



Chapter 6

Building Resilient Supply Chains

The year 2021 was when supply chains—the networks of producers, transportation companies, and distribution centers that develop and move products and services—entered dinner table conversations. Though this term has certainly been part of the lexicon going back to the 1980s, and has been a part of doing business for centuries, COVID-19 highlighted supply chains’ vulnerabilities, which became front-page news. Supply chains have become more complex, interconnected, and global than they were in decades past. The share of world trade that crossed at least two borders increased from 37 percent in 1970 to nearly 50 percent in 2014 ([World Bank 2020a, 2020b](#)).

This increasing segmentation of the production process has reduced prices in the United States, while also raising productivity and aggregate incomes in many of the low-income countries that are integral to global supply chains ([World Bank 2020a](#)). However, the globalization of production has also made supply chains more vulnerable to disruption. This fragility has been exacerbated as firms have removed excess capacity (e.g., extra inventory, or reserves of people with the time and skills to solve problems), making supply chains less resilient. That is, they have less ability to recover quickly from unexpected events. Thus, though modern supply chains have driven down consumer prices for many goods, they can also easily break ([Brede and de Vries 2009; Baldwin and Freeman 2021; Miroudot 2020; de Sá et al. 2019; White House 2021a](#)).

Though it was not inevitable, movement toward this more fragile configuration has been happening for decades, as public and private policies have undermined firms’ incentives to invest in such capacity to ensure

resilience. The COVID-19 pandemic is not the first time that supply chains have been disrupted; the production and distribution of goods have been regularly snarled by natural disasters, cyberattacks, labor strikes, supplier bankruptcies, industrial accidents, and climate-induced weather emergencies (de Sá et al. 2019). The pandemic simply exposed just how complex and interconnected modern supply chains have become. These highly publicized disruptions and product shortages made the public painfully aware of the many steps involved in getting a product produced, transported, and placed on shelves or doorsteps.

The first section of this chapter describes modern supply chains and explains their evolution, focusing on manufacturing. Supply chains are shaped by a complex network of relationships; these relationships affect not just the movement of supplies from place to place but also the incentives of lead firms and suppliers to invest in producing new products, in providing good jobs, and in achieving resilience. The second section describes how increasingly frequent disruptions of the economy suggest that supply chain fragility will continue to be a problem. The third section outlines the private sector's incentives to become more resilient in the face of these challenges. Finally, the fourth section suggests vital roles for government in helping to shape supply chains and overcome market failures.

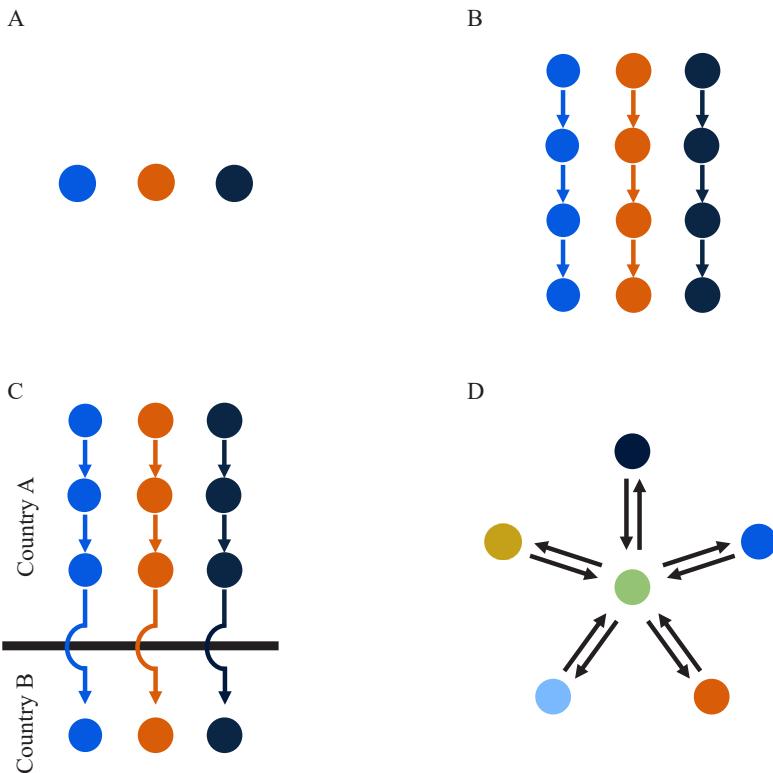
21st-Century Supply Chains

Supply chains are the linkages in the production process that facilitate the transformation of raw materials into finished goods or services. A supply chain is made up of producers and logistics providers that move inputs from one stage to the next, and also of participants in the distribution channels for the finished product, including wholesalers, distributors, and retailers. This chapter primarily focuses on manufacturing supply chains that facilitate the production of physical products from unprocessed materials.¹

Figure 6-1 depicts some of the ways supply chains are commonly organized. Even within the same industry, firms have different supply chain

¹ In addition to goods, services are also part of supply chains and often face some of the same issues that are discussed in this chapter.

Figure 6-1. Common Types of Supply Chains



Source: Adapted from Cavalho (2014).

Note: From left to right: A, vertical integration with isolated industries; B, outsourcing with isolated industries; C, outsourcing and offshoring with isolated industries; D, outsourcing with a central node (star-shaped). Arrows denote flows of products, information, and the like between companies.

configurations (Kamalahmadi and Parast 2016; Lund et al. 2020). This figure gives four stylized examples of how supply chain relationships could be formed:

Vertical Integration with Isolated Industries

Panel A of figure 6-1 illustrates a three-firm configuration, where each firm (shown by the dots in the figure) is self-sufficient—that is, completely vertically integrated. Thus each firm produces everything, starting from raw materials and ending with the finished product. In this configuration, supply chains are completely internal to a firm. A prototypical example of this is the automaker Ford's River Rouge Plant, which in the 1930s included a steel mill, glass factory, power plant, rubber factory, foundries, machine shops, stamping plants, assembly lines, a cement plant, a paper mill, a leather

plant, and a textile mill (Weber 2019). Ford also owned a rubber plantation in Brazil, coal mines in Kentucky and West Virginia, and railway cars to transport raw materials. This allowed Ford to maintain direct control over the entire manufacturing process. However, this complete vertical integration also made it difficult for Ford to cut costs during the sharp decrease in demand for cars during the Great Depression, as the automaker continued to bear the fixed costs of component production. In contrast, Chrysler, which was much less vertically integrated during this time period, did not need to bear these fixed capital and administrative costs; Chrysler's suppliers did (Chandler 1962, 1992). A firm's decision to vertically integrate depends in part on whether the costs of transacting in different markets outweighs the cost of managing these activities internally (Coase 1937).

Outsourcing with Isolated Industries

Panel B of figure 6-1 represents three industries, each with significant supply-chain relationships. Here, inputs travel “downstream,” where they are transformed into a final good. The lead firm typically designs products and directs production by multiple tiers of suppliers in many locations, but it does not own most of these suppliers. This is called *outsourcing*. Outsourcing allows the lead firm to contract with firms that may have lower production costs due to lower wages or other competitive advantages (see box 6-3 below).

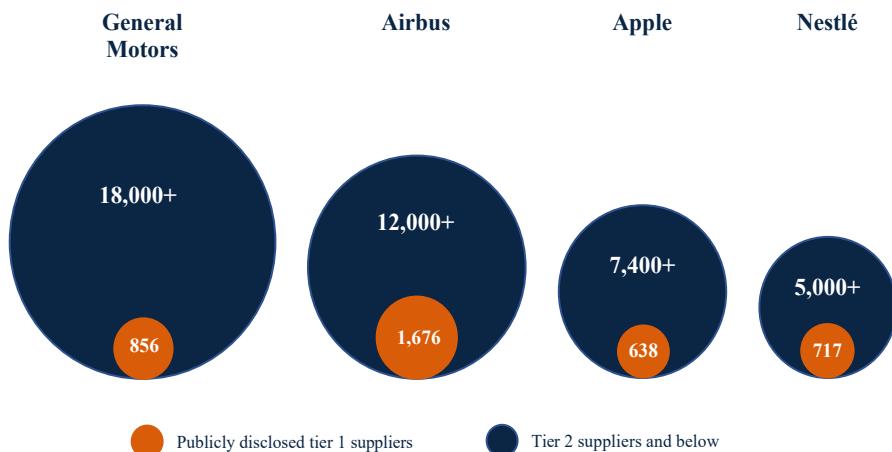
The chain includes direct suppliers of the lead firm (tier 1 suppliers), as well as suppliers to those suppliers (tier 2 suppliers), and so on—all the way back to the raw materials used to produce the good. A firm can have hundreds of tier 1 suppliers and thousands of tier 2 suppliers, as shown in figure 6-2 (Lund et al. 2020).² Looking at the publicly disclosed lists of suppliers for 668 companies, the McKinsey Global Institute found that the number of direct suppliers was large and that the network of indirect suppliers was even larger, often numbering in the thousands (Lund et al. 2020). As discussed below, the degree of coordination between the firms, represented by the arrows in figure 6-1, can vary between two extremes: arm's-length transactions and collaborative relationships.

Offshoring and Outsourcing with Isolated Industries

If lead firms choose suppliers across national boundaries, this is called *offshoring*, as shown in panel C of figure 6-1. Offshoring gives companies expanded scope to locate production in areas with lower wages, or that have other competitive advantages not available in their home country, such

² Note that, due to data limitations, the tier 2 suppliers in figure 6-2 may not be supplying inputs into the lead firms' products; rather, they are suppliers of the tier 1 suppliers, which usually produce for more than one lead firm.

Figure 6-2. Examples of Tier 1 and Tier 2 Supply Relationships



Source: Adapted from Lund et al. (2020), relying on the Bloomberg Supply Chain Database.

as access to natural resources or better technology (Antràs 2020; World Bank 2020b). Competitive advantage may be the result of naturally occurring endowments or developed by government or private sector policies (Mazzucato 2016; Lee 1995). In the past, internationally traded goods were largely either raw materials, such as cotton, or finished goods, such as clothing. Since the early 1990s, there has been a large rise in trade of “intermediate goods” or components, such as fabric that has been cut but not sewn.

In both panels B and C of figure 6-1, no connections exist between the blue industry and the parallel orange and black industries. In this diagram, nodes are industries with few overlapping suppliers, such as electronics and autos in the past.

Outsourcing with a Central Node

In contrast to the isolated industries depicted in panels B and C of figure 6-1, supplier firms usually sell to more than one lead firm and may sell to several different industries, as shown in panel D (Carvalho and Tahbaz-Salehi 2019; Carvalho 2014). One example is a star-shaped configuration, with one central node (the green node) that is used in production by all other nodes. Firms in this general-purpose industry supply a wide number of other industries and often also use inputs from the industries they supply (Carvalho 2014).³ These types of supplier relationships allow firms to take advantage of

³ In practice, some suppliers, and even the central node of panel D, may be offshored as well as outsourced; for simplicity, this configuration is not depicted.

economies of scale, where per-unit costs decrease as the number of units produced increases and the supplier is able to sell to multiple firms.

Firms' decisions regarding the design of their supply chains lead to a complex web of connections. Aggregating firm-to-firm supply chain connections, industry A has supply chain connections to industry B when firms in industry A purchase inputs from firms in industry B. Though comprehensive data on firm-to-firm supply relationships are lacking for the United States, the network structure of the U.S. economy can be visualized at an industry level. This industry-level analysis can shed light on which industries supply inputs to many other industries and the structure of network connections between industries. These connections can amplify microeconomic disruptions.

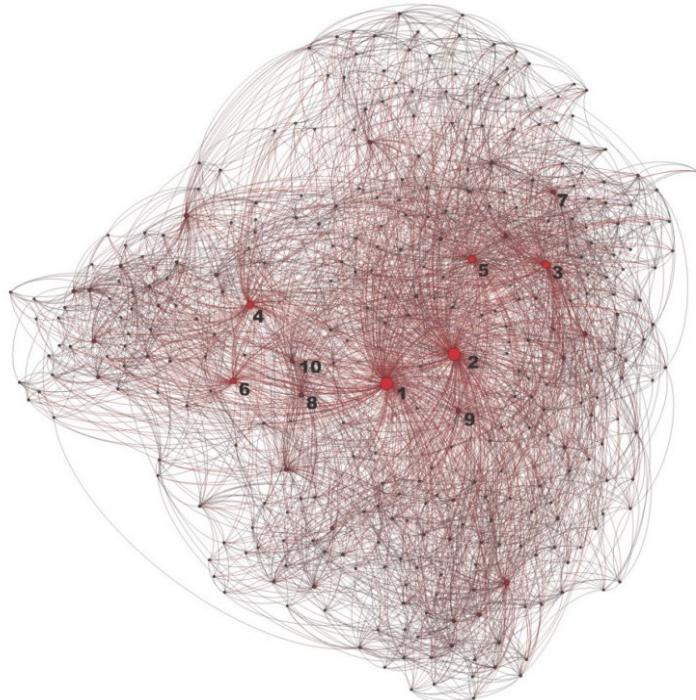
The U.S. economy is complex and interconnected, with several central hub industries that have connections to most other sectors. Using the most disaggregated, publicly available sectoral data—the Bureau of Economic Analysis's (BEA) Input-Output Accounts Data—it is possible to see the supply chain connections between 417 different industry sectors, as depicted in figure 6-3. Each node is a sector, and the connections between them represent flows of inputs from one supplying sector to another. The network is sparsely connected; on average, each narrowly defined industry is connected to only 11 other industries (Carvalho 2014). However, a small number of hub industries are highly connected to many others in the network. Although most industry pairs are not directly linked, they are indirectly connected by a small number of steps through these hub industries (Carvalho 2014). The most-connected input supply sectors (the numbered nodes) in 2002 included real estate, electricity generation and distribution, iron and steel mills, depository and credit intermediation, petroleum refineries, and truck transportation (Carvalho 2014). The CEA's analysis of the 2012 input-output tables shows that semiconductors have become a highly connected industry, while truck transportation has dropped from the top 10 list (Carvalho 2014; Bureau of Economic Analysis 2012). Other countries also have similar patterns of central hub industries, though the central industries may be different (Carvalho and Tahbaz-Salehi 2019; Fadinger, Ghiglino, and Teteryatnikova 2015; McNerney, Fath, and Silverberg 2013).

Arm's-Length and Collaborative Relationships

The arrows in figure 6-1 represent connections between the nodes in the supply chain. The nature of these connections can vary between two extremes: arm's-length transactions and collaborative relationships.

In an arm's-length transaction, a firm purchases a standard input from an unaffiliated firm, often choosing from a large set of possible sellers. In this case, the connection is very simple: the seller provides an off-the-shelf

Figure 6-3. The Production Network Corresponding to U.S. Input-Output Data in 2002



Source: Carvalho (2014). Copyright the American Economic Association; reproduced with permission of the *Journal of Economic Perspectives*.

product to the buyer, which sends payment. If there is a problem with a supplier (e.g., the price is too high or a disaster causes it to be unable to produce), the buyer can easily find another supplier. Lead firms may benefit from these relationships because they are able to easily change suppliers, creating competition that requires suppliers to reduce their prices to win business.

In collaborative relationships, firms in a supply chain communicate frequently about the product and production process; performance requirements (e.g., price, quality, specifications, and delivery schedule) are customized for a particular product, and are usually set by the lead firm (Gereffi 2020). In some instances, these are transactions between affiliates of a large company, while others involve a lead firm and financially independent suppliers. For instance, companies such as Nike do not own the facilities in which their products are manufactured; instead, they provide the design, product specifications, advertising, distribution, and coordination of the complex network of contractors that make the shoes (Gereffi and Korzeniewicz 1994).

Suppliers in collaborative relationships provide these highly customized inputs on a repeated basis, usually without complete or easily enforceable contracts (Hart and Moore 1990). Both the buyer and supplier invest in capital, equipment, or knowledge that is useful only with a particular partner (Antràs 2020). These relationship-specific investments increase the cost of finding and switching to a new supplier, but often pay off in components that better fit the lead firm's needs and in quicker responses to unexpected situations (Antràs 2020; Helper 1991; Gibbons and Henderson 2011). A large literature describes the potential benefits to lead firms of having collaborative relations with suppliers, such as reduced costs, defect rates, and lead times; and increased investment, responsiveness, innovation, and problem solving (Delbufalo 2012; Gibbons and Henderson 2011; Aoki and Wilhelm 2017).

A key reason for the long-term profitability of firms such as Toyota and Honda is their investment in collaborative relationships with their suppliers (Aoki and Wilhelm 2017; Liker 2004; Lieberman, Helper, and Demeester 1999). The rise of these sticky buyer-seller relationships is a distinctive aspect of the recent rise in global value chains (World Bank 2020a). Understanding why some firms adopt collaborative relationships and others do not is an area of active research in many disciplines, including economics, management, and sociology (Bernstein 2015; Gil and Zanarone 2018; Schrank and Whitford 2009). Box 6-1 provides an example of how one firm currently combines domestic production, offshoring, vertical integration, and offshoring to make its products.

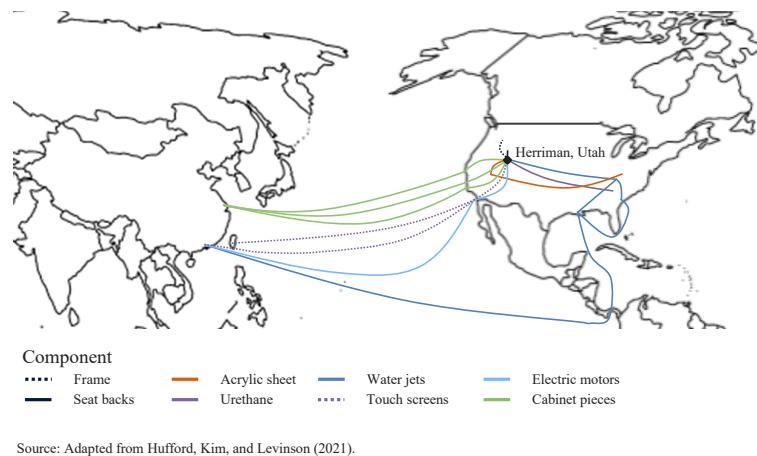
However, there is no single optimal way to organize a supply chain. Even within the same industry, firms often choose different strategies. For example, on average, automakers producing in the United States have 4.7 suppliers for each product category, a financial stake in 22 percent of transactions, and relationships with suppliers that last 2.4 years. However, there are substantial differences among automakers in these practices. Japanese vehicle manufacturers engage more in collaborative outsourcing than do their U.S. counterparts; therefore, Japanese relationships with suppliers last 70 percent longer, and they have fewer than half as many suppliers for each part as do U.S. automakers. These differences persist even when automakers are selling similar products in the same market, and after controlling for component volume and mix (Helper and Munasib 2022). Automakers differ in their offshoring strategies as well. For example, in 2020, Ford had 24 percent more production offshore than did Stellantis.⁴

⁴⁴ These data, from the American Automobile Labeling Act (AALA), do not allow the separation of U.S. and Canadian content (Center for Automotive Research 2020).

Box 6-1. The Supply Chain of a Hot Tub

The M9 hot tub is made by Bullfrog Spas in Utah, where 500 workers assemble almost 1,850 parts from 7 countries and 14 states (see figure 6-i). The hot tub top shell starts as a flat acrylic sheet from Kentucky, which is then combined with a different type of plastic in Nevada and sprayed with an industrial chemical from Georgia. Parts of the frame shell of the hot tub are driven in by trucks from Idaho several times a week. Many of the electric motors come from China and are assembled into water pumps in Mexico and then driven to Utah. Additional material for exterior cabinets is transported from Shanghai on container ships through the ports of Long Beach or Oakland. Water-spraying jets are made in Guangzhou, China; are sent through the Panama Canal and Eastern ports to the supplier's warehouse in Cleveland, Tennessee; and then are sent on to Utah. Once fully assembled, the finished hot tubs are placed on trucks or trains and delivered to retailer warehouses. This example illustrates both the extent of outsourcing, which increases the number of individual companies involved in the production of a single good, and the geographic distance traveled by each component, estimated to total nearly 900,000 miles, as well as the dependence on transportation and logistics this entails.

Figure 6-i. Sources of the Components of a Hot Tub



Drivers of Change in Supply-Chain Structures

Global supply chains that involve offshoring, and often outsourcing, multiplied rapidly from 1990 to 2008, though their growth slowed after the 2008

global financial crisis (World Bank 2020a). Manufacturing firms also outsource services, including logistics, cleaning, and security. That is, workers providing these services are no longer direct employees of manufacturers; instead, they work for financially independent contractors. For example, in food, cleaning, security, and logistics services, the share of those working for such contractors in the United States rose from about 5 percent to about 30 percent between 1950 and 2015 (Dorn, Schmieder, and Spletzer 2018).

Two key changes have increased the attractiveness of outsourcing and offshoring. *The first change is increased access to foreign suppliers*, making offshoring more cost-effective for firms, largely due to advances in information technology (IT) and reductions in trade barriers since the 1990s. Advances in IT allow firms to convey detailed information about product and process specifications across long distances, while improvements in transportation, such as containerization, allow goods to be moved more quickly and consistently (Grossman and Rossi-Hansberg 2006). These developments make it possible to segment the production process, keeping highly skilled functions, such as research and development and management, in more advanced economies, while moving others, such as production of components or assembly, to countries with lower wages (Gereffi 2020).

Major trading nations have signed agreements that reduced barriers to trade, such as the 1994 North American Free Trade Agreement. These trade pacts contain strong protections for property rights of corporations, but far weaker protections for labor rights. This disparity increased the attractiveness to multinational firms of offshoring production to low-wage countries (Drake 2018). The result has been increased availability of cheaper goods for American consumers, but also significant pressure on wages and benefits that have often driven workers from the middle class (Hakobyan and McLaren 2016).

Finally, widespread international government subsidization of manufacturing industries has lowered prices that lead firms pay for inputs, and has oriented many nations' domestic industry toward global supply chain participation (Hauge 2020). For instance, in the past few decades, the Taiwan Industrial Technology Research Institute has facilitated relationships between young, domestic semiconductor manufacturers and multinational buyers. The institute helped organize two firms—the Taiwan Semiconductor Manufacturing Company and the United Microelectronics Corporation—and gave them intellectual property. By 2020, these two companies accounted for 60 percent of global semiconductor revenue (Lee 2021; Breznitz 2005). Taiwan and China have extensively subsidized their semiconductor industries, with subsidies often approaching nearly 30 percent of a company's revenue, according to the U.S. Department of Defense (2022, 36). “Made in China 2025,” China’s 10-year plan to transform itself into a world leader in high-tech industries, promotes policies that increase Chinese

firms' market share and builds globally competitive industries in key sectors without relying on foreign firms ([Congressional Research Service 2020](#)). (See box 6-2.)

The second key change is the growing role of financial criteria and institutions in corporate decisionmaking. This “financialization” of the economy has encouraged outsourcing and offshoring because of savings in costs that are easily measurable. Firms increasingly tie executive compensation to such financial measures as earnings per share, stock prices, and return on equity. Before the 1970s, only 16 percent of the chief executive officers in Standard & Poor’s 500 companies had compensation based on such measures; by the 1990s, 47 percent did, and in 2021, the vast majority employed by large corporations did ([Admati 2017](#)). Such incentives have encouraged managers to focus more on these financial statement numbers than on less easily measurable metrics, such as resilience.

However, financial metrics can be misleading. Although an outside or offshore supplier may offer a lower unit price, these savings may be eaten away by hidden costs, such as longer lead times, increased vulnerability to disruption, and reduced access to ideas for innovation due to linguistic and geographic distance ([Gray, Helper, and Osborn 2020](#)). Such hard-to-estimate costs are often ignored, even though they may negate the estimated savings from outsourcing ([Barthelemy 2001](#)). These less easily measurable metrics are often characterized as “soft” information, which, in contrast to “hard” information, may require knowledge of the environment and/or personal relationships to collect and understand.

Soft information includes operational measures that use physical units, such as defect rates or downtime, and involve such intangibles as the value of research and development or of employee training ([Liberti and Peterson 2019](#); [Edmans, Heinle, and Huang 2016](#)). It is often difficult to convert soft information into dollars. For example, it is not easy to measure how much an investment in training will improve quality, and how much this improvement in quality will flow to the bottom line. Such investments are also hard for outsiders or those without experience with a given product to verify. Thus, the pursuit of favorable performance as measured by financial indicators may induce firms to act in ways that could be detrimental to long-term performance, essentially trading longer-term resilience and sustainability for nearer-term profitability ([Edmans, Heinle, and Huang 2016](#)).

For firms increasingly driven by short-term investors’ demands, the temptation to ignore these costs has often been great. A survey of senior U.S. financial executives found a willingness to sacrifice long-term shareholder value to meet Wall Street earnings targets or smooth reported earnings. For example, when managers were asked if they would “accept a sacrifice in value . . . to avoid volatile earnings,” 78 percent said yes; 55 percent would “delay starting a new project, even if this entails a small sacrifice in value”

Box 6-2. The Role of China in U.S. Supply Chains

A significant factor in the recent evolution of global supply chains has been the rise of China, which is now the largest source of U.S. imports. China's manufacturing began exploding in the 1990s, and its share of world manufacturing exports rose from 3.1 percent in 1991 to 17.6 percent in 2015, before dipping to 14.2 percent in 2018 (Autor, Dorn, and Hansen 2021).

Initially, China specialized in simply assembling products from imported components and designs. For example, it is estimated that in 2010 China provided less than 2 percent of the value added of the Apple iPhone 4; the product was designed in the United States, and the components were made in places like Japan and South Korea; no Chinese suppliers contributed components (Linden, Kraemer, and Dedrick 2011). However, China learned quickly, and for the iPhone X in 2018, it contributed more than 25 percent of the value added, including assembly and high-value components such as the battery pack and touch screen (Linden, Kraemer, and Dedrick 2007; Xing 2019).

China's entry into global supply chains was facilitated not only by technological advance in transportation and communication but also by changes in institutions. Particularly important were the United States' granting of Permanent Normal Trading Relations (PNTR) to China in 2000 and the admission of China to the World Trade Organization in 2001, steps that gave imports from China permanent access to the relatively low tariff rates reserved for members of the World Trade Organization. These steps did not require China to change its labor policies, which banned workers from joining independent trade unions, involved reprisals against workers who sought higher wages, and involved forced labor. These policies suppressed wages in China, increasing the competitiveness of firms, including multinational firms, that produced there.

China's competitiveness was also facilitated by large subsidies, and requirements that multinationals transfer technology to Chinese firms. As the Congressional Research Service concluded, China aims to advance its national development goals and future global economic position through industrial policies that seek global civilian and military leadership in advanced and emerging technologies. China's policies feature a heavy government role in directing and funding Chinese firms to obtain foreign expertise and intellectual property in strategic industries, including aerospace, semiconductors, microelectronics, pharmaceuticals, and electric vehicles (Congressional Research Service 2020). Through these policies, and aided by U.S. companies pursuing asset-light strategies, China gained large degrees of market power in a variety of critical supply chains. For example, China has 97 percent global market share of the ingots and wafers used to make solar panels (U.S. Department of

Energy 2022). It also produces 73 percent of global lithium-ion batteries, which are the primary source of energy for electric cars (Henze 2022).

These policies may have contributed to the decrease in extreme poverty in China, which fell by over 90 percent between 1990 and 2016 (the latest year for which data are available) (World Bank 2016; Goodman 2021). These policies had significant effects on U.S. consumer prices; one estimate is that prices for consumer tradables fell 0.19 percentage point annually between 2004 and 2015 due to trade with China (Bai and Stumpner 2019).

However, these policies had negative effects on U.S. factories' vitality and innovation; increased exposure to Chinese imports significantly reduced sales, profitability, and research-and-development expenditures at U.S. firms facing import competition (Autor et al. 2020). The China shock also had adverse effects on workers. In the decade from 2000 to 2010, one-third of U.S. manufacturing workers lost their jobs; at least a quarter of this effect was due to China's accession to the World Trade Organization (Autor, Dorn, and Hanson 2016). Workers in affected industries saw rapid job loss after the United States granted PNTR status to China (Pierce and Schott 2016). Communities more exposed to Chinese imports had reduced earnings for low-wage workers, housing prices, and tax revenues; and larger increases in childhood and adult poverty, single-parenthood, and mortality related to drug and alcohol abuse, as well as greater uptake of government transfers (Pierce and Schott 2016; Autor, Dorn, and Hansen 2021).

to avoid missing an earnings target (Graham, Harvey, and Rajgopal 2019, 8). Underlying this willingness is a view that stock market investors lack the information to properly value long-term investments (Asker, Farre-Mensa, and Ljungqvist 2015; Poterba and Summers 1995).

This financialization of the economy has been an important driver of U.S. lead firms' supply chain strategies. Outsourcing of production and other capital-intensive activities is prescribed by consulting firms promoting an "asset-light" strategy. These firms note that, all else held equal, a lower amount of capital makes a given amount of revenue yield a higher measured return on assets (Kachaner and Whybrew 2014); the importance of the "all else held equal" assumption is discounted. Offshoring to suppliers with a low quoted price is also attractive. Chinese subsidies and wage suppression have yielded very low unit costs for Chinese suppliers; often, the price from a Chinese manufacturer of a finished manufactured component has been less than the price of raw materials for a U.S. supplier (U.S. Department of Defense 2022, 27). The disadvantages of such purchasing strategies are hard

to quantify; in a financialized environment, where many purchasing agents are rewarded exclusively for driving down quoted prices, these disadvantages have typically been assumed (without much evidence) to be small (Gray, Helper, and Osborn 2020).

Implications of Supply Chain Structures

This section examines the relationship between supply chains and innovation, and the role of supply chains in the business cycle. Both outsourcing and offshoring have significant effects on innovation, some positive and some negative.

Impact on Innovation

Outsourcing can lead to the development of highly specialized and innovative suppliers. Take the example of semiconductors. The particular trajectory of innovation in this industry has led to a production process with very large economies of scale; for instance, a new fabrication plant (fab) now costs at least \$12 billion to build. Because of the significant overhead involved, the more semiconductor chips a fab produces, the lower the average cost of each chip. And, with more sales, a fab's owner can invest more in research and development, enabling it to produce even more sophisticated chips (White House 2021; Jie, Yang, and Fitch 2021). In part for this reason, it has become more advantageous for firms to purchase semiconductors from a specialized semiconductor firm than to make them in house (Breznitz 2005).⁵

This semiconductor example illustrates how a buyer can obtain the benefits of suppliers' innovation simply by buying the product; as semiconductors improved and their prices fell, manufacturers were able to dramatically increase the computing power of products ranging from refrigerators to computers. Though many firms buy generic semiconductors from distributors, innovation often results from the interaction between a buyer's needs and a supplier's capabilities (Batra et al. 2016; von Hippel 1988). Apple's cutting-edge products often result from significant interaction between its designers and the producers of its semiconductors (Owen 2021; Jie, Yang, and Fitch 2021).

Although collaborative relationships have many benefits, as described above, they may also have costs, particularly in lost flexibility (Levin 2002). To minimize the costs of switching suppliers, a lead firm may use arm's-length relationships and design its production processes to enable it to outsource to firms with weak bargaining power. Though this flexibility has benefits for lead firms, it may cause their suppliers to invest less in both

⁵ As discussed above, government subsidies for semiconductor manufacturers were also an important reason why firms reduced their vertical integration into this industry.

innovation and workers due to uncertainty about the continuing demand for their products, because these investments often have customer-specific elements (see box 6-3) (Baker, Gibbons, and Murphy 1995; Helper and Henderson 2014).

The use of semiconductors in the auto industry illustrates this point. Although semiconductors became key to the operation of modern vehicles more than a decade ago, many automakers did not begin to communicate directly with semiconductor manufacturers until late 2021. Rather, they bought chips indirectly, through distributors or first-tier suppliers, and did not commit to purchases more than a few weeks out. Thus, although their product plans included more intensive use of semiconductors in future vehicles, automakers had not been credibly signaling this intention to manufacturers. Without this commitment, semiconductor manufacturers were unwilling to build new fabs for automotive-grade chips, since fabs must maintain very high capacity utilization to be profitable. Further, they did not devote resources to innovating on the dimensions important to automakers, such as reduced cost and increased reliability. In contrast, Apple has long paid to reserve capacity in advance at fabs, and has worked with semiconductor manufacturers and design firms to innovate on the dimensions important to them—speed and power (Burkacky, Lingemann, and Pototsky 2021; Ewing and Boudette 2021; Fogarty 2020; Lawrence and VerWey 2019).⁶

Innovation is affected by offshoring as well. In some cases, foreign purchases increase the ability of U.S. firms to innovate by allowing access to innovative technology developed abroad. For example, companies such as Apple, Qualcomm, and Advanced Micro Devices rely on semiconductor designs from a U.K. firm called Arm; firms such as Intel rely on the Dutch company ASML for its advanced lithography equipment (Associated Press 2022a). And some scholars have argued that offshoring of production increases U.S. firms' innovation by allowing them to focus on high-value tasks.

However, there is evidence suggesting that geographically separating production and innovation impedes innovation. Engineers overseeing production are exposed to the capabilities and problems of existing technology, helping them to generate new ideas both for improving processes and for applying a given technology to new markets. Losing this exposure reduces the opportunity to generate such innovative ideas. For example, when production of consumer electronics migrated to Asia in the 1980s, the United States lost the potential to later compete in the burgeoning market for follow-on products like flat-panel displays, LED lighting, and advanced batteries (Pisano and Shih 2012; Berger 2015; Fuchs and Kirchain 2010).

⁶ As discussed below, U.S. automakers have recently announced significant changes in the way they purchase semiconductors.

Box 6-3. Outsourcing and Job Quality

Overall, 43 percent of U.S. workers are in supply-chain industries, employed either at lead firms or their suppliers (Delgado and Mills 2020). The structure of supply chains has significant implications for job quality for these workers.

As mentioned above, sometimes outsourcing is efficient. However, in other cases, lead firms use outsourcing to gain access to suppliers with weak bargaining power, adopting a strategy that David Weil has called “fissuring.” In these cases, supplier firms have little ability to compete except by aggressively holding down wages (Weil 2017). For example, firms that sell to a small number of buyers pay lower wages than do similar firms with more customers; this greater dependence on large buyers lowers suppliers’ wages and has accounted for 10 percent of wage stagnation in nonfinancial firms since the 1970s, according to one estimate (Wilmers 2018).

Research suggests that jobs that are outsourced from lead firms to suppliers are often worse for most workers, for several reasons (Handwerker and Spletzer 2015; Goldschmidt and Schmieder 2017; Helper 2021). As summarized by Helper (2021), these reasons include:

- *Design for supplier interchangeability.* Many lead firms structure their supply chains to make contractors easily replaceable. For instance, U.S. automakers in the past brought product design and complex subassemblies in house, making it possible to have contractors compete on making small, predesigned components under short-term contracts. This strategy lowered barriers to entry for suppliers, meaning that suppliers did not capture many rents (Helper and Henderson 2014). This style of production has led many lead firms in the apparel industry to employ long chains of anonymous subcontractors. Walmart Corporation, for example, was surprised when goods marked with its label were found in the aftermath of the horrific fire at the Rana Plaza complex, in which over 1,100 Bangladeshi apparel workers were killed due to subcontractors’ poor safety practices (White 2017).
- *Monitoring without accountability.* Some lead firms specify in detail the actions to be taken by workers in their supply chains, even those who are not their employees (Davis-Blake and Broschak 2009). That is, lead firms can control workers without taking responsibility for paying them benefits. Tight monitoring from lead firms means that one of the few profit-making strategies available to subcontractors is to keep wages low. Sometimes these workers are misclassified as independent contractors, even though they lack the autonomy of running their own business. When firms misclassify workers in this way, “they offload labor costs and risks onto workers—for example, by avoiding unemployment insurance

taxes and workers' compensation premiums—and make it difficult for workers to organize or join a union and bargain collectively for better wages and conditions" ([U.S. Department of the Treasury 2022, i](#)).

- *Low supplier capability.* When lead firms maintain tight control over suppliers' work methods, subcontractors' ability to create or capture value is low. Even though investments might yield productivity improvements, contractors often do not make them because they lack the capability to do so or they would not capture much of the benefit due to fierce competition. As a result, subcontractors often cannot increase pay without risking bankruptcy. Suppliers to lead firms that adopt financialized metrics also have difficulty adopting management practices that have been shown to be effective. Fewer than half of second-tier auto suppliers have adopted practices such as quality circles, in which production employees gather regularly to explore ways to improve quality; one-third report that they do not consistently do preventive maintenance, and one-quarter employ no engineers. In contrast, suppliers that report a collaborative relationship with customers were more likely to adopt high-road policies such as cross-training of workers, and had higher productivity ([Helper and Martins 2020](#)).
- *Weak ecosystems.* Not only do U.S. suppliers lack support from lead firms; they are isolated in other ways as well ([Berger 2015](#)). The reason: There are few institutions to help with innovation, training, or finance ([Ezell and Atkinson 2011](#)). In contrast, Germany's Mittelstand, which are medium-sized firms, are the backbone of the German manufacturing sector due to the help they get from community banks, applied research institutes, training institutions, and unions ([Berger 2015](#)).

Impact on the Macroeconomy

The structure of production networks, as described in figure 6-1, has important effects on the macroeconomy. The location of supply relative to consumers, the degree of interconnection and substitutability among firms and industries, the geographic concentration of supply, and the amount of collaboration and trust between buyers and suppliers all affect the degree to which a shock to one firm or industry propagates through the entire economy.

Distinct configurations of supply chain structures carry distinct exposure profiles. For example, offshoring, or openness to international trade, can reduce exposure to domestic shocks by broadening supply or hedging against concentrated disruption ([Caselli et al. 2020; Miroudot 2020](#)).

However, the greater distance that imported inputs must travel increases risks associated with transportation. For example, 40 percent of U.S. containerized imports go through the ports of Los Angeles and Long Beach, where the rise in demand for goods induced by the COVID-19 pandemic caused significant delays (Karlamangla 2021). Even supply chains that had no production problems suffered from the shipping bottlenecks. In addition, risks to a supply chain can grow with more global connections, because a disruption in one country will affect suppliers in all other countries. For instance, Bonadio and others (2020) estimated that one-quarter of pandemic-related gross domestic product declines across 64 countries were related to global supply chain shock transmission. When disasters occur with supply chains abroad, as with the 2011 earthquake in Japan, recovery takes longer than if the supply chain was local due to the longer lead time involved in shipping.

Dependence on a single supplier or a single location also carries risk. This is true even if the suppliers are domestic; for example, a severe 2021 freeze in Texas led to months-long disruptions in U.S. and global supplies of plastics because of the concentration of petrochemical companies there (Wiseman and Krisher 2021). These risks can be greater in industries important to national security that are located abroad, because decisions about supply would be affected by the policies of another country, as discussed below.

If firms within an industry share suppliers with skills that are hard to replace, the bankruptcy of a few such suppliers can also take down other suppliers, and even lead firms, with them. Fear of this “cascading bankruptcy” in 2008, when auto sales suddenly fell 45 percent, led the CEO of Ford, Alan Mulally (2008), to ask for a government rescue of his major competitors, noting that 90 percent of Ford’s suppliers were shared with other automakers. Auto suppliers have hard-to-replace skills that include the ability to maintain high quality standards (e.g., to control variation in the size of parts produced to no more than 1/1000th of an inch, thinner than the width of a human hair), consistently over millions of parts that sell for a few dollars each. If these firms fail, other firms cannot easily enter the market to replace them. Dependence on shared suppliers is not uncommon; the computer giants Dell and Lenovo have more than 70 percent commonality in their top 20 suppliers (Lund et al. 2020). In contrast, if each downstream firm were vertically integrated (i.e., produced its own inputs), some firms might be affected by a disruption, but it is likely others would still be able to produce.

Some of these potential vulnerabilities carry offsetting benefits. For example, geographic clustering of suppliers is common, and often is efficient, because suppliers can share skilled labor, specialized inputs, and

innovative ideas (Marshall 1919; Delgado, Porter, and Stern 2015).⁷ In addition, repeated dealings and face-to-face contact build the trust required for collaborative supplier–buyer relationships (Bernstein 2015). As discussed above, close relationships among firms in the supply chain could speed recovery from disruptions (Baldwin and Freeman 2021; Alfaro and Chen 2018). That is, the reduced ability to seek new suppliers is often offset by suppliers’ increased incentive to pitch in to help others. If firms could quickly recover from supply disruptions, then the macroeconomy would not be affected as much by global supply chains’ increasing exposure to shocks and dependence on other firms (Carvalho and Tahbaz-Salehi 2019).

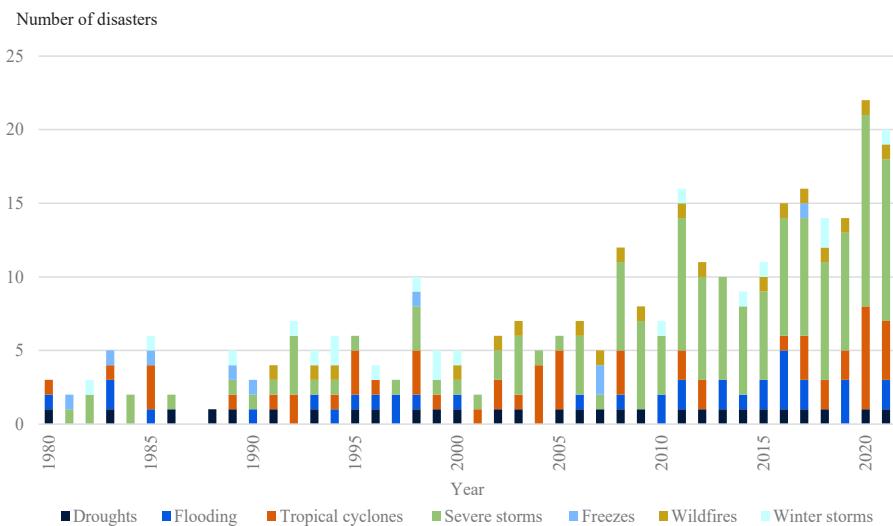
However, in the absence of such collaboration, shocks to supplier–buyer relationships can have persistent effects on the macroeconomy, especially if networks are highly connected (e.g., star-shaped) and frequently use hard-to-substitute inputs (Carvalho 2014). For instance, Barrot and Sauvagnat (2016) found that if a supplier was hit by a major U.S. natural disaster between 1978 and 2013, its key customers (those accounting for more than 10 percent of the supplier’s sales) experienced an average drop of 2 to 3 percentage points in sales growth for one to two years afterward. If the disrupted supplier produced hard-to-substitute inputs, this disruption further propagated to suppliers that were not exposed to the original shock (Barrot and Sauvagnat 2016). Bigio and La’O (2020) estimate that the input-output structure of the U.S. economy amplified financial distortions by a factor of 2 during the 2008 global financial crisis.⁸

As the consulting firm McKinsey noted in 2011, “Many global supply chains are not equipped to cope with the world we are entering. Most were engineered, some brilliantly, to manage stable, high-volume production by capitalizing on labor-arbitrage opportunities available in China and other low-cost countries” (Malik, Niemeyer, and Ruwadi 2011, 1). These conditions are less prevalent now. As networks become more connected, and climate change worsens, the frequency and size of supply-chain-related disasters rises. For this reason and others, understanding how to promote quick recovery is increasingly important. It is also vital for companies to have the incentive to make sufficient investments in resiliency, even when they may not be able to monetize all the benefits of these expenditures because of spillovers to other parts of the networked system.

⁷ Sometimes the clusters are near where natural resources required for production are or once were concentrated (e.g., steel in Cleveland). Other times “clusters” of suppliers develop near where an invention happened to occur (e.g., floor coverings in Dalton, Georgia; see Krugman 1991).

⁸ The authors compared the effects of the current star-shaped structure of the U.S. economy (panel D of figure 6-1) to what they would have been if the economy looked more like panel A (vertically integrated firms).

Figure 6-4. Frequency of Billion-Dollar Natural Disasters by Type, United States



Sources: NCEI (2021, 2022).

Note: Disaster costs are adjusted for inflation using the Consumer Price Index for All Urban Consumers.

The Rising Incidence of Supply-Chain-Related Disasters

Although the pandemic has been a particularly dramatic example of a supply-side disruption, the global frequency of natural disasters increased almost threefold between 1975–84 and 2005–14 (Vinod and López 2015), mostly due to increases in climate-related events (NCEI 2021). Lund and others (2020) found that supply chain shocks affecting global production lasting at least a month occur on average every 3.7 years.

The magnitude of damage from these events is also growing; the number of billion-dollar disasters has risen from an average of 5 annually to 20 over the past 40 years (figure 6-4). The frequency of such events is likely to continue to rise in the future, according to the United Nations Intergovernmental Panel on Climate Change (IPCC 2022).

Private Sector Incentives for Resilience

As supply chains have increased in complexity, firms' need for risk management has also grown (Baldwin and Freeman 2021). When unable to produce due to lack of inputs, firms lose revenue, providing some incentive to invest in resilience (Miroudot 2020). Practices include understanding the structure of their supply chains (visibility), investing in backup capacity (redundancy), and improving their ability to solve problems and substitute

between inputs (agility), as well as vertically integrating components of the production process (Christopher and Peck 2004; de Sá and de Souza Miguel 2019). However, these strategies, especially redundancy, increase costs (Baldwin and Freeman 2021). Thus, it is not cost-effective for firms to invest in completely avoiding all disasters. Instead, these practices are designed to reduce firms' risks, such that the perceived expected value of additional revenue during a disruption compensates for the cost of minimizing production issues (Miroudot 2020; Baldwin and Freeman 2021).

One consequence of a firm underinvesting in resiliency is that it increases the exposure of other firms in the networked system to the negative spillover effects of a disruption. This type of market failure is likely when the firm's investment decisions consider only its private costs and benefits, and it is unable to monetize the spillover benefits of its investment decisions for the rest of the system. Under certain conditions, the private sector can achieve an efficient level of investment. For example, if parties can bargain without high transaction costs, an efficient market outcome may be achieved through private contracting, or through self-policing, cooperative arrangements (Bernstein 2015). However, these approaches are infeasible when there is a large number of entities and/or contingencies involved, because these raise the transaction costs of negotiating and enforcing contracts (Coase 1960). In this case, there is an important role for government to play, as discussed below.

Visibility

A first step toward achieving resilience is for firms to learn more about their suppliers' production and inventory levels. This allows firms to monitor the capability of their supply chain to meet demand, even if the suppliers do not directly supply the lead firm. Visibility into supply chain relationships is necessary to identify vulnerabilities in supply chains, so that firms can properly plan for disruptive events (Fujimoto and Park 2014). Gaining this knowledge is not just a technical challenge but also depends on trust between buyer and supplier (MacDuffie, Heller, and Fujimoto 2021). One reason is that if a buyer learns that a supplier has a lot of extra production capacity, the buyer could push for a lower price. Beyond being able to identify suppliers, key metrics include "time to survive"—how long demand for a particular component could be met from inventory or another supplier if the regular supplier was unavailable—and suppliers' "time to recover" in case of an emergency (Simchi-Levi 2020; Simchi-Levi and Simchi-Levi 2020).

Redundancy

Firms may also invest in developing relationships with additional suppliers. Finding alternative suppliers for an input is time-consuming, and suppliers

must often go through quality verification. If firms proactively invest in building relationships with several suppliers, the lead firm has ready alternatives. Even if one supplier is unable to produce, another one can step in as a replacement.

Firms can also hold additional inventory, particularly if suppliers' lead time, or how long it takes to make their products, cannot be brought down below their time to recover from a shock (Michaelman 2007). For example, Toyota learned that its semiconductor suppliers' lead time was four months, so the automaker has kept four months of inventory of these products (Shirouzu 2021). Though redundancy generally increases costs, it can also increase profits during periods of supply chain stress by allowing production to continue. However, holding inventory may not always be effective, given that the stored parts may not be the parts needed in a crisis (Sheffi 2022). (See box 6-4.)

Agility

Firms can invest in their and their workers' ability to solve problems, thus enabling them to pivot quickly to alternative products or processes or react to abnormal situations (Baldwin and Freeman 2021; MacDuffie, Heller, and Fujimoto 2021; Helper 2021). The new process may be one that allows use of a different raw material to replace one that is unavailable, or it may be a product and process very different from what the firm has traditionally made. Another option is to increase the flexibility of their production process so that the firm can use a less specialized input. A variety of techniques promote such flexibility, including:

- Reducing lead times, by identifying the critical path and working to speed it up (Ericksen 2021).
- Investing in surge capacity, for example, by maintaining more general-purpose equipment (such as 3D printers), and more generally trained workers.
- Maintaining collaborative relationships between suppliers and customers, to identify problems early and provide incentives to fix them.
- Building problem-solving capability, including for front-line workers (see the “high-road” discussion in chapter 4, on human capital).
- Maintaining real options, or the ability to postpone decisionmaking until more information is available; for example, by producing domestically rather than enduring long shipping lead times (de Treville and Trigeorgis 2010).

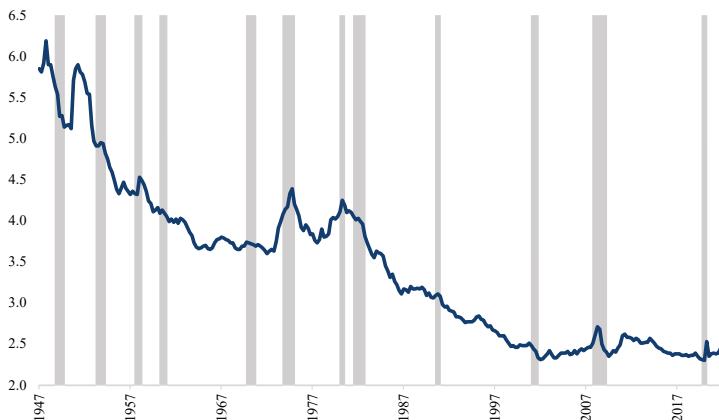
Agility may require upfront investment by firms in a supply chain, but over time may reduce costs and enhance efficiency. Investing in problem-solving capability that reduces lead time can improve performance in normal times as well as in emergencies.

Box 6-4. Low Inventories and Just-in-Time Production

In addition to moving production across firm and national boundaries, companies have been holding less inventory of both final and intermediate goods. Figure 6-ii graphs the ratio of private inventories to final sales from 1947 to 2021, for establishments operating in the United States. It is clear that, over the past 30 years, this ratio has decreased. Holding extra inventory for production increases storage costs; the lower their inventory, the less working capital is needed and the lower the probability the firm gets stuck with inputs that may become obsolete or spoil. However, if supply is disrupted and the firm has a low ratio of inventory to final sales, it has less inventory to fall back on, perhaps requiring it to shut down production until its supplier can recover its ability to produce or another supplier can be found.

As originally envisioned by Taichi Ohno at Toyota, just-in-time production combines low inventories with additional policies that offset the dangers discussed above, by speeding up the supply chain's ability to recover from disruption. These policies include localizing production near consumers and increasing operational "agility," as discussed above (Liker 2004; Handfield 2021). In contrast, many U.S. firms have combined reduced inventory with *longer* supply lines, often of 4 to 6 weeks (Buchholz 2020), and with workforce policies that limit their ability to respond to shocks, as discussed above. That is, low inventories by themselves do not necessarily lead to fragility; problems arise when low inventories are combined with low agility.

Figure 6-ii. Domestic Business Ratios of Private Inventories to Final Sales



Sources: Bureau of Economic Analysis; FRED Database of the Saint Louis Federal Reserve Bank.
Note: Shaded areas indicate U.S. recessions.

Collaborative relationships with suppliers are key to agile supply chains. For example, in February 1997, a fire at Aisin Seiki, the sole source for proportioning valves used in all Toyota vehicles, could have halted all Toyota production for weeks. However, assembly plants were reopened after only two days through collaboration between Toyota and its suppliers; more than 200 firms set up alternative valve production. This collaboration was orchestrated with limited direction from Toyota, haggling over intellectual property, or worry about repayment for expenses incurred. Long previous relationships, implicit competition for future contracts, pressure to maintain relationships, and trust with the Toyota group promoted the effectiveness and speed of the collaboration (Nishiguchi and Beaudet 1998).

Increasing domestic production may also make a firm more agile. Because proximity leads to reduced transportation time and increases the potential for better communication, domestic production helps firms develop build-to-order capability. Reduced lead time also allows decisionmakers to forecast for a smaller range of outcomes (de Treville and Trigeorgis 2010; MacDuffie, Heller, and Fujimoto 2021).

Public Sector Strategies for Promoting Resilience

The public sector can play an important role in promoting supply chain resilience, especially in helping to incentivize private sector decisions that align with broader geostrategic and economic priorities. A supply chain that crosses national boundaries means that production depends on the decisions and activities of other nations, adding uncertainty to supply. In addition, many aspects of supply chains have externalities; that is, decisions affect not only the direct decisionmakers but also other actors in the supply chain. In the presence of public goods, such as national security, government policy can improve national welfare.

The government's role in promoting robust supply chains is particularly important in two types of industries: those that provide inputs into many individual supply chains with large spillover effects, such as energy production, semiconductors, or transportation; and those that are important for national security, including climate and health security, where the assured supply provided by domestic production is especially valuable. Specifically, public sector interventions to build robust supply chains can address challenges related to aggregating and disseminating information, and to assuring that we have the products and goods essential to effective national security. Each is discussed here.

Aggregating and Disseminating Information

The public sector can play a role in disseminating information that helps markets work more efficiently. As noted above, firms often share suppliers with other firms, making them dependent on these other firms' actions. Because supply chain information can be a competitive advantage, firms may be unwilling to disclose certain data to other firms. For example, when there is a shortage of a product, such as personal protective equipment (PPE), individual hospitals are likely to overorder and hold more inventory because they want to ensure their supply. PPE suppliers in this situation do not know if they should increase capacity because they do not know if the new level of demand will continue or whether hospitals are accumulating inventory that will cause them to reduce the quantity they demand in the future. Yet hospitals would not be willing to share information about their true demand with suppliers because they could then be downgraded in priority or receive a smaller quantity of PPE.

The government has the capability to strategically collect sensitive data and release aggregate information to market participants in ways that can improve market functioning. For instance, the U.S. Department of Health and Human Services has taken on an important role in providing an accurate demand signal for PPE. The department's Supply Chain Control Tower receives near-daily data from distributors that represent more than 80 percent of the volume for the commodities it is tracking, along with supply status from 5,000 hospitals. This dashboard alleviates hospitals' fear of shortages, so they do not need to incur extra costs of holding inventory. The dashboard also allows distributors to receive a truer demand signal by reducing excessive ordering that exacerbates supply constraints (U.S. Department of Health and Human Services 2022, 13). In cases such as these, the public sector is well positioned to collect, aggregate, and disseminate this information.

The government also has a role to play in convening and coordinating private sector actors. For example, standards bodies, such as the National Institute for Standards and Technology in the Department of Commerce, have played a key role in developing standard interfaces, such as for USB ports, that allow many firms to easily participate in electronic supply chains, which promotes innovation and cost reduction.

In addition, major innovations in decentralized supply chains can suffer from a chicken-and-egg problem, in that upstream firms will not supply something until they see a demand for it, but downstream firms will not invest in products requiring that input unless there is a ready supply. A past success in resolving this dilemma was the 1990s development of a semiconductor industry road map by Sematech, a public-private partnership. The group came together to agree on common equipment needs and innovation

direction, and to fund such equipment. Sematech's convening helped equipment manufacturers make products that were compatible with what chip designers were thinking, and, conversely, helped chip designers understand the directions where equipment makers might go. Over the seven years that Sematech received Federal funding, more than \$1.65 in benefits was generated for each \$1 in Federal spending ([Link, Teece, and Finan 1996](#)).⁹

During the chip shortage arising from the pandemic, in the fall of 2021 the Department of Commerce convened CEOs of leading companies, enabling automakers and chip leaders to meet each other for the first time, and to discuss supply chain bottlenecks and identify common solutions. One such meeting led to a partnership between Ford Motor Company and Global Foundries. This partnership will focus on increasing the production capacity for Ford's existing product lines and on facilitating joint research on future chip technologies that will be critical to the next generation of vehicles. Ford's CEO announced that the company will also act to give chip producers "more confidence in future production" by buying directly from them, rather than buying chips indirectly through other suppliers ([Hicks 2021](#), 1). General Motors recently announced a similar partnership with seven semiconductor producers. Advances in supply chain management will be crucial for auto manufacturers in the next several years, given that new vehicles, especially electric vehicles, could lead to a doubling of semiconductor requirements ([Colias and Foldy 2021](#)).

National Security

Dependence on a foreign supplier in times of geopolitical conflict makes supply chains fragile, particularly for a good that has few close substitutes. Foreign control of a key resource is a valuable geopolitical bargaining chip ([Sanger and Schmitt 2022](#)). Currently, the United States is heavily dependent on foreign suppliers for semiconductors and batteries, which are key inputs for much military technology. In 2021, 92 percent of the world's supply of advanced semiconductors came from one company, TSMC, in one location, Taiwan ([Lee, Shirouzu, and Lague 2021](#)). Similarly, key parts of battery supply chains are largely located in China, which refines 60 percent of the world's lithium and 80 percent of the world's cobalt—two core inputs to high-capacity batteries, without close substitutes. Access to these inputs critical for defense is more assured if the goods are produced domestically ([White House 2021a](#)).

⁹ The rationale for this calculation is as follows: "The unweighted ratio [of benefits to costs] for fully burdened cost is 3.3. Of course, when Federal dollars are added to the cost basis, all of the ratios in table 4 are reduced in half"; [Link, Teece, and Finan \(1996, 748\)](#). So, $3.33/2 = 1.65$; these are private benefits only; the paper did not estimate public benefits (hence "more than" \$1.65).

Profit-maximizing firms do not take full account of this spillover benefit to domestic production. National defense is an example of a public good; it is both nonrival—that is, consumption does not diminish others' ability to consume the good—and nonexcludable, which means that those that do not pay cannot be blocked from using the good. Because people can use public goods without paying for them, the private sector will undersupply these goods. For this reason, governments typically provide for national security.

Having at least some domestic production of critical goods also means that, in the event of a natural disaster, U.S. firms are not dependent on the policy choices of other countries. China's COVID-19 policies that locked down whole cities or ports for a small number of cases disrupted production for firms in countries with different policy approaches and different case counts (Kuttner 2022). Though the United States has underinvested in a variety of industries, moving toward 100 percent domestic production is not necessarily the best response to these risks, given that allies and partners may have a competitive advantage in some goods, and may allow diversification in case of domestic disruption (White House 2021a).

In addition to inputs directly used in defense production, governments spend significant amounts of time and money to protect electricity and communication networks from supply chain disruptions. These sectors are hub industries; as such, they are part of the production process for almost all economic activity. To protect the power grid from cyberattacks, the Federal Energy Regulatory Commission mandates minimum cybersecurity standards for systems necessary for operating the electric transmission network, and the Department of Energy provides cybersecurity training and guidance (GAO 2021). Though power generation companies have an incentive to protect against shutdowns that would decrease their revenue, disruption of the power sector could cause economywide disruption far larger than the impact on electricity industry revenue. In these types of industries, where disruptions affect the ability of other industries to produce, particularly industries that are important to the Nation's health and safety, the private sector does not internalize the full costs of disruption to society.

Public sector intervention can be beneficial in these cases. In critical sectors, the public may be willing to pay a higher cost than would the private sector to avoid shortages. For example, the United States maintains large stocks of food and keeps defense capabilities ready even during peacetime, because the possibility of insufficient supply is so costly (Baldwin and Freeman 2021). In these cases, the public sector must intervene to reach the socially optimal level of resilience. Such intervention could include investments in U.S. manufacturing, using public procurement to stabilize demand for U.S. supply chains, and helping small business invest in upgraded capabilities (see box 6-5).

Box 6-5. Policies to Improve the Functioning of Supply Chains

The Biden-Harris Administration has been taking a number of steps to help improve the functioning of supply chains. The focus has been on strengthening critical supply chains, including those necessary to tackle the climate crisis. The Administration has taken steps such as the following:

- Signed an executive order that directs agencies to fortify our Nation’s supply chains and industrial bases, including focusing attention on the supply chains of products critical to our economic and national security ([White House 2021a](#); [Executive Order 14017 2021](#)).
- Established the Supply Chain Disruptions Task Force to address the challenges arising from the pandemic-affected economic recovery ([White House 2021c](#)).
- Directed seven Cabinet agencies to publish reports identifying key weaknesses in some of the Nation’s most crucial supply chains, and devised multiyear strategies to address these weaknesses ([White House 2022b](#)).
- Enacted the Bipartisan Infrastructure Law, which is our Nation’s most significant investment ever in modernizing the transportation systems on which our supply chains depend ([White House 2021d](#)).
- Enacted the American Rescue Plan, which, among other programs, authorized the \$10 billion State Small Business Credit Initiative, which will catalyze more than \$70 billion in lending and investment in small businesses—including small manufacturers—during the decade ([White House 2021e](#)).
- Issued the new Buy American rule that increases required U.S. content in Federal procurement, and will create a new category of critical products that are eligible for enhanced price preferences to ensure that Federal spending supports American businesses ([White House 2021f](#)).
- Proposed a new domestic financing initiative through the Export-Import Bank to strengthen U.S. manufacturing exports.

In addition to their direct effects, policies such as these have the potential to catalyze private sector investments, consistent with the argument in chapter 1 that the public sector can be a partner of the private sector, rather than a rival.

National security includes not only direct inputs into military security but also inputs critical to citizens’ health, climate, and economic security. As such, developing new supply chains is key to U.S. efforts to address climate change (see chapter 7 on climate). In general, private firms invest

too little in addressing climate change due to the fact they do not capture all of the benefits, providing a rationale for government intervention, as discussed in chapter 7. Decentralized supply chains face an additional issue in making these investments: coordination of demand and supply (Samford and Breznitz 2022).

For example, firms will not invest in making components for electric vehicles unless they think there will be demand for them. Conversely, automakers will slow their investments in electric vehicles if they think components will be hard to obtain. The Biden-Harris Administration’s actions will help to overcome these chicken-and-egg problems that make it hard to establish new industries. For example, the Bipartisan Infrastructure Law invests billions of dollars in establishing mining and recycling programs for batteries. The White House has also convened automakers, unions, environmental groups, and suppliers to coordinate plans to make and sell electric cars and trucks that would use these batteries. The Administration learned from these meetings what level of electric vehicle penetration might be feasible, before publicly announcing the goal that 50 percent of U.S. light vehicle sales should be “zero emission vehicles” by 2030 (White House 2021b). The certainty provided by these actions has unlocked billions in private sector investments in battery production that will employ thousands of people in states like Tennessee and Michigan (Associated Press 2022b; Eggert 2022). Similarly, the Administration has announced the goal that solar energy will produce 45 percent of U.S. electricity by 2050, with tax credits targeted at each stage of the solar panel supply chain (Fears 2021).

Indirect Supply Chain Policy

Many other government policies have implications for the structure of modern supply chains. This section provides examples of economic policies that are broader than supply chains but nevertheless have implications for their structure.

The price of shipping intermediate goods thousands of miles during the production process does not incorporate the social cost of emissions. Transportation contributes about 29 percent of all U.S. greenhouse gas emissions, which have been rising (EPA 2021). For example, international shipping currently accounts for about 3 percent of total global greenhouse gas emissions. If treated as a country, international shipping would have been the sixth-largest emitter of energy-related carbon dioxide in 2015—more than Germany (Chen, Fei, and Wan 2019; Gallucci 2021; IMO 2021; Olivier et al. 2016; Rose et al. 2021; Olner et al. 2017). Pricing in the true cost of moving goods—that is, to include greenhouse gas emissions—would incentivize firms to reduce their use of transportation services; for example, by producing closer to where their customers live, or investing in new low-carbon fuels. (See chapter 7, on climate.)

Trade policy also has enormous implications for the structure of supply chains. As discussed above, China’s entry into the World Trade Organization led to a significant increase in offshoring, which has reduced consumer prices but also has harmed U.S. innovation, employment, and wages for decades. The North American Free Trade Agreement (NAFTA) has been found to have had similar employment and wage effects, albeit on a smaller scale (Hakobyan and McLaren 2016), although a 2020 revision to NAFTA, the United States–Mexico–Canada Agreement, has somewhat addressed these issues. Newer emissions-based policies—like the global arrangement for steel and aluminum trade between the United States and the European Union—promise to further reshape supply chains by incentivizing production of lower-emissions goods. These newer policies offer the promise that global supply chains can be designed in a way that benefits people in rich and poor nations alike.

Conclusion

Because of outsourcing, offshoring, and insufficient investment in resilience, many supply chains have become complex and fragile, with central nodes that lack agility and have few substitutes. Some of this change has been driven by advances in technology, which have beneficial effects. For example, because more of today’s products are electronic, semiconductors have become a central node in the economy.¹⁰ However, this evolution has also been driven by shortsighted assumptions about cost reduction that have ignored important costs that are hard to turn into financial measures, or that spilled over to affect others. The validity of these assumptions is reduced in a world where disruptions have become more prevalent and firms are more tightly interconnected.

The COVID-19 pandemic has made these issues salient to the general public, which has experienced frustrating waiting times for the delivery of goods ranging from personal protective equipment to appliances. Though supply chains have performed well in the aggregate, with over 20 percent more goods flowing through the economy in 2021 compared with pre-pandemic times, it is still important to address supply chain fragility, given that disruptions are likely to continue. As disruptions become more common, private firms are beginning to increase their resilience through visibility, redundancy, and agility. The Federal Government has acted, and will continue to act, to build resilience in critical supply chains—for example, by providing clear signals of demand and supply that are already transforming sectors critical for the Nation’s military, climate, and health security.

¹⁰ Note that this change was also significantly promoted by U.S. government supply chain policy over many decades, as described in the text; see also Council of Economic Advisers (2021).