitigate the effects of potential shortages. It aims to increase supply chain transparency by overcoming the lack of data availability through the introduction of a quantitative, data-based semiconductor value chain monitoring mechanism. This mechanism would include early warning indicators based on data exchange such as lead-times for certain chip types or other external developments that could impact the value chain. These indicators would be defined by the EU member states (Pioch, 2022). For this information exchange the legislation proposes to extend existing industry initiatives, which strive to resolve errors in the anticipated demand for critical semiconductors such as microcontrollers and analogue chips. These errors can impact the entire supply chain (bullwhip effect) and quickly lead to an imbalance between supply and demand. The Commission suggests to implement a smart anonymized data platform based on semantic web methods to ensure the scalability to large user groups from raw material providers and foundries to chip makers and customers, which can allow for a better understanding of chip-specific capacities and, through computational methods, anticipate the actual demand (European Commission e., 2022).

4. Comparing empirical findings from expert interviews and literature-based review

As part of this research, six guideline-based interviews with policy and macroeconomic experts as well as supply chain experts from the semiconductor industry in the US and Europe were conducted to verify the theoretical and literature-based assumptions on: Challenges in global trade and supply chains, vulnerabilities in the semiconductor supply chain, and policy recommendations to promote resilience in the semiconductor supply chain (see *Table 3.*).

The interviews were analyzed in a qualitative content analysis in order to derive concrete categories. As illustrated in *Table 3.*, the 18 categories identified in the expert interviews correspond with the literature-based analysis provided in Chapter 2. All experts agreed that increased global conflicts and the resulting rise in inflation are a major challenge for global trade and supply chains. As part of that, in the interviews the role of China as a competitive rival was specifically highlighted.

Table 3. Category overview derived from expert interviews and comparison with literature-based review

Questions	Expert Interviews – Derived categories	Literature review/analysis – Derived categories	
Current challenges in global trade and supply chains	• Increased global conflict (war in Ukraine) • Threat of Chinese invasion of Taiwan • Rising inflation rate • Supply dependencies on autocratic regimes • China as a systemic competitor/rival with economic ambition, non-compliant with international rules-based trade order • Protectionist tendencies and unilateralism • Implementation of disproportionate export regimes (US-China trade conflict) • Climate change	• Global warming • Increased global conflict (war in Ukraine) and rising global inflation rate • Trade conflicts (e.g. with China)	**Literature-based research and interviews correspond**
Vulnerabilities in the semiconductor supply chain	• Lack of diversification in global production networks; geographic concentration of manufacturing in China and Southeast Asia • Prioritization of efficiency over resilience • Lack of supply chain transparency and end-to-end visibility • Bullwhip effect • Lack of collaboration between like-minded partners	• Lack of diversification in the global production networks; geographic concentration of manufacturing in China and Southeast Asia • Prioritization of efficiency over resilience • Lack of supply chain transparency and end-to-end visibility • Bullwhip effect • Lack of collaboration between like-minded partners	**Literature-based research and interviews correspond**
Policy recommendations to increase supply chain resilience	• Reshoring/Nearshoring (e.g. based on local/regional demand) • Diversification • Caution but no decoupling from China (instead, implementation of market distortion countermeasures) • Increased supply chain transparency through smart data analysis (e.g. to mitigate bullwhip effect) • Collaboration between like-minded partners	• Reshoring/Nearshoring (e.g. based on local/regional demand) • Diversification • Caution but no decoupling from China (implementation of market distortion countermeasures) • Increased supply chain transparency through smart data analysis (e.g. to mitigate bullwhip effect) • Collaboration between like-minded partners	**Literature-based research and interviews correspond**

Source: Own illustration

Concerns about a potential Chinese invasion of Taiwan were also raised, which would severely impair global value and supply chains due to the high level of geographic concentration of global manufacturing in the region (e.g. dependency on semiconductor foundry services on Taiwan and mass production dependency on China). At the same time, it was pointed out that protectionist tendencies and unilateralism hold extensive risks for Western partners and would result in negative effects on global and domestic trade. It was also highlighted that the implementation of disproportionate export regimes in light of increasing trade tensions with China cannot be considered as the solution to the country's repeated distortion of the international rules-based economic order due to its wide-ranging economic ambition. Cutting economic ties with China would negatively impact economic growth among Western partners and even further encourage the Chinese government to expand partnerships elsewhere. Instead, effective market distortion countermeasures should be implemented e.g. increased (cyber-)security.

In general, the supply dependency among Western partners on autocratic regimes (e.g. for energy and food supply) was pointed out as a major concern. In terms of the semiconductor supply chain, the experts also highlighted the issue of geographic concentration. The lack of diversification needs to be addressed by encouraging a partial restructuring of the industry's global manufacturing landscape, including through reshoring or nearshoring approaches, incentivized through policy subsidy programs. It was also stated that semiconductor companies can and should continue to do business in China, but must diminish single dependencies through a diversified sourcing, manufacturing, and distribution landscape. Furthermore, the experts addressed the lack of supply chain transparency in the long and highly complex semiconductor supply chain and recognized the need for better end-to-end supply chain visibility to avoid demand forecast errors (bullwhip effect) and detect crisis early on. However, they also pointed out the issue of data accessibility beyond tier 2 suppliers and the complexity of sensitive data sharing. In addition, they highlighted the importance of cooperation and collaboration between like-minded partners in resolving the global supply chain challenge, including in the semiconductor industry.

Lastly, climate change was addressed as one major challenge in global trade and supply chains. However, the experts also pointed out that despite the severity of the situation in light of increased global conflicts resulting in a lack of energy supply and rising inflation, in the majority of countries around the world climate protection is not a priority. Therefore, businesses need to take the primary initiative to enhance sustainability along their global supply chains.

5. Discussion: The global supply chain challenge and the semiconductor industry

This section discusses the literature-based and empirical findings described in the previous chapters and provides a comparison between the legislative initiatives to enhance supply chain resilience in the semiconductor industry in the US and EU (US CHIPS and Science Act; European Chips Act) to identify similarities, differences, and synergies.

5.1 Reflecting on the global supply chain challenge

Global economic value creation is based on the international division of labor, with a high regional specialization and geographic concentration of low value-added production in Southeast Asia and China. Due to a lack of diversification, in a lot of cases this exposes global supply chains to one single point of failure. Consequently, regional disruptions can severely impact supply and lead to extensive shortages. The COVID-19 pandemic first revealed the fragilities of this setup (Grossman et al., 2021). In addition, climate change, increased global conflicts resulting in a surge in inflation, and rising geopolitical trade tensions with increased protectionist tendencies are putting continuous pressure on global supply chains. Therefore, political attention around the issue of supply chain resilience has been rising and legislative attempts to overcome regional dependencies have been increasing (Knizek, 2022). However, policy initiatives need to acknowledge the system of globalized economic value creation and implement measures in accordance with this structure.

This is also reflected in Tyson's and Zysman's (2021) approach of competitive, resilient, secure, and sustainable (CRSS) supply chains. These four pillars provide a clear strategic focus and, as stated by the authors, must be embedded in well-modulated policy programs that are built around the benefits of specialization in global supply chains while also promoting diversification. CRSS requires international collaboration between like-minded partners to strategically diversify and partially restructure global value chains and production networks (including those based on regional demand) (Tyson & Zysman, 2021) through market driven incentives (Varas et al., 2021). It does not imply a race for national autonomy or self-sufficiency across industries (Tyson & Zysman, 2021).

In addition, policymakers should work towards further leveling the playing field in global trade. The WTO needs to be revitalized and reformed e.g. by reviving the appellate body and speeding up the timeline of case adjudication in order to create and successfully execute internationally recognized trade agreements and effectively counter their violations on the multilateral stage (BDI, 2021).

5.2 Reflecting on the semiconductor supply chain challenge

Semiconductors are among the world's most-traded products after crude oil, refined oil, and automobiles (Varas et al., 2021). According to McKinsey Research the industry will rise to become a 1 trillion USD industry by 2030 (Badlam et al., 2022). Its complex and globalized value chains are characterized by a high level of regional specialization and geographic concentration, which allows for extensive (cost-)efficiency and innovation through specialized regional semiconductor ecosystems (e.g. Silicon Valley chip design; Taiwan leading-edge chip fabrication). Therefore, striving for national/regional self-sufficiency in semiconductor technology is neither beneficial for technological progress, nor financially feasible (Kreps et al., 2022).

The European Commission (2022) states in an analysis that the construction of a leading-edge semiconductor manufacturing facility in the EU could amount to 20 billion Euros (European Commission e., 2022). According to a report by the Semiconductor Industry Association and the Boston Consulting Group (2021), in the US, manufacturing reshoring efforts with the goal to meet the full regional demand in semiconductor components would require an incremental upfront investment of around 1 trillion USD. This would result in a price increase of between 35 and 65 percent in chips, which would then be passed on to end-user products such as in electronics applications (Varas et al., 2021).

Zysman and Tyson (2022) apply their concept of CRSS supply chains to the semiconductor industry. The authors also stress that technological self-sufficiency in semiconductor technology is neither effective, nor feasible. In addition, the implementation of extensive trade barriers targeting China would not prevent China from achieving semiconductor autonomy – as targeted in its China 2025 initiative – or block its dual circulation strategy. It would rather further expose global supply chains to disruptions and even encourage the Chinese government in its self-sufficiency race (Tyson & Zysman, 2021). Instead, market distortions should be countered through "certain sensitive activities" such as increased (cyber-)security efforts to avoid IP theft (Segal et al., 2021). Policymakers should also incentivize supply and value chain diversification among chip makers to attract investments in the domestic manufacturing landscape and thus secure critical supply in case of an ad hoc crisis. At the same time, competitive market conditions must be maintained to avoid unnatural imbalances and excessive market power of singular market segments. The authors stress the importance of investment across "all parts of the industry, from design, fabrication, assembly, and packaging to materials and manufacturing equipment" (Tyson & Zysman, 2021). In addition, increased collaboration with like-minded international partners is required to mitigate existing vulnerabilities (Kreps et al., 2022). Policy efforts on the multilateral stage need to intensify in order to counter unilateral tendencies and further level the playing field in international trade. This would also highly benefit the semiconductor industry through enhanced fair market access and decreased macroeconomic uncertainties (Varas et al., 2021).

5.3 The US CHIPS and Science Act and the European Chips Act: Analysis and comparison

The semiconductor shortage has brought political and public attention to the industry. In order to counter current challenges, on both ends of the Atlantic policymakers aim to (1) rebuild domestic manufacturing capacity, (2) promote R&D in semiconductor technologies, and (3) increase international engagement with partners and allies to reduce supply chain fragility. These political efforts are reflected in the US CHIPS and Science Act and the European Chips Act. Both subsidy programs have a common denominator in these three strategic areas, but also differ in their legislative targets:

(1) US CHIPS and Science Act: As outlined in Chapter 3, with Division A, the funding program first and foremost aims to support innovation and technological leadership, but also STEM workforce development through general R&D subsidies for leading-edge. However, with Division B (CHIPS+), US policymakers set a clear focus on the semiconductor industry. The legislation aims to specifically drive research in microelectronics to maintain US global leadership in semiconductors, which is needed to ensure long-term competitiveness. Furthermore, it promotes secure, resilient, and competitive

semiconductor supply chains by providing incentives to revitalize domestic chip manufacturing capacities to mitigate vulnerabilities (US Senate, 2022).

The US's manufacturing capabilities have declined from around 37 percent in 1990 to 12 percent at present[16] (President's Council of Advisors on Science and Technology, 2022). In order to rebuild capacities, support through public funding and tax credits is essential due to the high cost of the construction of semiconductor fabs, which the private sector would not be able to balance alone. In addition, these subsidies also attract international semiconductor corporations, including foundries for leading-edge chip fabrication from Southeast Asia, which can diminish geographic concentration (Mazewski & Flores, 2022).

In January 2021, Taiwanese semiconductor foundry TSMC started construction of a new 5nm fab in Arizona (Reuters, 2021). In addition, under the umbrella of CHIPS, TSMC is also spurring additional investment in the US. It announced plans to bring "next generation chip facilities" to the United States to diversify its manufacturing landscape, if supported by CHIPS funding. Furthermore, Intel stated that it plans to invest 100 billion USD into eight factories in the US over the coming years, if it receives subsidies through the funding program (Intel, 2022). This illustrates that, through its long-term investments, CHIPS can be expected to have a positive impact on the semiconductor manufacturing landscape in the US and promote supply chain diversification among partners. However, in order to genuinely revitalize domestic capacity, in addition to front-end fabrication and leading edge technology, back-end production with assembly, packaging, and testing also has to be expanded. IDMs have to assess, whether in terms of cost effectiveness back-end capacity expansion in the United States would be profitable (if supported by subsidies) or whether they should instead continue to focus on foundry partnerships (PWC, 2022). In general, chip makers are faced with a challenge of maintaining efficiency and profitability while ensuring flexibility, agility, and resilience in their supply chains (Iakovou & White, 2020).

Furthermore, the program is also set out to specifically counter China's economic ambition in microelectronics and ensure US competitiveness. Therefore, subsidies are coupled with the boundary condition that funding recipients are prohibited from investing in capacities in China and other countries ranked according to US law as a potential security threat to the United States (White House c., 2022). The requirement only excludes legacy semiconductors that are manufactured for the specific local market. In addition, the US government can reserve the right to reassess which technologies are targeted by US export regulations to ensure the restrictions refer to the current status of semiconductor

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[16] US firms such as Intel, AMD, NVIDIA, Texas Instruments, Qualcomm, Broadcom or Micron are leading in the global semiconductor industry. However, both - Integrated Device Manufacturer (IDM) like Intel, Texas Instruments or Micron, which design, develop and produce or fabless companies such as AMD, NVIDIA, Qualcomm and Broadcom, which focus only on chip design and development and fully outsource their production – are dependent on supply and manufacturing abroad (Varas et al., 2021).

technology. Under these conditions, it is up to corporations to assess if the value of federal funding would outweigh business constraints that result from this political agenda (PWC, 2022).

(2) European Chips Act: Similar to the CHIPS+ section of the US CHIPS and Science Act, as described in its first strategic pillar, the European Chips Act focuses on the chip industry and aims to promote semiconductor R&D and workforce development, which is needed to strengthen the regional semiconductor architectural ecosystem and to ensure the EU's competitiveness and technological sovereignty in the long-term (European Commission e., 2022). It also incentivizes domestic manufacturing capacity expansion to build up the European semiconductor manufacturing landscape. Its current global manufacturing share lies at nine percent (Scheper, 2022). If no legislative action is taken, it may further decline to less than five percent once subsidy programs implemented in other parts of the world begin to show effect, in particular in China and the US. In order to counter this development, the European Commission aims to increase the semiconductor manufacturing share to 20 percent by 2030 (European Commission e., 2022).

Therefore, as outlined in its second strategic pillar, the EU Chips Act will provide subsidies for the construction of specific first-of-a-kind facilities (Open EU Foundries and Integrated Production Facilities), which should support the "next generation of chips" in the EU (ibid.). The Commission does not define concrete node sizes as the next generation of chips, which is generally being welcomed by the industry (BDI, 2022). Today, the majority of existing production facilities in Europe produce chips on 28nm and mature (>40nm) nodes, which corresponds with the European semiconductor industry's strong market position in automotive, industrial and power applications, for which larger node sizes are needed (European Commission e., 2022). For advanced manufacturing capacities[17], in particular for electronics applications, the EU is fully dependent on foundry partnerships in Southeast Asia (ibid.). Hence, at the same time the subsidy program needs to support foundries for leading-edge chip fabrication to reduce geographic concentration and encourage manufacturing partners to not only expand their capacities in the United States, but also in Europe (BDI, 2022). In addition, according to an analysis of the German Electro and Digital Industry Association, subsidies should not be limited to Open EU Foundries and Integrated Production Facilities, but instead remain accessible to the whole microelectronics industry to bolster the manufacturing landscape both for front-end and back-end production. In addition, the Association criticizes the limitation to first-of-a-kind production facilities in the EU, since this would not provide sufficient capacity for the targeted 20 percent manufacturing increase in the region (Pioch, 2022).

The third strategic pillar of the EU Chips Act is regarded as particularly problematic by the semiconductor industry. The Commission proposes an early warning crisis mechanism in case of

[17] Node sizes below 22nm and in particular leading-edge nodes with node sizes below 14nm (European Commission e., 2022).

serious disruptions. However, in an attempt to increase transparency along the semiconductor supply chain, wide-ranging market interventions would be implemented (Cota, 2022). The proposal also fails to clearly define "crisis" or "serious disruptions" and, as a result, in which cases the Commission would become active (Pioch, 2022). Generally, the industry questions the current proposal due to its lack of clear boundary conditions and violation of supply chain and trade information confidentiality, e.g. due to the proposed mandatory information requests and information sharing (ibid.). It is important to reflect on the actual root cause of the shortages. The current bottlenecks, for instance, did not result from a failure in one region's semiconductor ecosystem, but are the consequence of demand forecast errors and misled procurement approaches (JIT) by user industries. The bullwhip effect is briefly addressed in the Chips Act proposal. However, it is only stated that existing industry initiatives to balance these fluctuations are insufficient and that publicly funded projects have been established to create an anonymous data sharing platform using semantic web methods (BDI, 2022).

A disruption prevention strategy should not only address the semiconductor supply chain, but also the structural weaknesses in demand forecasts, including in user industries which often fail to acknowledge the relatively long lead times (four to six months) in semiconductor manufacturing (Cota, 2022). Instead of collecting cross-section quantitative data, which cannot predict ad hoc incidents such as the pandemic and/or the war in Ukraine, the industry recommends countering disruptions by including industry experts early on for a qualitative assessment to mitigate shortages (BDI, 2022). Furthermore, the static measures proposed in the emergency toolbox (mandatory information request, priority rated orders, joint procurement of chips, export authorization) do not acknowledge the complexity of the semiconductor supply chain, would severely intervene in the market and are therefore considered as ineffective for disruption/shortage prevention. The implementation of such measures would not only negatively impact the European semiconductor ecosystem, but also decrease its attractiveness for FDIs (Pioch, 2022). Instead, the industry would welcome guidance on strategic plans to maintain business continuity in case of disruptions (BDI, 2022).

Lastly, the legislative proposal is currently still lacking a detailed financial breakdown, including a guidance for foreign direct investments. It must be pointed out that the Chips Act cannot draw from funding for existing programs such as the Important Project of Common European Interest (IPCEI). Instead member states need to take responsibility to co-finance the funding program in order to make the European semiconductor industry futureproof and support technological sovereignty (Timmers, 2022). Despite these legislative inconsistencies and although the EU Chips Act is currently still in the legislative process – just like in the case of the US CHIPS Act – the European subsidy plans also already show effect, reflected for example in Intel's announcement of the construction of a 19 billion USD semiconductor factory in Germany or Infineon's plans to expand its manufacturing site in Dresden (Germany) (Infineon Technologies b., 2022).

In sum, the CHIPS+ section of the US CHIPS and Science Act and the European Chips Act address current challenges in the semiconductor industry and its supply chain in similar ways. *Table 4.* illustrates the similarities and differences between the two legislations. Since the financial breakdown of the EU subsidy program has not yet been issued, an assessment of the concrete respective investment volumes cannot be provided.

Table 4. Comparison of the CHIPS+ section of the US CHIPS and Science Act and the European Chips Act

	US CHIPS+ Act	EU Chips Act
Semiconductor R&D and workforce development	X	X
Semiconductor manufacturing	X	X
International collaboration/partnerships	X	X
Monitoring and crisis response measures		X
Bullwhip effect		X
Structural weaknesses e.g. in user industries' procurement strategies		
Boundary condition (prohibited manufacturing investments in China)	X	

Source: US Senate, 2022; European Commission e., 2022

However, both programs focus on the support of two areas: (1) Semiconductor R&D and workforce development and (2) semiconductor manufacturing. It can be assumed that both legislations will have a positive effect on the regions' semiconductor (architecture) ecosystem and manufacturing landscape. Although concerns about future overcapacities have been raised in light of these two subsidy plans, it must be recognized that due to the continuous rise in semiconductor demand for digital, intelligent, and energy-efficient technologies across applications, a significant expansion of chip production capacities will be needed (Badlam et al., 2022). With increased manufacturing capacities in the United States and Europe, the semiconductor supply and value chains will already be more diversified and thus more competitive, resilient, and secure. The level of resilience would however still be insufficient. Therefore, the US and EU need to promote collaboration with each other (e.g. through the TTC) and with other international partners (G7 and beyond) to diminish the geographic concentration in semiconductor manufacturing. Both legislations address international collaboration, though rather superficially. In light of global warming, policymakers should also collaborate more closely on promoting and incentivizing sustainability across global semiconductor supply chains, also considering the high environmental and energy costs in manufacturing (Tyson & Zysman, 2021). Until now, in general, little progress has been made in supply chain decarbonization. In 2019, the European Union raised the bar on responsible business with its Green Deal by requiring companies to also reassess their supply/value chain practices (Scope 3 emissions) (Schrauf, 2022). However, although this is already a step in the right direction, such standards ultimately need to be set on the international stage in a joint effort of governments together with industries to reduce carbon emissions (Koch, 2022).

While CHIPS+ focuses on increased domestic manufacturing capacities to enhance supply chain resilience, the European Chips Act also addresses monitoring and crisis response in its third strategic pillar. This includes the collection of anonymized, quantitative industry data to counter demand forecast errors (bullwhip effect), which is also being handled on the transatlantic stage in the supply chain working group of the TTC (European Commission d., 2022). In general, it makes sense to also specifically address this issue, but the proposed execution seems too far-reaching, infeasible, and ineffective (BDI, 2022). While data-driven supply chain management approaches (e.g. through real-time data collection and sharing) can help corporations deal with supply chain resilience, an invasive collection of sensitive data is not supported by the industry due to trade and supply chain confidentiality. The market interventions proposed as part of the static measures in case of disruptions, such as mandatory information requests, priority rated orders, joint procurement, and export authorizations, would also violate these confidentiality principles and distort the free market (Cota, 2022). Instead of applying such interventions, policymakers on both ends of the Atlantic should (1) include industry experts early on in case of disruptions to mitigate impact, (2) provide guidance on how to maintain and quickly restore business continuity and (3) build alliances with international partners, such as through trade agreements in order to increase resilience. In addition, structural weaknesses and misled procurement strategies (JIT) among user industries should be analyzed and existing vulnerabilities tackled in exchanges beyond the semiconductor industry (Pioch, 2022). Both legislative initiatives fail to address this issue.

Lastly, in an effort to counter China's economic ambition in microelectronics, potential CHIPS+ funding recipients will be prohibited from investing in manufacturing capacities in China. Such boundary conditions are not included in the EU Chips Act. As pointed out by Tyson and Zysman (2021), the effectiveness of such measures needs to be doubted. Policy initiatives should not specifically aim to counter China through protectionist or decoupling initiatives, since such actions would not prevent China from further thriving in the semiconductor field and rather encourage its race for self-sufficiency (Tyson & Zysman, 2021). In this regard, Tara Hariharan – macroeconomic expert, Managing Director of the New York-based hedge fund NWI Management and interview partner in this research project –stressed the importance of constructive, domestic approaches to technological self-sufficiency in the US and EU:

> "The deterioration in various facets of US-China relations and EU-China dynamics in recent years jeopardizes vital bilateral and multilateral cooperation on broader issues of global concern, including economic growth, support for developing nations, and climate change.

> Hence, instead of relying on outwardly-directed punitive measures against China, it is essential that the US and Europe forge more constructive, inward-focused approaches to technological self-sufficiency that prioritize much-needed domestic investment and provide subsidies for relevant sectors. Indeed, while the US has recently sought to address the China challenge through the maxim "invest, align and compete", the "invest" part of the equation is perhaps the most crucial – and constructive – way to address supply chain resiliency concerns and stem non-market practices by China." (Hariharan, 2022)

In addition, policymakers should focus on countering market distortions or security threats by implementing sensitive activities, such as increased cybersecurity efforts for IP protection, supply chain diversification, and/or strategic stockpiling of critical goods/minerals, such as rare earths and other resources from the region to reduce overreliance on supply from China (Segal et al., 2021).

6. Conclusion: Overcoming the supply chain challenge

This last section summarizes and recaps the research findings and results and answers the research questions outlined in Chapter 1.

RQ_1: Which challenges in global trade are currently impacting global supply chains?

In general, three challenges in international trade also specifically impact supply chains: (1) Global warming, the need for supply chain decarbonization, and at the same time adaptation to extreme weather conditions (Topping & Munoz, 2021; Cameron, 2019); (2) rising global conflicts reflected in a surge in inflation (Ollagnier, 2022); and (3) increased trade tensions in particular between the US and China, which result in the implementation of complex export regimes (Segal et al., 2021).

RQ_2: How can the current vulnerabilities in global supply chains be resolved?

The geographic concentration of low value-added production primarily in China and Southeast Asia, which resulted from increased offshoring activities of corporations of the global North to this region due to regional specialization, left global supply chains exposed to one singular point of failure. This came to the surface particularly through disruptions caused by the COVID-19 pandemic (Grossman et al., 2021). First and foremost, global supply chains currently lack diversification and thus competitiveness, resilience, security and sustainability (Tyson & Zysman, 2021). Policymakers on the one hand, need to introduce subsidy programs to incentivize diversification by expanding regional/domestic production capacities (near-/reshoring) and at the same time strategic stockpiling of critical minerals, such as rare earths, to ensure supply also in case of severe disruptions and/or aggregate shocks. On the other hand, they need to bring the issue to the multilateral stage and collaborate on increasing resilience e.g. through trade agreements (Schneider-Petsinger, 2022). However, businesses are also responsible for adapting their strategies and processes including through a partial restructuring of their supply and value chains as well as changes in their procurement strategies. The complexity is to balance resilience through agility and flexibility, as well as efficiency and profitability. For this, the use of smart information technology is key (Iakovou & White, 2020).

RQ_3: How can the current supply chain vulnerabilities in the semiconductor industry be resolved?

The same applies to the semiconductor industry. Its supply chain is particularly globalized with a strong geographic concentration of semiconductor manufacturing in Southeast Asia and China. This regional focus enables high efficiency, but lacks resilience (Varas et al., 2021). The current chip shortage was triggered by forecast errors (bullwhip effect) of user industries coupled with misled procurement strategies (JIT) and a steep rise in demand in light of the COVID-19 pandemic (Pioch, 2022). As a result, low inventory levels were quickly depleted and other disruptions caused by natural disasters, trade tensions, or conflicts (war in Ukraine) continued to strain the already vulnerable supply chain with its single regional manufacturing focus (Badlam et al., 2022). Since semiconductors are a key component in the value chain of innovative digitalized and energy efficient technologies (e.g. cars, electronic devices) and the shortage has thus highly impaired the value chain of other industries (US Department of Commerce, 2022), political attention on the chip industry arose on both sides of the Atlantic. In order to resolve the vulnerabilities and increase CRSS in the semiconductor supply chain, geographic manufacturing concentration must be diminished through diversification, including through global value chain restructuring e.g. subsidized re-/nearshoring activities to strengthen the ecosystem in partner countries, while continuing to foster international market engagement (Tyson & Zysman, 2021). Policymakers should also specifically promote collaboration beyond traditional partnership formats such as the G7 to establish e.g. trade agreements that bolster infrastructure across strategic partner countries to enable increased supply chain resilience (Schneider-Petsinger, 2022).

RQ_4: What are similarities, differences, and synergies of the US CHIPS and Science Act and the European Chips Act?

The US and EU both introduced political initiatives to tackle the semiconductor supply chain issue and promote the industry on the long-term including through R&D subsidies and funding for domestic manufacturing capacity expansion with the CHIPS+ section of the US CHIPS and Science Act and the European Chips Act (Cota, 2022; PWC, 2022). These programs are expected to have a positive effect on the semiconductor (architecture) ecosystem and the supply chain due to their effort to increase diversification in the manufacturing landscape through re-/nearshoring (Kersten et al., 2022; Pioch, 2022). However, in promoting this capacity expansions, policymakers need to maintain competitive market conditions to avoid excessive market power of singular market segments. Funding should be provided to "all parts of the industry from design, and fabrication to assembly, and packaging and materials as well as manufacturing equipment" (Tyson & Zsyman, 2021).

Both legislations also promote international engagement among like-minded partners, instead of striving for semiconductor self-sufficiency, which would neither be efficient nor feasible. Nevertheless, additional efforts in international collaboration beyond the transatlantic exchange through the TTC and also the G7 format, as for instance with the countries of the IPEF (e.g. India, South Korea, Australia and New Zealand), must be made to increase CRSS in semiconductor supply chains (Schneider-Petsinger, 2022).

There are also rather counterproductive aspects in both policy initiatives: (1) As for the European Chips Act, the proposed market interventions as part of public monitoring and crisis response mechanisms are ineffective and violate supply chain and trade information confidentiality. Efforts to increase supply chain transparency would be welcomed, but rather through qualitative exchange with industry experts to monitor the supply chain and jointly mitigate impact in case of disruptions (BDI, 2022). (2) As for the US CHIPS and Science Act, the boundary condition that funding recipients are prohibited from investing in manufacturing capacities in China in order to counter China's economic ambition in semiconductors is considered ineffective. Instead, corporations will now assess if the subsidies in the US outweigh the cost of prohibited manufacturing investments in China (PWC, 2022).

Lastly, preventing demand forecast errors (bullwhip effect) and avoiding misled procurement strategies (JIT), which caused the current chip bottlenecks, generally remain a challenge for the semiconductor industry and beyond (BID, 2022). The issue is briefly addressed in the EU Chips Act proposal, but not in CHIPS+. It is currently also being discussed on the transatlantic stage in the supply chain TTC working group. Efforts to resolve the issue should, however, not only focus on the semiconductor industry, but also on structural weaknesses across supply chains, including those of user industries (Pioch, 2022).

In sum, both legislative initiatives set the right focus and create valuable incentives for chip makers, which hold the potential to strengthen the semiconductor supply chain. First and foremost, they should also focus on expanding international partnerships. This will be needed to diminish geographic concentration in semiconductor manufacturing and strengthen infrastructures elsewhere to expand manufacturing partnership opportunities and increase resilience sustainably (Schneider-Petsinger, 2022).

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