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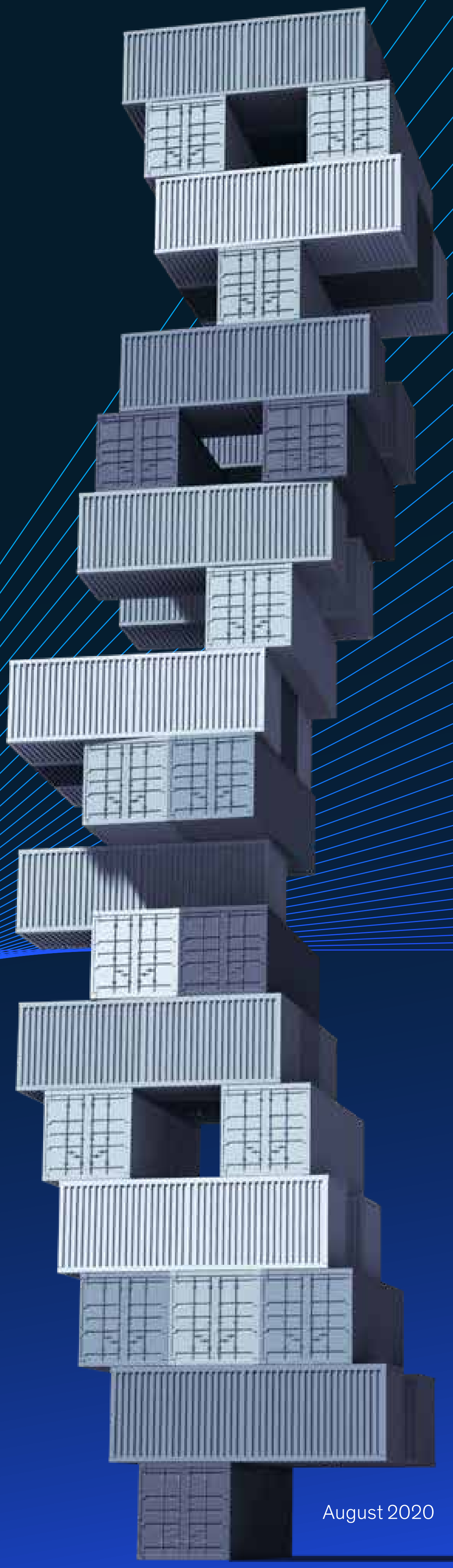
Risk, resilience, and rebalancing in global value chains



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MGI is led by three McKinsey & Company senior partners: co-chairs James Manyika and Sven Smit and director Jonathan Woetzel. Michael Chui, Susan Lund, Anu Madgavkar, Jan Mischke, Sree Ramaswamy, Jaana Remes, Jeongmin Seong, and Tilman Tacke are MGI partners. Mekala Krishnan is an MGI senior fellow, and Sundiatu Dixon-Fyle is a visiting senior fellow. Project teams are led by the MGI partners and a group of senior fellows and include consultants from McKinsey offices around the world. These teams draw on McKinsey's global network of partners and industry and management experts.

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Preface

Manufactured goods take lengthy and complex journeys through global value chains as raw materials and intermediate inputs are turned into the final products that reach consumers. But global production networks that took shape to optimize costs and efficiency often contain hidden vulnerabilities—and external shocks have an uncanny way of finding and exploiting those weaknesses. In a world where hazards are occurring more frequently and causing greater damage, companies and policy makers alike are reconsidering how to make global value chains more resilient. All of this is occuring against a backdrop of changing cost structures across countries and growing adoption of revolutionary digital technologies in global manufacturing.

Applying MGI's micro-to-macro methodology, this report considers the issues and investment choices facing individual companies as well as the implications for global value chains, trade, and national economies. It builds on a large multiyear body of MGI research on topics such as global value chains and flows, manufacturing, digitization, and climate risk. This includes major reports such as *Manufacturing the future* (2012), *Global flows in a digital age* (2014), *Digital globalization* (2016), *Making it in America* (2017), *Globalization in transition* (2019), and *Climate risk and response* (2020), among others. This work also draws on McKinsey's on-the-ground experience in operations, supply chain management, and risk across multiple industries.

Our past research highlights important structural changes in the nature of globalization; goods producing value chains have become less trade-intensive, even as cross-border services are increasing. The share of global trade based on labor-cost arbitrage has been declining over the last decade and global value chains are becoming more knowledge-intensive and reliant on high-skill labor. Finally, goods-producing value chains are becoming more regionally concentrated. This report extends that research to better understand supply chain risk and resiliency. While the COVID pandemic has delivered the biggest and broadest value chain shock in recent memory, it is only the latest in a series of disruptions that has exposed value chains and companies to damages.

The research was led by Susan Lund, an MGI partner based in Washington, DC; James Manyika, MGI's co-chair, based in San Francisco; Jonathan Woetzel, an MGI director based in Shanghai; Ed Barriball, a Washington, DC–based partner who specializes in manufacturing, supply chain, and logistics; Mekala Krishnan, an MGI senior fellow, based in Boston; Knut Alicke, a Stuttgart-based partner with expertise in manufacturing and supply chains; Michael Birshan, a London-based senior partner who focuses on strategy and risk; Katy George, a New Jersey–based senior partner with expertise in manufacturing, operations strategy, and operating model design; Sven Smit, MGI's co-chair, based in Amsterdam; and Dan Swan, who leads McKinsey's global supply chain practice. The project team, led by Kyle Hutzler, included Bader Almubarak, Djavaneh Bierwirth, Mackenzie Donnelly, Dhiraj Kumar, Karol Mansfeld, Palak Pujara, and Stephanie Stefanski. Henry Marcil also provided leadership, insight, and support.

Many McKinsey colleagues contributed to this effort, and our research benefited immensely from their industry expertise and perspectives. We are grateful to Ingo Aghte, Emre Akgul, Aykut Atali, Xavier Azcue, Cengiz Bayazit, Stefan Burghardt, Ondrej Burkacky, Ana Calvo, Bob Cantow, Stephen Chen, Jeffrey Condon, Alan Davies, Arnav Dey, Reed Doucette, Hillary Dukart, Elena Dumitrescu, Phil Duncan, Kim Elphinstone, Ankit Fadia, Ignacio Felix, Tacy Foster, Kevin Goering, Arvind Govindarajan, Paul Hackert, Will Han, Philipp Härle, Liz Hempel, Drew Horah, Tore Johnston, Roos Karssemeijer, Pete Kimball, Tim Koller, Vik Krishnan, Randy Lim, Karl-Hendrik Magnus, Yogesh Malik, Adrian Martin, Brenden McKinney, Ricardo Moya-Quiroga, Mike Parkins, Parag Patel, Fernando Perez, Moira Pierce, Jose Maria Quiros, Sree Ramaswamy, Rafael Rivera, Sean Roche, Peter Russell, Paul Rutten, Julian Salguero, Hamid Samandari, Emily Shao, Smriti Sharma, Anna Strigel, Krish Suryanarayan, Nicole Szlezak, Vaibhav Talwar, and Bill Wiseman.

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This report contributes to MGI's mission to help business and policy leaders understand risks our society and the global economy face and how to build resilience against them. As with all MGI research, this work is independent, reflects our own views, and has not been commissioned by any business, government, or other institution. We welcome your comments on the research at MGI@mckinsey.com.

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SHIPPING
CARGO

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In brief

Risk, resilience, and rebalancing in global value chains

Intricate supplier networks that span the globe can deliver with great efficiency, but they may contain hidden vulnerabilities. Even before the COVID-19 pandemic, a multitude of events in recent years temporarily disrupted production at many companies. Focusing on value chains that produce manufactured goods, this research explores their exposure to shocks, their vulnerabilities, and their expected financial losses. We also assess prospects for value chains to change their physical footprint in response to risk and evaluate strategies to minimize the growing cost of disruptions.

Shocks that affect global production are growing more frequent and more severe. Companies face a range of hazards, from natural disasters to geopolitical uncertainties and cyberattacks on their digital systems. Global flows and networks offer more "surface area" for shocks to penetrate and damage to spread. Disruptions lasting a month or longer now occur every 3.7 years on average, and the financial toll associated with the most extreme events has been climbing. Shocks can be distinguished by whether they can be anticipated, how frequently they occur, the breadth of impact across industries and geographies, and the magnitude of impact on supply and demand.

Value chains are exposed to different types of shocks based on their geographic footprint, factors of production, and other variables. Those with the highest trade intensity and export concentration in a few countries are more exposed than others. They include some of the highest-value and most sought-after industries, such as communication equipment, computers and electronics, and semiconductors and components. Many labor-intensive value chains, such as apparel, are highly exposed to pandemics, heat stress, and flood risk. In contrast, food and beverage and fabricated metals have lower average exposure to shocks because they are among the least traded and most regionally oriented value chains.

Operational choices can heighten or lessen vulnerability to shocks. Practices such as just-in-time production, sourcing from a single supplier, and relying on customized inputs with few substitutes amplify the disruption of external shocks and lengthen companies' recovery times. Geographic concentration in supply networks can also be a vulnerability. Globally, we find 180 traded products (worth $134 billion in 2018) for which a single country accounts for the vast majority of exports.

Value chain disruptions cause substantial financial losses. Adjusted for the probability and frequency of disruptions, companies can expect to lose more than 40 percent of a year's profits every decade on average. But a single severe event that disrupts production for 100 days—something that happens every five to seven years on average—could erase almost a year's earnings in some industries. Disruptions are costly to societies, too: after disasters claim lives and damage communities, production shutdowns can cause job losses and goods shortages. Resilience measures could more than pay off for companies, workers, and broader societies over the long term.

The interconnected nature of value chains limits the economic case for making large-scale changes in their physical location. Value chains often span thousands of companies, and their configurations reflect specialization, access to consumer markets around the world, long-standing relationships, and economies of scale. Primarily labor-intensive value chains (such as apparel and furniture) have a strong economic rationale for shifting to new locations. Noneconomic pressures may prompt movement in others, such as pharmaceuticals. Considering both industry economics and national policy priorities, we estimate that 16 to 26 percent of global goods exports, worth $2.9 trillion to $4.6 trillion, could conceivably move to new countries over the next five years if companies restructure their supplier networks.

Building supply chain resilience can take many forms beyond relocating production. This includes strengthening risk management capabilities and improving transparency; building redundancy in supplier and transportation networks; holding more inventory; reducing product complexity; creating the capacity to flex production across sites; and improving the financial and operational capacity to respond to shocks and recover quickly from them.

Becoming more resilient does not have to mean sacrificing efficiency. Our research highlights the many options for strengthening value chain resilience, including opportunities arising from new technologies. Where companies cannot directly prevent shocks, they can still position themselves to reduce the cost of disruption and the time it takes to recover. Companies have an opportunity to emerge from the current crisis more agile and innovative.

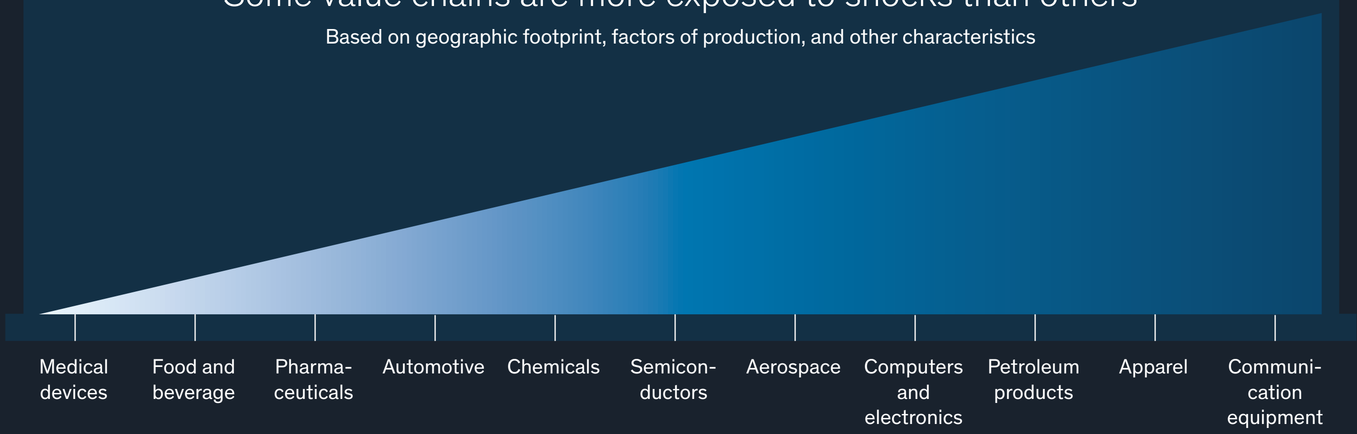
Risk, resilience, and rebalancing in global value chains

Supply chain shocks are becoming more frequent and severe

A disruption of this length . . .	. . . occurs at this interval
1–2 weeks	2.0 years
2–4 weeks	2.8 years
1–2 months	3.7 years
2+ months	4.9 years

Some value chains are more exposed to shocks than others

Based on geographic footprint, factors of production, and other characteristics



Supply chain disruptions are costly

Shock exposure × **Vulnerability** = **Value chain risk**

Shock exposure

Unexpected events that cause disruption

Force majeure

Macropolitical

Malicious actors

Idiosyncratic

Vulnerability

Fragility in key areas

Demand planning and inventory

Supplier network structure

Transportation and logistics

Balance sheet

Product and portfolio complexity

Value chain risk

Companies can expect to lose

42%

of one year's EBITDA every decade. Investing to minimize these losses can pay off over the long term

Companies can build resilience by improving supply chain management and transparency, minimizing exposure to shocks, and building their capacity to respond

McKinsey Global Institute

Executive summary

In recent decades, value chains have grown in length and complexity as companies expanded around the world in pursuit of margin improvements. Since 2000, the value of intermediate goods traded globally has tripled to more than $10 trillion annually. Businesses that successfully implemented a lean, global model of manufacturing achieved improvements in indicators such as inventory levels, on-time-in-full deliveries, and shorter lead times.

However, these operating model choices sometimes led to unintended consequences if they were not calibrated to risk exposure. Intricate production networks were designed for efficiency, cost, and proximity to markets but not necessarily for transparency or resilience. Now they are operating in a world where disruptions are regular occurrences. Averaging across industries, companies can now expect supply chain disruptions lasting a month or longer to occur every 3.7 years, and the most severe events take a major financial toll.

This report explores the rebalancing act facing many companies in goods-producing value chains as they seek to get a handle on risk. Our focus is not on ongoing business challenges such as shifting customer demand and suppliers failing to deliver, nor on ongoing trends such as digitization and automation. Instead, we consider risks that manifest from exposure to the most profound shocks, such as financial crises, terrorism, extreme weather, and, yes, pandemics.

The risk facing any particular industry value chain reflects its level of exposure to different types of shocks, plus the underlying vulnerabilities of a particular company or in the value chain as a whole. We therefore examine the growing frequency and severity of a range of shocks, assess how different value chains are exposed, and examine the factors in operations and supply chains that can magnify disruption and losses. Adjusted for the probability and frequency of disruptions, companies can expect to lose more than 40 percent of a year's profits every decade, based on a model informed by the financials of 325 companies across 13 industries. However, a single severe shock causing a 100-day disruption could wipe out an entire year's earnings or more in some industries—and events of this magnitude can and do occur.

Recent trade tensions and now the COVID-19 pandemic have led to speculation that companies could shift to more domestic production and sourcing. We examined the feasibility of movement based on industry economics as well as the possibility that governments might act to bolster domestic production of some goods they deem essential or strategic from a national security or competitiveness perspective. All told, we estimate that production of some 16 to 26 percent of global trade, worth $2.9 trillion to $4.6 trillion, could move across borders in the medium term. This could involve some combination of reverting to domestic production, nearshoring, and shifting to different offshore locations.

Moving the physical footprint of production is only one of many options for building resilience, which we broadly define as the ability to resist, withstand, and recover from shocks. In fact, technology is challenging old assumptions that resilience can be purchased only at the cost of efficiency. The latest advances offer new solutions for running scenarios, monitoring many layers of supplier networks, accelerating response times, and even changing the economics of production. Some manufacturing companies will no doubt use these tools and devise other strategies to come out on the other side of the pandemic as more agile and innovative organizations.

With shocks growing more frequent and severe, industry value chains vary in their level of exposure

The COVID pandemic has delivered the biggest and broadest value chain shock in recent memory (see Box E1, "Globalization before and after COVID-19"). But it is actually the latest in a long series of disruptions. In 2011, for instance, a major earthquake and tsunami in Japan shut down factories that produce electronic components for cars, halting assembly lines worldwide. The disaster also knocked out the world's top producer of advanced silicon wafers, on which semiconductor companies rely. Just a few months later, flooding swamped factories in Thailand that produced roughly a quarter of the world's hard drives, leaving the makers of personal computers scrambling. In 2017, Hurricane Harvey, a Category 4 storm, smashed into Texas and Louisiana. It disrupted some of the largest US oil refineries and petrochemical plants, creating shortages of key plastics and resins for a range of industries.

80%

of global trade involves nations with declining political stability scores from the World Bank

This is more than just a run of bad luck. Changes in the environment and in the global economy are increasing the frequency and magnitude of shocks. Forty weather disasters in 2019 caused damages exceeding $1 billion each—and in recent years, the economic toll caused by the most extreme events has been escalating.[1] As a new multipolar world takes shape, we are seeing more trade disputes, higher tariffs, and broader geopolitical uncertainty. The share of global trade conducted with countries ranked in the bottom half of the world for political stability, as assessed by the World Bank, rose from 16 percent in 2000 to 29 percent in 2018. Just as telling, almost 80 percent of trade involves nations with declining political stability scores.[2] Increased reliance on digital systems increases exposure to a wide variety of cyberattacks; the number of new ransomware variations alone doubled from 2018 to 2019.[3] Interconnected supply chains and global flows of data, finance, and people offer more "surface area" for risk to penetrate, and ripple effects can travel across these network structures rapidly.

To understand the full range of potential disruptions and avoid the trap of "fighting the last war," companies must look beyond the latest disaster. Not all shocks are created equal. Some pass quickly, while others can sideline multiple industry players for weeks or even months. Business leaders often characterize shocks in terms of their source. These may include *force majeure* events, such as natural disasters; macropolitical shocks, such as financial crises; the work of malicious actors, such as theft; and idiosyncratic shocks, such as unplanned outages. But characteristics beyond the source of a shock determine its scope and the severity of its impact on production and global value chains.

Exhibit E1 classifies different types of shocks based on their impact, lead time, and frequency of occurrence. In a few cases, we show hypothetical shocks like a global military conflict or a systemic cyberattack that would dwarf the most severe shocks experienced to date. While these may be only remote possibilities, these scenarios are in fact studied and planned for by governments and security experts. The impact of a shock can be influenced by how long it lasts, the ripple effects it has across geographies and industries, and whether a shock hits the supply side alone or also hits demand.

1 *Eye of the Storm*, "Earth's 40 billion-dollar weather disasters of 2019," *Scientific American* blog entry by Jeff Masters, January 22, 2020; and Matteo Coronese et al., "Evidence for sharp increase in the economic damages of extreme natural disasters," *Proceedings of the National Academy of Sciences,* October 2019, Volume 116, Number 43.
2 World Bank, Worldwide Governance Indicators 2018 (political stability and absence of violence/terrorism).
3 Anthony Spadafora, "Ransomware mutations double in 2019," TechRadar, August 20, 2019.

Box E1

Globalization before and after COVID-19

Trade flows ultimately reflect where countless companies decide to invest and make, buy, or sell things—as well as the intermediaries and arrangements they set up to do this as productively as possible. Trade in manufactured goods soared in the 1990s and early 2000s, propelled by China's entry into the WTO and the search by multinational companies for lower-cost inputs and wages. Digital communication lowered transaction costs, enabling companies to do business with suppliers and customers halfway around the world. Overall, goods trade grew at more than twice the rate of global GDP growth over this period. MGI's analysis finds that, over a decade, all types of flows acting together have raised world GDP by 10.1 percent over what would have resulted in a world without any cross-border flows.[1]

The 2008 financial crisis interrupted those trends, causing global trade flows to plummet. When the global economy recovered, they stabilized but did not return to their past growth trajectory. As described in MGI's 2019 research, this was largely because China and other emerging economies reached the next stage of their development.[2] They initially participated in global value chains as assemblers of final goods, but increasingly became the world's major engine of demand growth and started to develop more extensive domestic supply chains, decreasing their reliance on imported inputs. As a result of these developments, a smaller share of the goods produced worldwide is sold across borders.

The latest wave of manufacturing technologies also meant shifting dynamics within global value chains; only 13 percent of overall goods trade in 2018 involved exports from a low-wage country to a high-wage country.[3] In all except the most labor-intensive industries, companies started to base location decisions on other factors, including access to highly skilled talent, supplier ecosystems, infrastructure, business environment, and IP protection. Another long-term evolution is the regionalization of production networks. Long-haul trade between regions took off in the 1990s and early 2000s as global supply chains lengthened. But recently, trade has become more regionally concentrated, particularly within Europe and Asia–Pacific. This has enabled companies to serve major markets quickly and responsively. With rising complexity of global production, as well as concerns over trade disputes pre-COVID, supply chain risk and resilience have also been emerging as increasing considerations on companies' radars.

In the wake of the pandemic, travel, tourism, and migration may take years to return to previous levels. Trade in goods has taken a substantial hit, falling by 13 percent in the first three months of 2020. But much of this is due to a sharp contraction in demand that should eventually reverse when the virus is contained and economies recover. In the meantime, cross-border digital flows continue to take on greater importance as the connective tissue of the global economy.

COVID-19 seems to be accelerating some of the trends that were already manifesting within the world's value chains, including the regionalization of trade and production networks, the growing role of digitization, and the focus on proximity to consumers.[4] The increasing use of automation technologies in manufacturing is lessening the importance of low labor costs—and more automated plants could be more resilient in the face of pandemics and heat waves (although potentially more vulnerable to cyberattacks).

Companies and governments alike are reassessing the way goods flow across borders, and they may still make targeted adjustments to shore up the places where they see fragility. But the pandemic has not reshaped the world's production networks in dramatic ways thus far. After all, global value chains took on their current structures over many years, reflecting economic logic, hundreds of billions of dollars' worth of investment, and long-standing supplier relationships. A major multinational's supplier network may encompass thousands of companies, each with its own specialized contribution.

Tariffs and tax policies are often used by governments to try to shift where things are made. But many considerations go into where companies place manufacturing and where they source. These include growth in consumer demand, speed to market, changing labor and input costs, new technologies, and the availability of specialized workforce skills. Risk and resilience now feature prominently on that list as well—and even though the costs of risk are growing, they do not imply the end of globalization's opportunities.

1 *Digital globalization: The new era of global flows,* McKinsey Global Institute, March 2016.
2 All of the structural trends described here are explored in *Globalization in transition: The future of trade and value chains,* McKinsey Global Institute, January 2019.
3 Defined as exports from a country where GDP per capita is one-fifth that of the importing country or less. Even if we vary the ratio of GDP per capita of the exporter and importer, we continue to see a decline in labor-cost arbitrage in value chains producing labor-intensive goods.
4 See *Globalization in transition: The future of trade and value chains,* McKinsey Global Institute, January 2019.

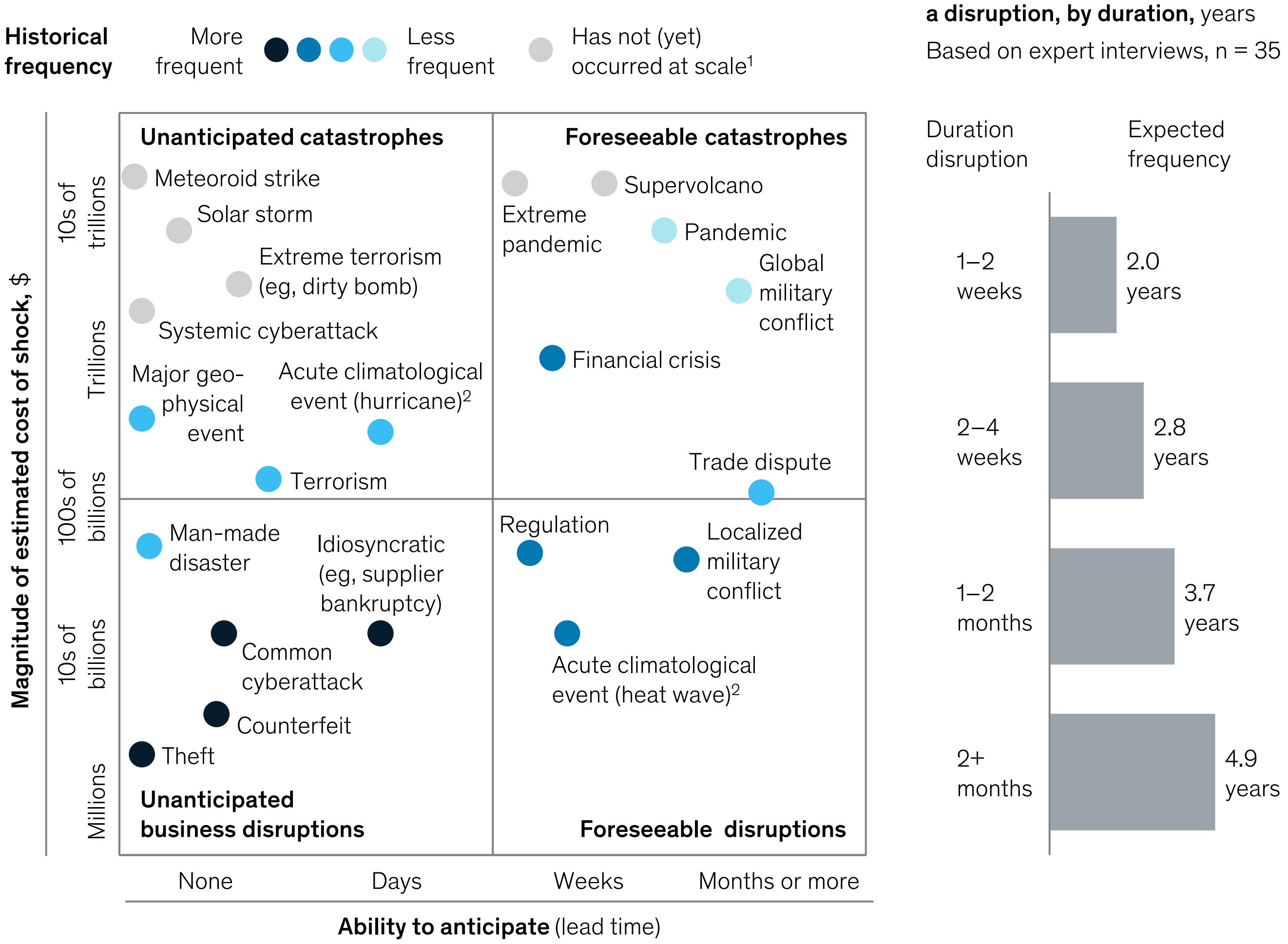
Exhibit E1

Disruptions vary based on their severity, frequency, and lead time—and they occur with regularity.

Magnitude and ability to anticipate

Expected frequency of a disruption, by duration, years

Based on expert interviews, n = 35



1. Shocks that have not occurred either at scale (eg, extreme terrorism, systemic cyberattack, solar storm) or in modern times (eg, meteoroid strike, supervolcano).
2. Based on experience to date; frequency and/or severity of events could increase over time.
Source: McKinsey Global Institute analysis

This analysis reveals four broad categories of shocks. Catastrophes are historically remarkable events that cause trillions of dollars in losses. Some are foreseeable and have relatively long lead times, while others are unanticipated. Shocks that offer at least some degree of advance warning include financial crises, major military conflicts, and pandemics such as the one gripping the world today. Another set of catastrophes includes extreme weather, geophysical natural disasters, and major terrorist attacks. It may be possible to anticipate the frequency and magnitude of these events by looking at larger patterns and probabilities; hurricanes strike in the Gulf of Mexico every year, for example. But the manifestation of a specific event can strike with little to no warning. This includes some calamities that the world has avoided to date, such as a cyberattack on foundational global systems.

Disruptions are serious and costly events, although on a smaller scale than catastrophes. They, too, can be split into those that telegraph their arrival in advance (such as the recent US–China trade disputes and the United Kingdom's exit from the European Union) and unanticipated events such as data breaches, product recalls, logistics disruptions, and industrial accidents. Disruptions do not cause the same cumulative economic toll as catastrophes.

Companies tend to focus much of their attention on managing the types of shocks they encounter most often, which we classify as "unanticipated disruptions." Most companies now consider cybersecurity part of their overall risk management processes, for example. Some other shocks such as trade disputes have made headlines in recent years and, as a result, companies have started to factor them into their planning. But other types of shocks that occur less frequently could inflict bigger losses and also need to be on companies' radars. The COVID pandemic is a reminder that outliers may be rare—but they are real possibilities that companies need to consider in their decision making.

Shocks may emerge within or from outside the affected supply chain ecosystem. Disruptions that are internal to the ecosystem, such as a supplier bankruptcy or unexpected plant shut-down, are often preventable. By contrast, companies cannot hold off external disruptions such as pandemics and natural disasters—but they can assume a posture focused on minimizing their impact. Managing each of these shocks requires companies to analyze their exposure and vulnerability and put different types of resilience measures in place. For example, shocks that come with long lead times may require establishing early warning systems. Those that are difficult to anticipate may require more backup capacity and inventory that can be activated once a shock occurs.

Shocks lasting a month or more occur every

3.7 years

All four types of shocks can disrupt operations and supply chains, often for prolonged periods. We surveyed dozens of experts in four industries (automotive, pharmaceuticals, aerospace, and computers and electronics) to understand how often they occur. Respondents report that their industries have experienced material disruptions lasting a month or longer every 3.7 years on average. Shorter disruptions have occurred even more frequently.

We analyzed 23 industry value chains to assess their exposure to specific types of shocks. The resulting index (Exhibit E2) combines multiple factors, including how much of the industry's current geographic footprint is found in areas prone to each type of event, the factors of production affected by those disruptions and their importance to that value chain, and other measures that increase or reduce susceptibility. For example, heat waves affect some regions more than others. Within them, labor-intensive value chains are at comparatively higher risk—and within that group, those with the highest concentration of workers in outdoor or non-climate-controlled settings are most exposed to disruption.[4]

[4] This is an assessment of value chain *exposure* to shocks; it does not consider vulnerability, or an industry's degree of resilience against the shocks to which it is exposed. For instance, while semiconductor production is common in places that are earthquake prone, engineering standards may mean that factories are built to withstand them.

Exhibit E2

Each value chain's exposure to shocks is based on its geographic footprint and factors of production.

Less exposed — More exposed

Rank of exposure (1 = most exposed)

	Value chain	Overall shock exposure	Pandemic[1]	Large-scale cyber-attack[2]	Geo-physical event[3]	Heat stress[4]	Flooding[5]	Trade dispute[6]
Global innovations	Chemical	11	16	4	6	19	16	8
	Pharmaceutical	19	23	2	17	23	19	4
	Aerospace	8	2	1	18	20	21	5
	Automotive	14	6	9	12	21	18	6
	Transportation equipment	4	5	12	7	13	5	15
	Electrical equipment	16	17	11	9	15	15	10
	Machinery and equipment	18	9	10	20	17	20	7
	Computers and electronics	6	15	5	4	14	14	9
	Communication equipment	1	13	3	2	16	7	2
	Semiconductors and components	9	19	6	1	18	23	1
	Medical devices	23	22	8	22	22	22	3
Labor-intensive	Furniture	13	3	21	14	4	12	17
	Textile	7	7	22	11	3	2	21
	Apparel	2	1	20	15	2	1	11
Regional processing	Fabricated metal products	21	14	18	19	6	17	15
	Rubber and plastic	15	8	17	16	8	13	13
	Food and beverage	19	21	14	13	12	6	22
	Glass, cement, and ceramics	10	11	16	5	5	11	20
Resource-intensive	Agriculture	17	20	19	23	1	4	14
	Petroleum products	3	4	7	10	7	10	18
	Basic metal	12	18	13	8	11	8	12
	Mining	5	10	15	3	10	3	19
	Wooden products	22	12	23	21	9	9	23

1. Based on geographic footprint in areas with high incidence of epidemics and high people inflows. Also considers labor intensity and demand impact. Sources: INFORM; UN Comtrade; UN World Tourism Organization; US BEA; World Input-Output Database (WIOD).
2. Based on knowledge intensity, capital intensity, degree of digitization, and presence in geographies with high cross-border data flows. Sources: MGI Digitization Index; MGI LaborCube; Telegeography; US BLS.
3. Based on capital intensity and footprint in geographies prone to natural disasters. Sources: INFORM; UN Comtrade; WIOD.
4. Based on footprint in geographies prone to heat and humidity, labor intensity, and relative share of outdoor work. Sources: MGI Workability Index; O*Net; UN Comtrade; US BLS.
5. Based on footprint in geographies vulnerable to flooding. Sources: UN Comtrade; World Resources Institute.
6. Based on trade intensity (exports as a share of gross output) and product complexity, a proxy for substitutability and national security relevance. Sources: Observatory of Economic Complexity; UN Comtrade.

Note: Overall exposure averages the six assessed shocks, unweighted by relative severity. Chart considers exposure but not mitigation actions. Demand effects included only for pandemics.

Source: McKinsey Global Institute analysis

Read horizontally, the chart shows each value chain's level of exposure to different types of shocks, which can vary sharply. Aerospace and semiconductors, for example, are susceptible to cyberattacks and trade disputes because of their high level of digitization, R&D, capital intensity, and exposure to digital data flows. However, both value chains have relatively low exposure to the climate-related events we have assessed here (heat stress and flooding) because of the footprint of their production. By contrast, agriculture, textiles, apparel, and, to a lesser extent, food and beverage, are labor-intensive. As a result, these value chains are highly exposed to heat stress. Much of their activity also takes place in regions that face disruption due to flooding.

Read vertically, the index shows which value chains are likely to be touched by specific types of shocks. Pandemics, for example, have a major impact on labor-intensive value chains. In addition, this is the one type of shock for which we assess the effects on demand as well as supply. As we are seeing in the current crisis, demand has plummeted for nonessential goods and travel, hitting companies in apparel, petroleum products, and aerospace. By contrast, while production has been affected in value chains like agriculture and food and beverage, they have continued to see strong demand because of the essential nature of their products. In general, heat stress is more likely to strike labor-intensive value chains (and some resource-intensive value chains) because of their relatively high reliance on manual labor or outdoor work. Perhaps surprisingly, these same value chains are relatively less susceptible to trade disputes, which are increasingly focused on value chains with a high degree of knowledge intensity and high-value industries. Cyberattacks are more likely to affect value chains with a high degree of digitization, such as communication equipment.

Overall, value chains that are heavily traded relative to their output are more exposed than those with lower trade intensity. Some of these include value chains that are the most sought after by countries: communication equipment, computers and electronics, and semiconductors and components. These value chains have the further distinction of being high value and relatively concentrated, underscoring potential risks for the global economy. Heavily traded labor-intensive value chains, such as apparel, are highly exposed to pandemic risk, heat stress (because of their reliance on labor), and flood risk. In contrast, the value chains including glass and cement, food and beverage, rubber and plastics, and fabricated metals have much lower exposure to shocks; these are among the least traded and most regionally oriented value chains.

$4.4 trillion

in global trade flows through the five most exposed value chains

All in all, the five value chains most exposed to our assessed set of six shocks collectively represent $4.4 trillion in annual exports, or roughly a quarter of global goods trade (led by petroleum products, ranked third overall, with $2.4 trillion in exports). The five least exposed value chains account for $2.6 trillion in exports. Of the five most exposed value chains, apparel accounts for the largest share of employment, with at least 25 million jobs globally, according to the International Labor Organization.[5]

Even value chains with limited exposure to all types of shocks we assessed are not immune to them. Despite recent headlines, we find that pharmaceuticals are relatively less exposed than most other industries. But the industry has been disrupted by a hurricane that struck Puerto Rico, and cyberattacks are a growing concern. In the future, the industry may be subject to greater trade tensions as well as regulatory and policy shifts if governments take action with the intent of safeguarding public health. Similarly, the food and beverage industry and agriculture have relatively low exposure overall, as they are globally dispersed. Yet these value chains are subject to climate-related stresses that are likely to grow over time. In addition to disrupting the lives and livelihoods of millions, this could cause the industries to become more dependent on trade or force them to undertake expensive adaptations.[6]

[5] International Labor Organization, "Employment by sex and economic activity—ILO modelled estimates," ILOSTAT, accessed June 20, 2020.

[6] *Will the world's breadbaskets become less reliable?: Case study,* McKinsey Global Institute, May 2020.

In addition to observing variations in exposure across industry value chains, it is important to note that risk exposure varies for individual companies within those value chains. Similarly, each company has unique vulnerabilities, as we discuss below. Some have developed far more sophisticated and effective supply chain management capabilities and preparedness plans than others.

Shocks exploit vulnerabilities within companies and value chains

Shocks inevitably seem to exploit the weak spots within broader value chains and specific companies. An organization's supply chain operations can be a source of vulnerability or resilience, depending on its effectiveness in monitoring risk, implementing mitigation strategies, and establishing business continuity plans. We explore several key areas of vulnerability, including demand planning, supplier networks, transportation and logistics, financial health, product complexity, and organizational effectiveness.[7]

Some of these vulnerabilities are inherent to a given industry; the perishability of food and agricultural products, for example, means that the associated value chains are vulnerable to delivery delays and spoilage. Industries with unpredictable, seasonal, and cyclical demand also face particular challenges. Makers of electronics must adapt to relatively short product life cycles, and they cannot afford to miss spikes in consumer spending during limited holiday windows.

Other vulnerabilities are the consequence of intentional decisions, such as how much inventory a company chooses to carry, the complexity of its product portfolio, the number of unique SKUs in its supply chain, and the amount of debt or insurance it carries.[8] Changing these decisions can reduce—or increase—vulnerability to shocks.

Weaknesses often stem from the structure of supplier networks in a given value chain. Complexity itself is not necessarily a weakness to the extent that it provides companies with redundancies and flexibility. But sometimes the balance can tip. Complex networks may become opaque, obscuring vulnerabilities and interdependencies. A large multinational company can have hundreds of tier-one suppliers from which it directly purchases components. Each of those tier-one suppliers in turn can rely on hundreds of tier-two suppliers. The entire supplier ecosystem associated with a large company can encompass tens of thousands of companies around the world when the deepest tiers are included.[9]

Exhibit E3 applies network analytics to illustrate the complexity of the first- and second-tier supply ecosystems for two Fortune 500 companies in the computer and electronics industry. This is based on publicly available data and may therefore not be exhaustive.[10] These multitiered, multinational networks span thousands of companies and extend to deeper tiers that are not shown here. This illustration also underscores the fact that, even within the same industry, companies may make materially different decisions about how to structure their supply ecosystems, with implications for risk.

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7 Knut Alicke, Ed Barriball, Susan Lund, and Daniel Swan, "Is your supply chain risk blind—or risk resilient?," McKinsey.com, 2020.

8 SKUs are stock-keeping units, indicating a distinct type of product for sale.

9 We refer to supply chains when specifically discussing the tiers of vendors that provide inputs and services to create products for a downstream company. We refer to industry value chains when discussing the broader end-to-end journey from producers of raw inputs to distribution channels and, eventually, customers. The latter view is important because companies increasingly consider proximity to customers when deciding where to base production; furthermore, customer product usage data can form the basis of design improvements and after-sales services.

10 Data from the Bloomberg Supply Chain database, based on regulatory filings and other public disclosures. The database does not capture all supplier relationships, but the results provide a relative overview of connectivity and network structure compared to other companies with similar data availability.

Exhibit E3

Even within the same industry, companies can have very different supply chain structures—and significant overlap.

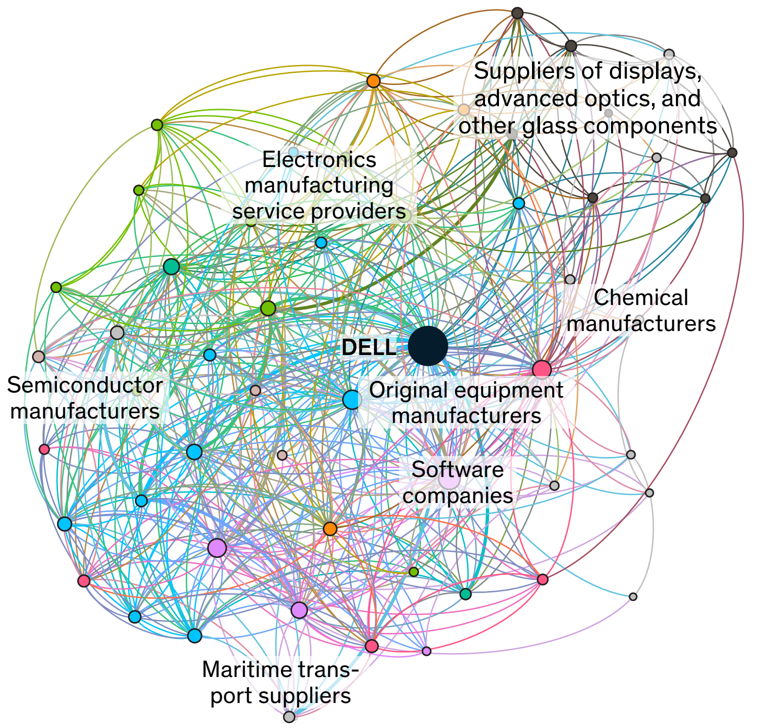
Companies rely on complex, multitiered. and interconnected networks

Example: Semiconductors, computers and electronics, and communication equipment

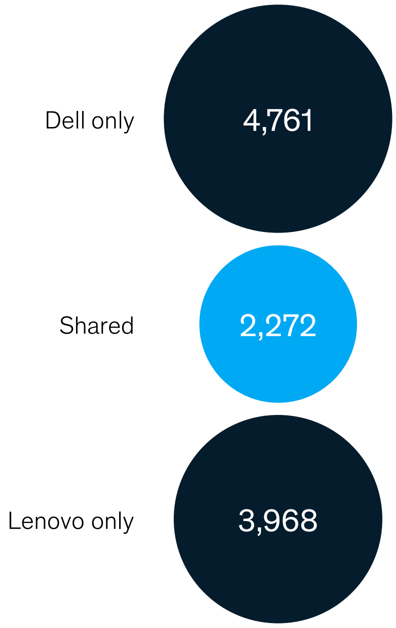
Dell

Revenue, 2019 = $90 billion

Dell's supplier ecosystem is more clustered, meaning it is potentially more exposed to bottlenecks[1]



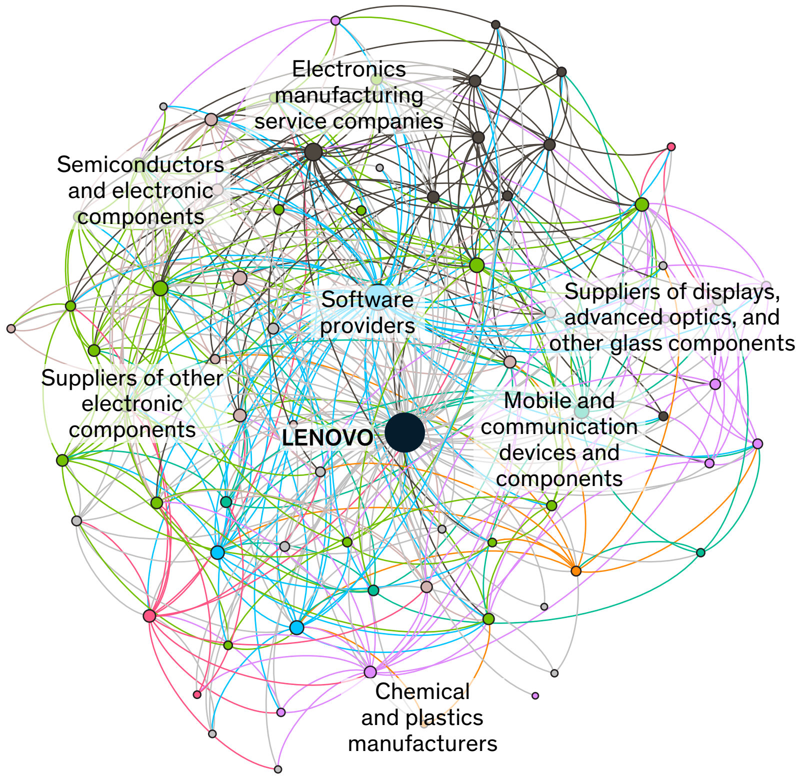
Known tier 1 and 2 suppliers



Lenovo

Revenue, 2019 = $51 billion

Lenovo's supplier ecosystem is deeper, meaning it has potentially less visibility[2]



1. Clustering is based on the clustering coefficient, which is calculated with network analysis of all supplier-customer relationships. The clustering coefficient measures the degree to which nodes cluster together and form interconnected subgroups.
2. The level of network depth is measured through the network diameter, using network analysis of all supplier-customer relationships. The network diameter is a measurement of network size that accounts for the overall structure by measuring the longest shortest path in the network.

Source: Bloomberg Supply Chain database; McKinsey Global Institute analysis

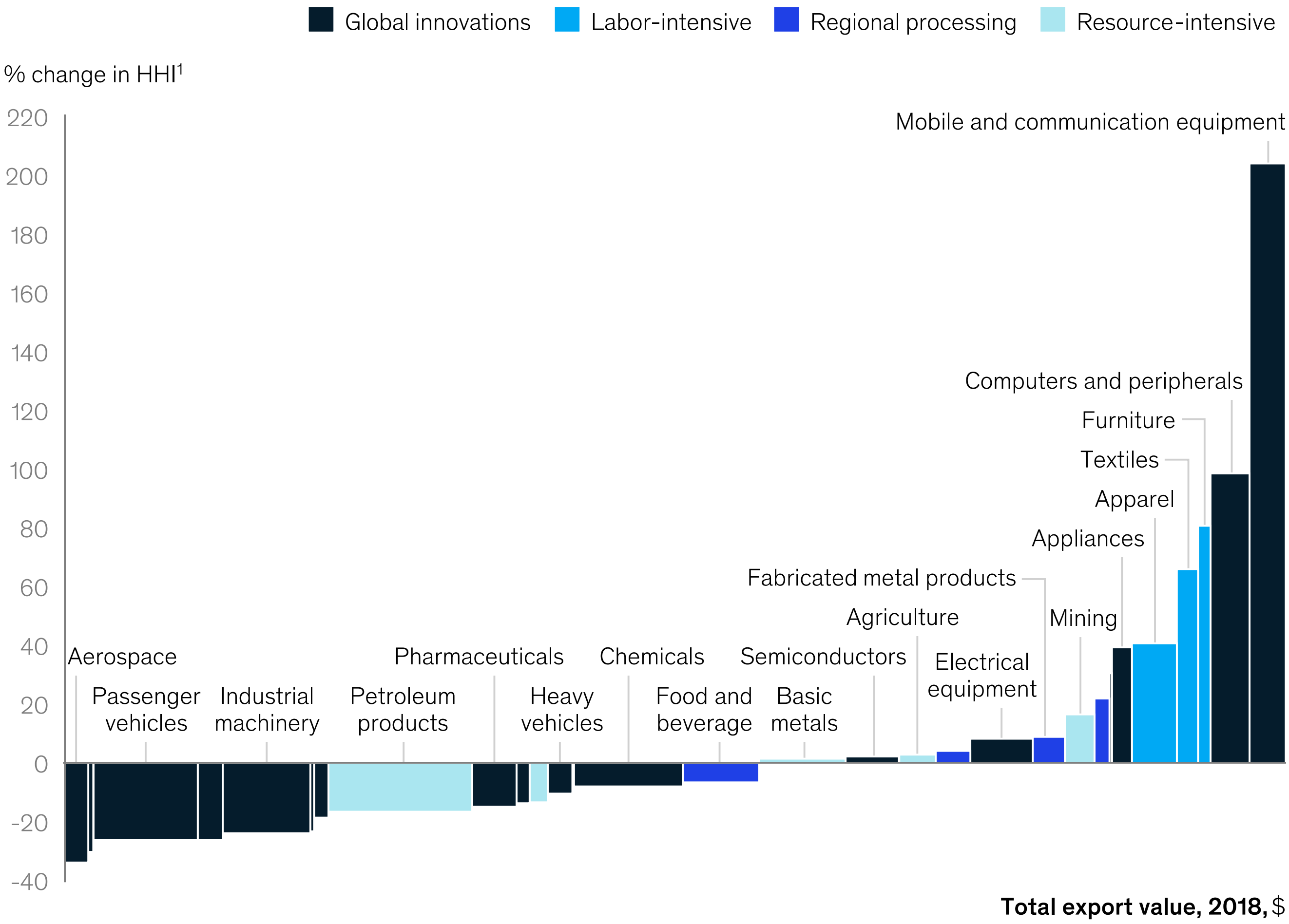
Companies' supplier networks vary in ways that can shape their vulnerability. Spending concentrated among just a few suppliers may make it easier to manage them, but it also heightens vulnerability should anything happen to them. Suppliers frequently supply each other; one form of structural vulnerability is a subtier supplier that accounts for relatively little in spending but is collectively important to all participants. The number of tiers of participating suppliers can hinder visibility and make it difficult to spot emergent risks. Suppliers that are dependent on a single customer can cause issues when demand shocks cascade through a value chain. The absence of substitute suppliers is another structural vulnerability.

In some cases, suppliers may be concentrated in a single geography due to that country's specialization and economies of scale. A natural disaster or localized conflict in that part of the world can cause critical shortages that snarl the entire network. Some industries, such as mobile phones and communication equipment, have become more concentrated in recent years, while others, including medical devices and aerospace, have become less so (Exhibit E4). The aerospace value chain, for example, has diversified in part due to secure market access.

Exhibit E4

Globalization has led to diversification of production across countries in some sectors, but others have grown more concentrated.

Change in geographic concentration by sector, 2000–18, measured by change in Herfindahl-Hirschman Index of exports (HHI)[1]



1. A measure of concentration that is the sum of the square of each country's share of exports.
Note: Data includes 5,444 unique final and intermediate products from 2018 trade data. The weighted average is weighted by the share of trade for each product within each value chain. All other measurements of HHI are calculated using the raw, unweighted score.
Source: UN Comtrade; McKinsey Global Institute analysis

180

products are predominantly exported from a single country, opening the door to bottlenecks

Even in value chains that are generally more geographically diversified, production of certain key products may be disproportionately concentrated. Many low-value or basic ingredients in pharmaceuticals are predominantly produced in China and India, for instance. In total, we find 180 products across value chains for which one country accounts for 70 percent or more of exports, creating the potential for bottlenecks. The chemicals value chain has a particularly large number of such highly concentrated products, but examples exist in multiple industries. Other products may be produced across diverse geographies but have severe capacity constraints, which creates bottlenecks in the event of production stoppages. Similarly, some products may have many exporting countries, but trade takes place within clusters of countries rather than on a global basis. In those instances, importers may struggle to find alternatives when their predominant supplier experiences a disruption. Geographic diversification is not inherently positive, particularly if production and sourcing expands into areas that are more exposed to shocks.

Over the course of a decade, companies can expect disruptions to erase half a year's worth of profits or more

When companies understand the magnitude of the losses they could face from supply chain disruptions, they can weigh how much to invest in mitigation. We built representative income statements and balance sheets for hypothetical companies in 13 different industries, using actual data from the 25 largest public companies in each. This enables us to see how they fare financially when under duress.

We explore two scenarios involving severe and prolonged shocks:

— **Scenario 1.** A complete manufacturing shutdown lasting 100 days that affects raw material delivery and key inputs but not distribution channels and logistics. In this scenario, companies can still deliver goods to market. But once their safety stock is depleted, their revenue is hit.

— **Scenario 2.** The same as above, but in this case, distribution channels are also affected, meaning that companies cannot sell their products even if they have inventory available.

Our choice to model a 100-day disruption is based on an extensive review of historical events. In 2018 alone, the five most disruptive supply chain events affected more than 2,000 sites worldwide, and factories took 22 to 29 weeks to recover.[11]

Our scenarios show that a single prolonged production-only shock would wipe out between 30 and 50 percent of one year's EBITDA for companies in most industries. An event that disrupts distribution channels as well would push the losses sharply higher for some.

Industries in which companies typically hold larger inventories and have lower fixed costs tend to experience relatively smaller financial losses from shocks. If a natural disaster hits a supplier but distribution channels remain open, inventory levels become a key buffer. However, the downstream company will still face a cash drain after the fact when it is time to replenish its drawn-down safety stock. When a disruption outlasts the available safety stock, lower fixed costs become important to withstanding a decline in EBITDA.

[11] Shahzaib Khan and Andrew Perez, *Eventwatch 2018 annual report,* Resilinc, 2019.

Companies can expect to lose almost

45%

of one year's profits over the course of a decade

Having calculated the damage associated with one particularly severe and prolonged disruption, we then estimated the bottom-line impact that companies can expect over the course of a decade, based on probabilities. We combined the expected frequency of value chain disruptions of different lengths with the financial impact experienced by companies in different industries. On average, companies can expect losses equal to almost 45 percent of one year's profits over the course of a decade (Exhibit E5). This is equal to seven percentage points of decline on average. We make no assessment of the extent to which the cost of these disruptions has already been priced into valuations.

These are not distant future risks; they are current, ongoing patterns. On top of those losses, there is an additional risk of permanently losing market share to competitors that are able to sustain operations or recover faster, not to mention the cost of rebuilding damaged physical assets. However, these expected losses should be weighed in the context of the additional profits that companies are able to achieve with highly efficient and far-reaching supply chains.

Exhibit E5

Expected losses from supply chain disruptions equal 42 percent of one year's EBITDA on average over the course of a decade.

■ Above average

	Net present value (NPV) of expected losses over 10 years,[1] % of annual EBITDA	NPV for a major company,[2] $ million	NPV of expected losses,[2] EBITDA margin, pp
Aerospace (commercial)	66.8 (above average)	1,564	7.4
Automotive	56.1 (above average)	6,412	7.3
Mining	46.7 (above average)	2,240	8.4
Petroleum products	45.5 (above average)	6,327	8.9
Electrical equipment	41.7	556	5.4
Glass and cement	40.5	805	6.2
Machinery and equipment	39.9	1,084	6.5
Computers and electronics	39.0	2,914	5.9
Textiles and apparel	38.9	788	7.8
Medical devices	37.9	431	8.7
Chemicals	34.9	1,018	5.7
Food and beverage	30.0	1,578	7.6
Pharmaceuticals	24.0	1,436	6.0

Average

1. Based on estimated probability of a severe disruption twice per decade (constant across industries) and proportion of revenue at risk due to a shock (varies across industries). Amount is expressed as a share of one year's revenue (ie, it is not recurring over modeled 10-year period). Calculated by aggregating cash value of expected shocks over a 10-year period based on averages of production-only and production and distribution disruption scenarios multiplied by probability of event occurring for a given year. Expected cash impact is discounted based on each industry's weighted average cost of capital.
2. Based on weighted average revenue of top 25 companies by market cap in each industry.

Source: S&P Capital IQ; McKinsey Global Institute analysis

Will global value chains shift across countries?

Today much of the discussion about resilience in advanced economies revolves around the idea of increasing domestic production. But the interconnected nature of value chains limits the economic case for making large-scale changes in their physical location. Value chains often span thousands of interconnected companies, and their configurations reflect specialization, access to consumer markets around the world, long-standing relationships, and economies of scale.

We set out to estimate what share of global exports could move to different countries based on the business case and how much might move due to policy interventions. To determine whether industry economics alone support a future geographic shift, we considered a number of factors. One is whether there is already some movement under way. Between 2015 and 2018, for instance, the share of trade produced by the three leading export countries in apparel dropped. In contrast, the top three countries in semiconductors and mobile communications increased their share of trade markedly.

Other considerations include whether the value chain is capital- or knowledge-intensive, or tied to geology and natural resources. All of these make relocation less feasible. Highly capital-intensive value chains are harder to move for the simple reason that they represent hundreds of billions of dollars in fixed investments. These industries have strong economies of scale, making them more costly to shift. Value chains with high knowledge intensity tend to have specialized ecosystems that have developed in specific locations, with unique suppliers and specialized talent. Deciding to move production outside of this ecosystem to a novel location is costly. Finally, value chains with comparatively high levels of extraregional trade have more scope to shorten than those that are already regionalized. We also consider overall growth, the location of major (and rising) consumer markets, trade intensity, and innovation dynamics.

With respect to noneconomic factors, we consider governments' desire to bolster national security, national competitiveness, and self-sufficiency. Some nations are focusing on safeguarding technologies with dual-use (civilian and military) implications, which could affect value chains such as semiconductors and communication equipment (particularly as 5G networks are built out). In other cases, governments are pursuing industrial policies intended to capture leading shares of emerging technologies ranging from quantum computing and artificial intelligence to renewable energy and electric vehicles. This, too, has the potential to reroute value chains. Finally, self-sufficiency has always been a question surrounding energy. Now the COVID pandemic has driven home the importance of self-sufficiency in food, pharmaceuticals, and certain medical equipment as well.

16–26%

of global exports could shift to different countries due to economic and noneconomic factors

Exhibit E6 compiles these metrics for individual value chains and estimates what proportion of production for export has the potential to move to new countries. We estimate that 16 to 26 percent of exports, worth \$2.9 trillion to \$4.6 trillion in 2018, could be in play—whether that involves reverting to domestic production, nearshoring, or new rounds of offshoring to new locations. It should be noted that this is not a forecast: it is a rough estimate of how much global trade *could* relocate in the next five years, not an assertion that it *will* actually move.

The value chains with the largest share of total exports potentially in play are pharmaceuticals, apparel, and communication equipment. In dollar terms, the value chains with the largest potential to move production to new geographies are petroleum, apparel, and pharmaceuticals.[12] In all of these cases, more than half of their global exports could potentially move. With few exceptions, the economic and noneconomic feasibility of geographic shifts do not overlap. Thus, countries would have to be prepared to expend considerable sums to induce shifts from what are otherwise economically optimal production footprints.

[12] The potential to move petroleum production is of course limited by the presence of geologic deposits. But if the price of oil rises, exploration and extraction now considered uneconomic in some sites could become viable. New technologies, too, could make it possible to expand into new locations.

Exhibit E6

The potential for value chains to shift across borders over the next five years depends on economic and noneconomic factors.

Feasibility of geographic shift: Low ○ ◑ ● High

Value of exports with shift feasibility (annual exports)[1]: Low → High

Drivers of economic shift feasibility: Low → High

	Value chain	Feasibility of geographic shift: Economic factors	Feasibility of geographic shift: Noneconomic factors[2]	Value of exports with shift feasibility: Range, $ billion	Value of exports with shift feasibility: Share of value chain exports, %	Total exports, 2018, $ billion	Top 3 exporter share change, 2015–18, pp	Capital intensity,[3] %	Knowledge intensity,[4] %	Product complexity[5]	Intraregional trade,[6] %
Global innovations	Chemicals	○	◔	86–172	5–11	1,584	-1.4	72	26	5	57
	Pharmaceuticals	◔	●	236–377	38–60	626	0	58	41	5	40
	Aerospace	◔	◑	82–110	25–33	333	-2.9	53	40	5	34
	Automotive	◔	◑	261–349	15–20	1,730	-1.6	51	16	5	60
	Transportation equipment	◕	◔	60–89	29–43	209	0	48	18	5	43
	Electrical equipment	◕	◔	213–319	23–34	928	-2.5	43	23	5	54
	Machinery and equipment	◑	◔	271–362	19–25	1,455	-2.2	36	19	6	50
	Computers and electronics	◕	◔	165–247	23–35	708	-1.9	47	57	5	53
	Communication equipment	◔	●	227–363	34–54	673	9.5	51	45	5	46
	Semiconductors and components	○	●	92–184	9–19	995	10.5	62	39	5	81
	Medical devices	◑	◕	100–120	37–45	268	0.1	47	29	5	40
Labor intensive	Furniture	●	○	37–74	22–45	164	-5.7	40	15	4	55
	Textiles	●	○	67–134	23–45	297	-3.2	34	15	4	55
	Apparel	●	◔	246–393	36–57	688	-8.1	30	18	3	43
Regional processing	Fabricated metal products	◕	◔	94–141	21–32	440	-3.5	33	16	5	57
	Rubber and plastic	◕	◔	97–145	20–30	488	-2.7	40	16	5	60
	Food and beverage	◔	○	63–125	5–11	1,149	-1.1	57	14	4	56
	Glass, cement, and ceramics	◑	○	22–45	11–21	209	-4.5	48	15	5	57
Resource intensive[7]	Agriculture	◔	◑	112–149	20–26	568	0.4	24	10	4	47
	Wooden products	○	◔	8–17	5–11	155	0.9	43	11	4	57
	Basic metal	○	◔	77–153	6–12	1,250	-3.6	54	16	4	51
	Petroleum products	○	◔	212–423	9–18	2,414	1.3	81	32	3	30
	Mining	◔	○	29–57	6–13	452	3.8	72	16	3	49
		Total	Low	**2,900**	**16**						
			High	**4,600**	**26**						

1. Low-end sizing = global imports from outside importing country's region average of economic and noneconomic feasibility. High-end sizing = global imports from outside importing country's region maximum of economic and noneconomic feasibility. 2. Noneconomic factors take into account goods deemed essential or targeted for national security or economic competitiveness considerations, based on proposed and enacted government policies and definitions of essential goods. 3. Amount of capital compensation as a share of gross output. 4. Defined as share of labor with a tertiary education. 5. Product Complexity Index measures the relative substitutability of production across sites of products in value chain. 6. Percent of total trade that takes place within same region as its importer. 7. Dependent on access to resources that are geographically determined.

Source: Federal Reserve Bank of St. Louis; Observatory of Economic Complexity; UN Comtrade; US Bureau of Economic Analysis; US Bureau of Labor Statistics; World Input-Output Database; McKinsey Global Institute analysis

In general, the economic case to move is most viable for labor-intensive value chains such as furniture, textiles, and apparel. These value chains were already experiencing shifts away from their current top producers, where the cost of labor has risen, to other developing countries. The continuation of this trend could represent a real opportunity for some nations. By contrast, resource-intensive value chains, such as mining, agriculture, and energy, are generally constrained by the location of natural resources that provide crucial inputs. But policy considerations may encourage new exploration and development that can shift value chains at the margins.

The value chains in the global innovations category (semiconductors, automotive, aerospace, machinery, communication, and pharmaceuticals) are subject to the most scrutiny and possible intervention from governments, based on their high value, cutting-edge technologies as well as their perceived importance for national competitiveness. But the feasibility of moving these value chains based on the economics alone is low. For example, the recent decision to site a new semiconductor fabrication plant in the United States was contingent upon significant government subsidies.

Production networks have begun to regionalize in recent years, and this trend may persist as growth in Asia continues to outpace global growth. But multinationals with production facilities in countries such as China, India, and other major emerging economies are typically there to serve local consumer markets, whether or not they also export from those places. As prosperity rises in these countries, they are key sources of global growth that companies will continue to pursue.

Four industry case studies illustrate what could drive the complexity of geographic rebalancing of value chains

Up to 60%

of global pharma exports could shift to different countries due to economic and noneconomic factors

Pharmaceuticals. Overall, the pharmaceutical value chain has become less concentrated and more globally dispersed over the past 20 years. But the manufacture of some specific products is highly concentrated. While China and India export a relatively small share (3 percent each) of overall pharmaceutical products by value, they are the world's key producers of active pharmaceutical ingredients and small-molecule drugs. In some categories, such as antibiotics, sedatives, ibuprofen, and acetaminophen, China is the world's dominant producer, accounting for 60 percent or more of exports. India is the world's leading provider of generic drugs, accounting for some 20 percent of global exports by volume, but it relies on China for most of the active pharmaceutical ingredients that go into them. When the flow of these ingredients dried up in the early stages of the COVID pandemic, India temporarily placed export controls on dozens of essential drugs, including antibiotics.

Based on economics alone, there is little reason to believe that pharmaceutical production will shift unless companies respond to the rise of new consumers in developing countries. But many governments are weighing whether to boost domestic production of some key medicines (as well as medical equipment). As a result, we estimate that 38 to 60 percent of the pharmaceutical value chain could shift geographically in the coming years. However, production of small-molecule drugs would likely need to be highly digitized and automated to be viable in advanced economies; otherwise, the higher cost of doing business might lead to higher drug prices.

Automotive. The auto industry has some of the most intricate value chains in the global economy, and the most regionalized. Most exports of intermediate parts circulate within three broad regions: Asia, Europe, and North America. The US auto industry is integrated with Mexico and Canada; Germany has production networks in Eastern Europe; and Japan and South Korea source from China, Thailand, and Malaysia. Despite the largely regional nature of automotive production, OEMs rely on some imported Chinese parts—and the initial COVID outbreak centered in Hubei Province quickly produced global ripple effects in the industry.

Automotive is a prized industry from the standpoint of jobs, innovation, and competitiveness, and nations have historically enacted tariffs, trade restrictions, and local content requirements to try to attract and retain auto manufacturing. Trade disputes are an ongoing concern, leading companies to build in more flexibility and redundancy. We estimate that a relatively modest share of auto exports, between 15 and 20 percent by value, has the potential to shift in the medium term, driven predominantly by noneconomic factors.

Semiconductors. While the United States designs advanced chips, their manufacturing is highly concentrated in places like South Korea and Taiwan. Overall, Asia accounts for more than 95 percent of outsourced semiconductor assembly and testing capacity. This concentration brings potential risks. MGI research has found that companies sourcing advanced chips from South Korea, Japan, Taiwan, or other hubs in the western Pacific can expect that hurricanes severe enough to disrupt suppliers will become two to four times more likely by 2040.[13] Other dynamics can also invite potential complications. A single firm leads production of lithographic machines, which place circuits on the wafers.

Economies of scale and high barriers to entry leave very little room for semiconductor production to move on its own. A semiconductor fabrication plant can cost $10 billion or more to build, and the industry requires specialized engineers. But geopolitical and trade tensions could reshape the value chain in ways that market forces alone might not. National security and competitiveness concerns could lead governments to take action, potentially shifting an estimated 9 to 19 percent of trade flows.

Textiles and apparel. Apparel and textiles are highly traded, labor-intensive value chains that are already moving. China has long been the dominant player, and it still accounts for some 29 percent of apparel sold globally. But its wages are rising, and Chinese producers can now focus on meeting domestic demand. In 2005, China exported 71 percent of the finished apparel goods it produced. By 2018, that share was just 29 percent.

Relative to all other value chains, textiles and apparel feature the highest proportion of trade that could feasibly shift due to purely economic factors (36 to 57 percent in apparel, and 23 to 45 percent in textiles). While some apparel production may nearshore to US and EU markets, most would likely shift to Southeast Asian countries due to their comparative advantage in labor and overhead costs. As China's exports have plateaued, more apparel manufacturing for export has moved to places such as Bangladesh, Vietnam, and Ethiopia. Turkey is also a major producer of clothing that is exported to Europe. But companies will need to mitigate against natural disasters and future pandemics in these geographies. National needs for PPE could cause some footprint changes as well.

Companies have a range of options for improving resilience

In a McKinsey survey of supply chain executives conducted in May 2020, an overwhelming 93 percent reported that they plan to take steps to make their supply chains more resilient, including building in redundancy across suppliers, nearshoring, reducing the number of unique parts, and regionalizing their supply chains (Exhibit E7). The respondents included supply chain and operations' executives representing diverse value chains, such as pharmaceutical and medical products, automotive, advanced electronics and semiconductors, consumer packaged goods, chemicals, and metals and mining, among others.

When companies understand the magnitude of the losses they could face from supply chain disruptions, they can weigh how much to invest in building resilience. Many options can boost productivity at the same time, providing a win-win.[14]

[13] *Could climate change become the weak link in your supply chain?,* McKinsey Global Institute, August 2020.
[14] For a broader discussion, see Nassim Nicholas Taleb, *Antifragile: Things That Gain from Disorder,* New York, NY: Random House, 2012.

Exhibit E7

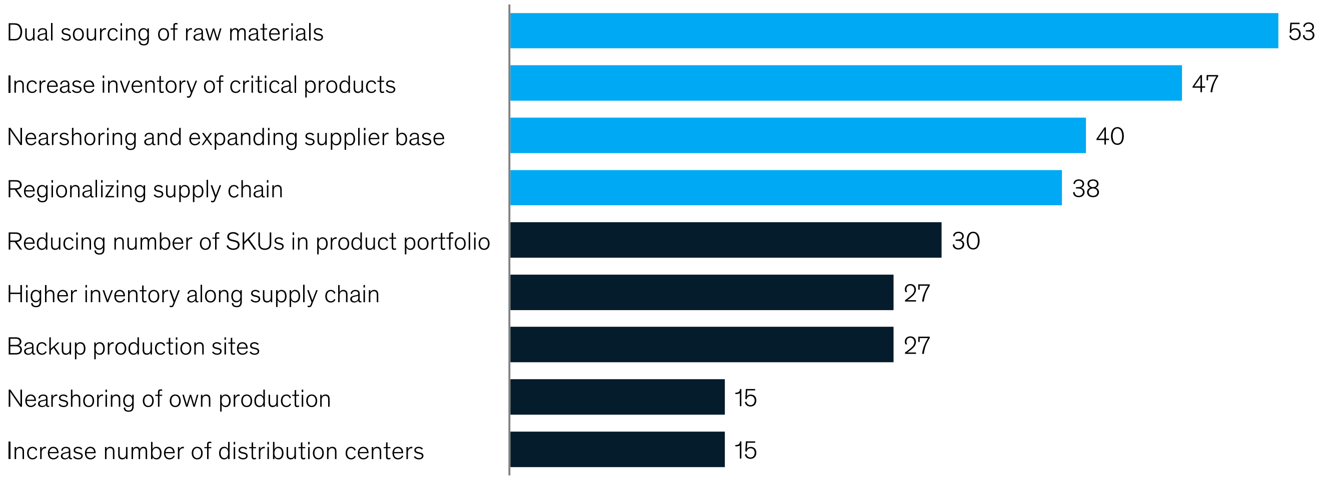
Surveyed business leaders are increasing resilience in supply chains and production through multiple strategies.

93% of global supply chain leaders are planning to increase resilience[1]

44% would increase resilience even at expense of short-term savings[2]

Planned actions to build resilience

% of respondents[1]



1. McKinsey survey of global supply chain leaders, May 2020.
2. McKinsey survey of business executives, May 2020.

Source: McKinsey survey of business executives, May 2020 (n = 605); McKinsey survey of global supply chain leaders, May 2020 (n = 60); McKinsey Global Institute analysis

Strengthen supply chain risk management and improve end-to-end transparency

Global manufacturing has only just begun to adopt a range of technologies, such as analytics and artificial intelligence, the Internet of Things, advanced robotics, and digital platforms. Companies now have access to new solutions for running scenarios, assessing trade-offs, improving transparency, accelerating responses, and even changing the economics of production.[15]

Most companies are still in the early stages of their efforts to connect the entire value chain with a seamless flow of data. Digital can deliver major benefits to efficiency and transparency that are yet to be fully realized. Consumer goods giant Procter & Gamble, for example, has a centralized control tower system that provides a company-wide view across geographies and products. It integrates real-time data, from inventory levels to road delays and weather forecasts, for its own plants as well as suppliers and distributors. When a problem occurs, the system can run scenarios to identify the most effective solution.[16]

Creating a comprehensive view of the supply chain through detailed subtier mapping is a critical step to identifying hidden relationships that invite vulnerability. Today, most large firms have only a murky view beyond their tier-one and perhaps some large tier-two suppliers. Working with operations and production teams to review each product's bill of materials can reveal whether critical inputs are sourced from high-risk areas and lack ready substitutes. Companies can also work with their tier-one suppliers to create transparency. But in cases where those suppliers lack visibility themselves or consider their own sourcing to be proprietary information, risk management teams may have to turn to other

[15] See, for example, Katy George, Sree Ramaswamy, and Lou Rassey, "Next-shoring: A CEO's guide," *McKinsey Quarterly,* January 2014; and Kevin Goering, Richard Kelly, and Nick Mellors, "The next horizon for industrial manufacturing: Adopting disruptive digital technologies in making and delivering," McKinsey.com, November 2018.

[16] Emma Cosgrove, "How P&G created a 'ready-for-anything' supply chain," *Supply Chain Dive*, June 3, 2019.

information sources to do detective work.[17] After mapping upstream suppliers, downstream companies need to understand their production footprint, financial stability, and business continuity plans.

Minimize exposure to shocks

Targeted measures taken before an event occurs can mitigate the impact of a shock or speed time to recovery.[18] As more physical assets are digitized, for example, companies will need to step up investment in cybersecurity tools and teams.

One of the most important steps is building more redundancy into supplier networks.[19] Relying on a single source for critical components or raw materials can be a vulnerability. In fact, even if a company relies on multiple suppliers, they may be concentrated in the same place. Taking the time to identify, prequalify, and onboard backup vendors comes at a cost. But it can provide much-needed capacity if a crisis strikes.[20] Auditing and diversifying the supply chain can have the added benefit of reducing carbon intensity, raising environmental and labor standards, and expanding opportunities for women- and minority-owned businesses.

One way to achieve supply chain resilience is to design products with common components, cutting down on the use of custom parts in different product offerings. Auto manufacturers are perhaps the most advanced in this regard, having implemented modular manufacturing platforms that share components across product lines and production sites.

Physical assets may need to be hardened to withstand natural disasters. In regions that are vulnerable to worsening hurricanes and storm surges, this may involve installing bulkheads, elevating critical machinery and utility equipment, adding more waterproof sealing, and reworking drainage and valves.[21] Many factories that are not air-conditioned today will need cooling systems to prepare for rising temperatures and potential heat waves in some parts of the world. Plants located in earthquake-prone areas may need seismic retrofitting. Companies can also build more redundancies into transportation and logistics.

When a shock does hit, companies need the ability to respond quickly

The shift to just-in-time and lean production systems has helped companies improve efficiency and reduce their need for working capital. But now they may need to strike a different balance between just-in-time and “just in case.” Having sufficient backup inventory of key parts and safety stock is a critical buffer that can minimize the financial impact of disrupted supplies. It can also position companies to meet sudden spikes in demand.

The ability to reroute components and flex production dynamically across sites can keep production going in the wake of a shock. This requires robust digital systems as well as the analytics muscle to run scenarios based on different responses. When the COVID pandemic hit, Nike used predictive analytics to selectively mark down goods and reduce production early on to minimize impact. The company was also able to reroute products from brick-and-mortar stores to e-commerce sales, driven in part by direct-to-consumer online sales through its own training app. As a result, Nike sustained a smaller drop in sales than some of its competitors.

When disaster strikes, companies have to be laser focused on cash management. But those at the top of a value chain also have a vested interest in preserving the supplier networks on which they depend. In the aftermath of the global financial crisis, some companies accelerated payments or guaranteed bank loans to give key vendors a lifeline.

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17 Knut Alicke, Ed Barriball, Susan Lund, and Daniel Swan, “Is your supply chain risk blind—or risk resilient?,” McKinsey.com, May 2020; and Knut Alicke, Xavier Azcue, and Edward Barriball, “Supply-chain recovery in coronavirus times—plan for now and the future,” McKinsey.com, March 2020.

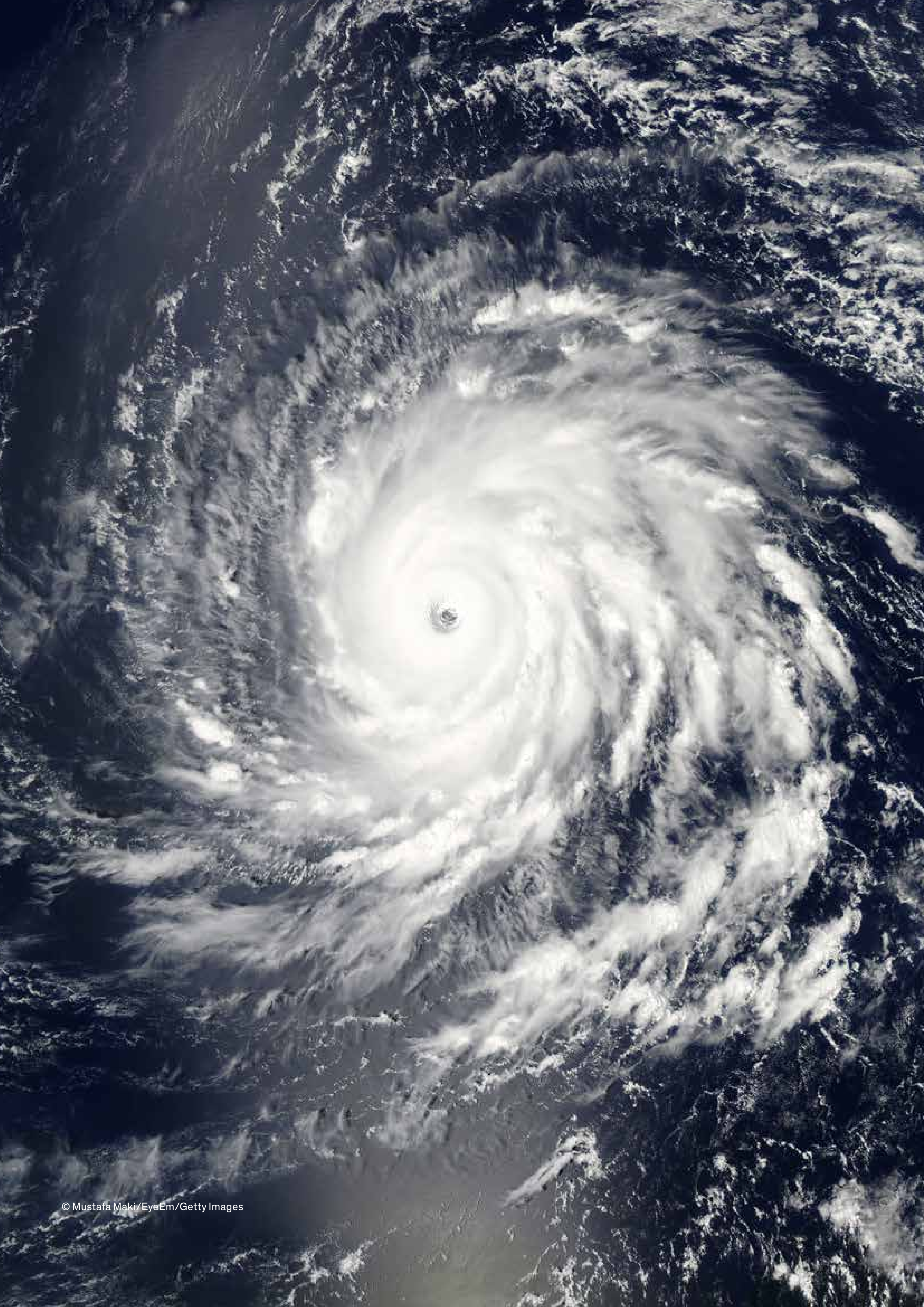
18 Knut Alicke, Ed Barriball, Susan Lund, and Daniel Swan, “Is your supply chain risk blind—or risk resilient?,” McKinsey.com, May 2020.

19 Petr Matous and Yasuyuki Todo, “Analyzing the coevolution of interorganizational networks and organization performance: Automakers’ production networks in Japan,” *Applied Network Science,* February 2017, Volume 2, Issue 1.

20 Tom Linton and Bindiya Vakil, “Coronavirus is proving we need more resilient supply chains,” *Harvard Business Review,* March 5, 2020.

21 *Climate risk and response: Physical hazards and socioeconomic impacts,* McKinsey Global Institute, January 2020.

Coming on the heels of Brexit and a flare-up in US–China trade tensions, the COVID pandemic has forced businesses to focus on building resilience in their supply chains and operations. Not everything that can go wrong actually does go wrong, but businesses and governments cannot afford to be caught flat-footed when disaster strikes. Preparing for future hypotheticals has a present-day cost. But those investments can pay off over time—not only minimizing losses but also improving digital capabilities, boosting productivity, and strengthening entire industry ecosystems. Rather than a trade-off between resilience and efficiency, this rebalancing act might deliver a win-win.



1. Understanding shocks and evaluating exposure

For the past 25 years, revolutions in communication and transportation have enabled companies to create truly global value chains. Producers of raw materials linked to the makers of manufactured inputs and parts. They in turn linked to the makers of final products, then to distribution channels that delivered to consumers around the world. More than 95 percent of global trade flows through these tightly choreographed value chains. In the two decades before the COVID-19 pandemic struck, the value of intermediate goods exported across borders tripled to more than $10 trillion annually.

But complexity can open the door to unwelcome visitors. These long and complex value chains are efficient, but they are exposed to disruptions that are becoming more frequent and more severe. Natural disasters are a big part of this list, but some hazards have nothing to do with earth, wind, or fire. The list also includes trade disputes, cyberattacks, terrorism, industrial accidents, and infrastructure failures. The pandemic, coming on the heels of Brexit and US—China trade tensions, has forced businesses to focus urgently on building resilience in their supply chains and operations.

Resilience starts with understanding the full range of what can happen and the damage that can result. But not every global value chain is equally susceptible to every kind of threat. As the world has just learned, unforeseen shocks can affect supply and demand in varying and even contradictory ways. Demand can go into free fall for many classes of goods, even as suppliers scramble to deliver enough medical products, groceries, and similar necessities.

This chapter begins by considering a wide array of potential shocks. We then consider the characteristics and geographic footprint of 23 value chains to determine their relative exposure to them. This analysis can help companies better understand their exposures and prioritize resilience efforts. It can also assist policy makers in identifying potential bottlenecks of products that are essential or important to economic competitiveness.

Value chain risk is a product of exposure to shocks plus vulnerabilities within companies and broader value chains

The Roman philosopher Seneca said that luck is what happens when preparedness meets opportunity. The inverse can be said about value chain risk. It is what happens when an unforeseen event exploits weaknesses that were there all along. The risk facing any particular industry value chain reflects its level of exposure to different types of shocks and the underlying vulnerabilities in a particular company or the ecosystem as a whole (Exhibit 1).

Exhibit 1

Value chain risk stems from exposure to shocks and vulnerabilities in supplier networks and business practices.

Value chain risk = **Shock exposure** × **Vulnerability**

Value chain risk

Disruptions that cause operational and/or financial impact

Shock exposure

Sources of disruption

- *Force majeure* (eg, earthquake, hurricane, pandemic)
- Macropolitical (eg, conflict, financial crisis, recession, trade dispute)
- Malicious actor (eg, cyberattack, theft)
- Idiosyncratic (eg, supplier bankruptcy, IT outage, industrial accident)

Vulnerability

Characteristics that make a supply chain more or less resilient

- Demand planning
- Supplier network
- Transportation and logistics
- Financial health
- Product complexity
- Organizational effectiveness

Source: McKinsey Global Institute analysis

On the exposure side, shocks can arise from four main sources:

— *Force majeure* events are extraordinary disruptions that bring business to a sudden halt. These include disasters such as hurricanes, flooding, earthquakes, wildfires, and volcanic eruptions. Many of these events strike locally but cause wider ripple effects as production and logistics networks become bottlenecked. A few, such as the COVID pandemic, are truly global in scope.

— Macropolitical shocks run the gamut from financial crises, trade disputes, abrupt regulatory shifts, and recessions to military conflict and terrorism.

— Malicious actors can wreak damage through cyberattacks, theft, and counterfeiting.

— Idiosyncratic shocks more commonly affect one or several companies, although they can have ripple effects. They include industrial accidents, labor disputes, IT outages, and supplier bankruptcies. Price shocks for a key input are another common occurrence.

Vulnerability can stem from characteristics inherent to an industry value chain as well as firm-level decisions. It can manifest in planning and supplier networks, where sole sourcing seems efficient one day but suddenly results in bottlenecks when a crisis hits. It may show up in transportation and logistics if companies depend on unreliable infrastructure. It may lurk on balance sheets in the form of high leverage or low cash reserves that can leave a company close to insolvent in any but the shortest disruptions. Product complexity can leave a company dependent on custom inputs, and short sales windows can be devastating to miss. And if a company's supply chain management team is not effective, it may fail to spot brewing threats ahead of time or have continuity plans in place. (See chapter 2 for a more in-depth discussion of these and other vulnerabilities.)

Shocks vary in frequency, lead time, and nature of impact

Not all shocks are created equal. Some pass quickly, while others can sideline multiple industry players for weeks or even months. Business leaders often characterize shocks according to their source (*force majeure* events, the macropolitical environment, or malicious actors, for instance). But characteristics beyond the source of a shock determine its scope and the severity of its impact on production and global value chains.

One key factor is lead time—that is, the amount of advance warning companies have before an event strikes. Trade disputes, for example, reflect the buildup of economic imbalances, diverging standards, or geopolitical tensions over months or even years, but earthquakes and cyberattacks strike out of nowhere.

The nature of the event also matters. Some shocks last for a prolonged period. Some are isolated, while others have ripple effects across geographies and entire industries. Shocks with higher contagion potential are generally more severe, as they take a toll on larger parts of the global economy.

Severity is also determined by whether a shock hits the supply side alone or also affects customer demand. Events that affect both supply and demand simultaneously, such as a pandemic and war, are most severe.

Exhibit 2 illustrates how these dimensions vary for 13 different types of shocks. For most of them, we show the most extreme example from the past two decades and its associated toll. In a few cases, we show hypotheticals: global military conflict (since the world has thankfully been spared from it since the 1940s) and a cyberattack that disrupts the Internet or foundational payment systems. The latter would exceed the scale of any cybercrime or cyberwarfare experienced to date, but we include it because of the ever-growing potential for such an event.

The most severe shocks are long-lasting and spread across geographies and industries; they affect supply, demand, and access to finance. Examples include major pandemics and military conflicts. These highly damaging events can cause trillions of dollars in damage. Natural disasters are slightly less damaging. They have historically caused hundreds of billions of dollars of damage, both in property destruction and temporary dislocations to supply chains, but their severity and frequency is growing. A more moderate set of shocks, with costs in the tens of billions of dollars, tend to be broad but less intense. They include regulatory changes and localized military conflicts. Finally, companies frequently encounter a host of idiosyncratic shocks, such as IT outages, labor disputes, and industrial accidents. They are typically firm-specific, with costs that rarely cross the threshold of macroeconomic concern. However, input price shocks are common sources of disruption for many value chains—and not all industries are equally able to pass these higher costs on to downstream customers. This may occur because of trade disputes, natural disasters that create shortages, or swings in commodity prices.

The COVID pandemic has had such an outsize impact precisely because of these characteristics.[22] It is lingering for months without resolution and affecting almost every country on earth. Shutdowns and stay-at-home restrictions, while necessary to protect public health, not only halted production but depressed incomes and discretionary spending, deepening the economic fallout and sending ripple effects across industries.[23] Indeed, its main impact on some sectors is not a supply chain disruption but rather a collapse in demand. While the ultimate economic losses are still unknown, they extend into the tens of trillions of dollars, and more than 607,000 lives have already been lost as of this writing.[24]

[22] For more on the financial fallout from pandemics, see Oscar Jorda, Sanjay R. Singh, and Alan M. Taylor, *Longer-run economic consequences of pandemics,* Federal Reserve Bank of San Francisco, working paper number 2020-9, June 2020.
[23] Dabo Guan et al., "Global supply-chain effects of COVID-19 control measures," *Nature Human Behaviour,* 2020, Volume 4.
[24] Johns Hopkins University of Medicine, Coronavirus Resource Center; data as of July 20, 2020.

Exhibit 2

Shocks vary based on their frequency, lead time, and nature of impact, with the most severe events affecting both supply and demand.

1. Based on initial impact of shock, not including spread or knock-on effects. 2. Cost impact based on World Economic Forum estimate for sum of current total annual cost of global conflicts. 3. Cost impact estimate based on expected global GDP loss from Oxford Economics and McKinsey estimates and survey of executives. 4. The Ponemon Institute, a security and data protection researcher, estimates that the average company's cost for every minute of internet downtime during a DDoS attack is $22,000, with cost for some companies reaching up to $100,000 per minute of downtime. Single-day outage of connectivity for 5,000+ companies would cost ~$160 billion, a 7-day outage over $1 trillion. 5. Based on *New York Times* estimate of sum of physical damage and direct economic impact. Does not include Homeland Security or war-related cost. 6. Direct costs. 7. Includes, eg, supplier bankruptcy, labor dispute, IT outage.

Source: IMF; New York Times; Oxford Economics; Ponemon Institute; World Economic Forum; McKinsey Global Institute analysis

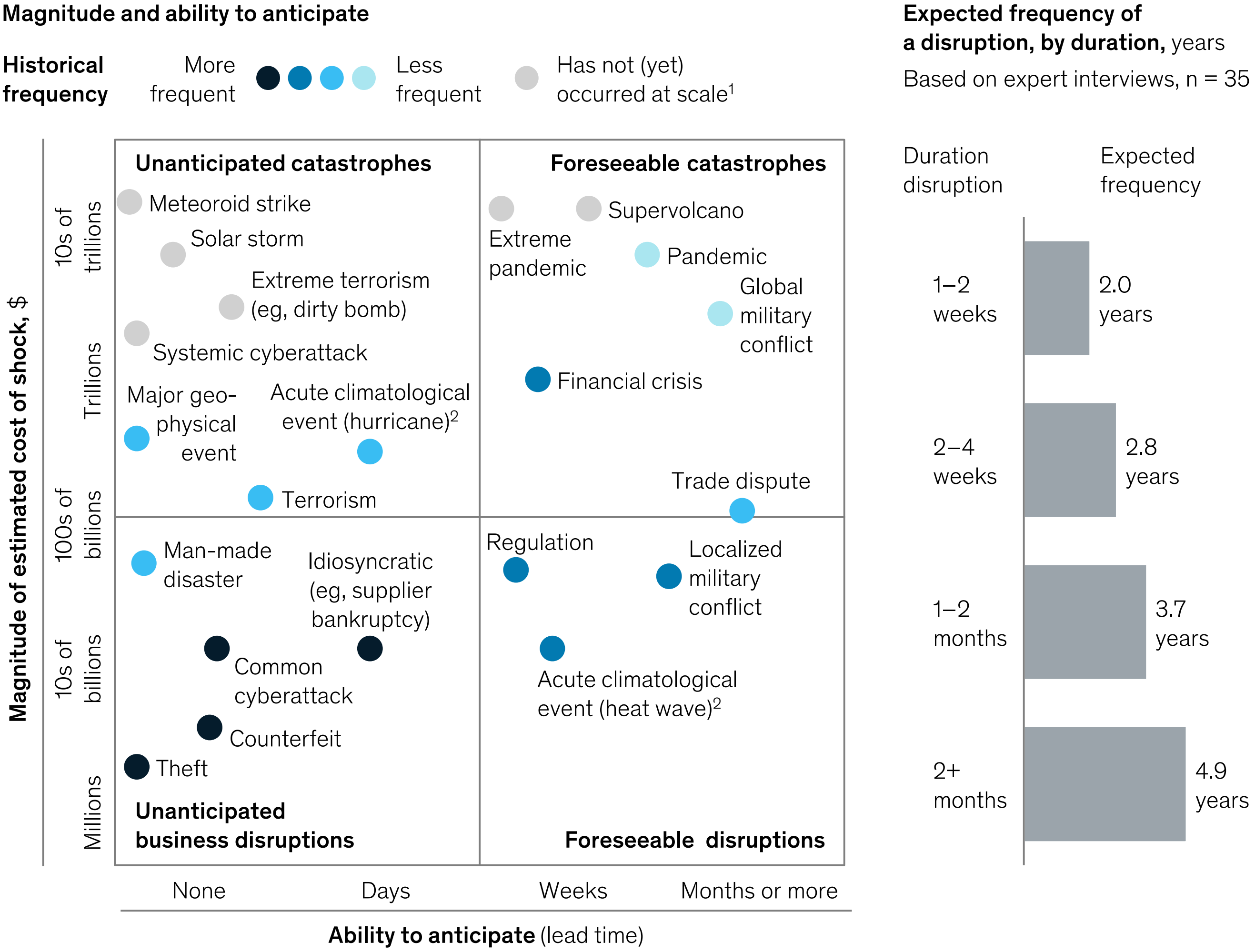
Expect the unexpected

Exhibit 3 groups different types of shocks based on the magnitude of their impact and whether they can be anticipated. It shows historic examples from recent decades as well as events that remain theoretical possibilities. We pair this with results from a survey of global executives indicating how often shock events cause business disruptions.

For instance, the world has not yet experienced a truly large-scale cyberattack, although experts have consistently warned about the potential for malicious actors to take down large portions of the Internet, payment systems, or hard assets such as electrical grids. Such a disruption could create trillions of dollars in losses.[25]

Exhibit 3

Disruptions vary based on their severity, frequency, and lead time—and they occur with regularity.



1. Shocks that have not occurred either at scale (eg, extreme terrorism, systemic cyberattack, solar storm) or in modern times (eg, meteoroid strike, supervolcano).
2. Based on experience to date; frequency and/or severity of events could increase over time.
Source: McKinsey Global Institute analysis

[25] According to a study by the Ponemon Institute, which specializes in cybersecurity issues, the average company loses more than $20,000 per minute of downtime to distributed denial of service attacks. Damage from a hypothetical weeklong disruption affecting several thousand companies would exceed $1 trillion. *Cyber security on the offense: A study of IT security experts,* Ponemon Institute, November 2012.

A meteor striking a major city could deliver the explosive equivalent of nuclear weapons. Such strikes are estimated to occur two or three times every 100 years.[26] In 2013, a meteor the size of a six-story building broke up over the Russian city of Chelyabinsk, injuring thousands but doing less damage than it could have caused if its speed and trajectory had been slightly different.[27] A major solar storm could zap much of the world's electronics, as when the nascent telegraph industry was hit by the 1859 Carrington Event; on a similar but smaller scale, a flare in 1989 knocked Quebec's power grid offline.[28] Other dire scenarios in the realm of the theoretical include terrorism involving nuclear or biological weapons, viruses more lethal and infectious than COVID, and a supervolcano eruption that blankets a vast surrounding area with ash. The possibilities have all been subject to serious scientific and governmental scrutiny, even if they exceed the threshold at which companies can reasonably or economically prepare.

To assess the frequency of value chain disruptions, we surveyed dozens of experts with decades of experience in four industries: automotive, aerospace, consumer electronics, and pharmaceuticals. Their responses indicate that disruptions happen regularly, and restoring damaged factories and logistics systems takes time. On average, a shock that stops supply and production for one to two weeks occurs every two years. Even longer disruptions occur with regularity. Disruptions that drag on for two months or longer happen every five years. As discussed in chapter 3, the cost of these events, to companies and societies alike, is very high.

Shocks are growing more frequent and severe, reflecting structural changes in the global economy

Disasters have always been with us. But the range of what is possible has grown, as has the ability of these events to touch the world's value chains either directly or indirectly. Now that industry value chains are global and the world is more interconnected, there are more avenues that allow shocks to travel from one part of the world to another—and to do so faster than ever. Contagion can occur via any type of global flow. When the movement of goods or services is disrupted, the effects of a bottleneck cascade downstream. Financial contagion can be wide and instantaneous, given the dependence of all sectors on increasingly global and digital financial services. International travelers carried the coronavirus to nearly every country in the world in a matter of weeks. All sectors are digitizing, which exposes vital corporate operations to breaches, malware, and IT outages.

As Earth's temperatures rise, climate science tells us that acute events such as heat waves and wildfires could become more intense, more frequent, or both. Climate change is also creating a set of chronic hazards, such as rising heat and humidity levels and higher sea levels.

The destruction of habitat increases opportunities for viruses to jump from animals to people. Global travel and cities with unprecedented density create the mechanisms for exponential spread. Since 2000, the world has experienced broad outbreaks of SARS, swine flu, MERS, Ebola, Zika, and avian flu. But these events have been dwarfed by the scope of the COVID pandemic, which is unlikely to be the last novel contagious disease that spreads through an interconnected world.

26 Paul Rincon, "US detects huge meteor explosion," BBC News, March 18, 2019.
27 "Explainer: What have scientists learned from the Chelyabinsk meteor," Radio Free Europe, November 7, 2013, rferl.org/a/explainer-meteor-russia/25161323.html.
28 "A super solar flare," National Aeronautics and Space Administration, May 6, 2008, science.nasa.gov/science-news/science-at-nasa/2008/06may_carringtonflare.

Finally, an evolving and volatile geopolitical environment increases the potential for conflict, whether through military confrontations, terrorism, trade disputes, intellectual property (IP) theft, or divergent standards for technology, privacy, and other issues.[29] Protectionism has taken root in some of the Western democracies that were once champions of free trade. Borders have gone up again in Europe after decades of integration, and the full implications of that are not yet clear. There is a real chance that tariffs and nontariff barriers will continue to rise, reversing decades of trade liberalization. Companies have to be prepared to respond to rapid shifts in regulatory policy, tax laws, and tariffs.

Industry value chains have different levels of shock exposure, based on their geographic footprint and other factors

Value chains are exposed to this array of shocks in different ways. One of the biggest determinants (although not the only one) is an industry's geographic footprint. Countries across South and Southeast Asia, for example, frequently experience flooding—a phenomenon that is likely to worsen over time in the face of global warming. Earthquakes often strike in countries such as Japan, Indonesia, Mexico, and Turkey. Other countries have recent histories of political instability and social unrest. Value chains heavily present in these regions are therefore more susceptible to those specific shocks. The share of global trade conducted with countries ranked in the bottom half of the world for political stability, as assessed by the World Bank, rose from 16 percent in 2000 to 29 percent in 2018. Just as telling, almost 80 percent of trade involves nations with declining political stability scores.[30]

The factors of production that are central to a given industry will also influence how a particular unexpected shock affects it. Capital-intensive value chains, for example, face the possibility of heavy losses if their specialized plants and equipment are damaged by conflict or natural disasters. Pandemics are a particular threat to labor-intensive industries such as textiles and apparel.

We analyze 23 industry value chains to assess their exposure to six specific shocks (Exhibit 4). In narrowing down the range of shocks shown in Exhibit 4, we omitted idiosyncratic disruptions since they often affect only one or a handful of companies. We then chose representative severe shocks from the remaining quadrants; they include diverse types of events that affect different factors of production. To assess each industry's relative exposure, we consider its current geographic footprint and its factors of production. (See the technical appendix for further details on methodology.) This does not account for the vulnerabilities or resilience measures taken within those value chains. Subsequent chapters address these topics.

[29] See Richard Haas, *The World: A Brief Introduction,* New York, NY: Penguin Press, June 2020.
[30] World Bank, Worldwide Governance Indicators 2018 (political stability and absence of violence/terrorism).

Exhibit 4

Each value chain's exposure to shocks is based on its geographic footprint and factors of production.

Less exposed → More exposed

Rank of exposure (1 = most exposed)

	Value chain	Overall shock exposure	Pandemic[1]	Large-scale cyber-attack[2]	Geo-physical event[3]	Heat stress[4]	Flooding[5]	Trade dispute[6]
Global innovations	Chemical	11	16	4	6	19	16	8
	Pharmaceutical	19	23	2	17	23	19	4
	Aerospace	8	2	1	18	20	21	5
	Automotive	14	6	9	12	21	18	6
	Transportation equipment	4	5	12	7	13	5	15
	Electrical equipment	16	17	11	9	15	15	10
	Machinery and equipment	18	9	10	20	17	20	7
	Computers and electronics	6	15	5	4	14	14	9
	Communication equipment	1	13	3	2	16	7	2
	Semiconductors and components	9	19	6	1	18	23	1
	Medical devices	23	22	8	22	22	22	3
Labor-intensive	Furniture	13	3	21	14	4	12	17
	Textile	7	7	22	11	3	2	21
	Apparel	2	1	20	15	2	1	11
Regional processing	Fabricated metal products	21	14	18	19	6	17	15
	Rubber and plastic	15	8	17	16	8	13	13
	Food and beverage	19	21	14	13	12	6	22
	Glass, cement, and ceramics	10	11	16	5	5	11	20
Resource-intensive	Agriculture	17	20	19	23	1	4	14
	Petroleum products	3	4	7	10	7	10	18
	Basic metal	12	18	13	8	11	8	12
	Mining	5	10	15	3	10	3	19
	Wooden products	22	12	23	21	9	9	23

1. Based on geographic footprint in areas with high incidence of epidemics and high people inflows. Also considers labor intensity and demand impact. Sources: INFORM; UN Comtrade; UN World Tourism Organization; US BEA; World Input-Output Database (WIOD).
2. Based on knowledge intensity, capital intensity, degree of digitization, and presence in geographies with high cross-border data flows. Sources: MGI Digitization Index; MGI LaborCube; Telegeography; US BLS.
3. Based on capital intensity and footprint in geographies prone to natural disasters. Sources: INFORM; UN Comtrade; WIOD.
4. Based on footprint in geographies prone to heat and humidity, labor intensity, and relative share of outdoor work. Sources: MGI Workability Index; O*Net; UN Comtrade; US BLS.
5. Based on footprint in geographies vulnerable to flooding. Sources: UN Comtrade; World Resources Institute.
6. Based on trade intensity (exports as a share of gross output) and product complexity, a proxy for substitutability and national security relevance. Sources: Observatory of Economic Complexity; UN Comtrade.

Note: Overall exposure averages the six assessed shocks, unweighted by relative severity. Chart considers exposure but not mitigation actions. Demand effects included only for pandemics.

Source: McKinsey Global Institute analysis

Read horizontally, the chart shows each value chain's level of exposure to different types of shocks—and those results can vary sharply. Aerospace and semiconductors, for example, are both susceptible to cyberattacks and trade disputes; semiconductors are also made in earthquake-prone places. However, both value chains have relatively low exposure to climate-related events. Agriculture and, to a lesser extent, food and beverage are huge sources of jobs, and developing countries have high levels of participation. These value chains are highly exposed to climate events.

Read vertically, the index shows which value chains are likely to be touched by specific types of shocks. Pandemics, for example, have a major impact on labor-intensive value chains. In addition, this is the one type of shock for which we assess the effects on demand as well as supply. As we are seeing in the current crisis, demand has plummeted for nonessential goods and travel, hitting companies in apparel, petroleum products, and aerospace. In general, climate-related shocks are more likely to strike labor-intensive value chains (and some resource-intensive value chains); cyberattacks are more likely to focus elsewhere. Perhaps surprisingly, these same value chains are relatively less susceptible to trade disputes. This is because the index takes a forward-looking view. The aim of trade policy has shifted away from protecting large numbers of jobs and toward capturing or retaining more knowledge-intensive and high-value industries.

Overall, value chains that are most traded relative to output are more exposed to value chains which are least traded. These include the medical devices, communication equipment, apparel, computer and electronics, and semiconductor and components value chains. These value chains have the further distinction of being high value and relatively concentrated, underscoring what is at stake for the global economy. From the vantage point of value chain archetypes, labor-intensive value chains on average rank as the most exposed, due to their high exposure to pandemic risk, heat stress (because of their reliance on labor), and flood risk (since many of these value chains are located in areas with high exposure to flooding).

Finally, at the level of individual value chains, communications equipment has the highest exposure to the full range of shocks that we assessed. As a heavily traded, geographically concentrated value chain, it may be caught up in trade disputes—and most of its footprint is in the Asia—Pacific region, which is vulnerable to earthquakes, tsunamis, and typhoons. The centrality of intellectual property and digital assets also heightens vulnerability to cyberattacks.

The value chain with the next highest exposure is apparel. In a pandemic, it is susceptible to production shutdowns because of its labor-intensive nature as well as drops in consumer demand. Furthermore, a large share of apparel exports come from countries subject to heat waves and flooding. Petroleum products ranks as the third most exposed value chain to the six shocks we have assessed. While a pandemic does not directly disrupt production in this value chain, the severe drop-off in demand induced by a pandemic (which briefly sent oil futures negative during the current pandemic) makes this value chain highly exposed.[31] The value chain is also exposed to cyberattacks given its high reliance on physical and digital capital.[32] It is also in the top 10 most exposed value chains to geophysical events, heat stress, and floods, based on the geography of its production.

[31] Stephanie Kelly, "Oil price crashes into negative territory for the first time in history amid pandemic," *Reuters*, April 19, 2020.

[32] *Drilling deep: a look at cyberattacks on the oil and gas industry.* Trend Micro, December 12, 2019.

$4.4 trillion

in annual exports flows through the five most exposed value chains

All in all, the five value chains most exposed to our assessed set of six shocks collectively represent $4.4 trillion in annual exports or roughly a quarter of global goods trade (led by petroleum products, ranked third overall, with $2.4 trillion in exports); the five least exposed value chains account for $2.6 trillion in exports. Labor-intensive value chains are followed in having the highest overall average severity rank by global innovation value chains, many of which are exposed to cyberattacks and trade disputes. Regional processing value chains are among the least exposed, their production is globally dispersed and thus not concentrated in areas exposed to a certain kind of shock, and they are also less exposed to cyberattacks and trade disputes. Of the top five most exposed value chains, apparel accounts for the largest share of employment, with at least 25 million employed globally, according to the International Labor Organization.[33] While agriculture is relatively less exposed due to its dispersed footprint, it is the largest source of global employment—and shocks in certain parts of the world could disrupt the lives and livelihoods of millions.

Value chains that are the most traded—in terms of value and relative to output—and most concentrated all have higher exposure scores on average. On average, the five largest value chains by export, accounting for $8.4 trillion or more than 40 percent of exports, rank three positions higher than the smallest value chains.[34] The five most traded value chains relative to their gross output have an average overall exposure rank of eight; the five least traded value chains have an average overall exposure rank of 18.[35] Finally, the value chains that have the fewest countries responsible for 75 percent or more of exports have an average overall exposure rank of 9 versus value chains with the most country participation at 15.[36]

Even value chains with lower exposure to specific types of shock are not immune to them. The pharmaceutical industry, for example, is generally less exposed overall than most others. But it has recently been disrupted by a hurricane that struck Puerto Rico, and cyberattacks are a growing concern. In the future, the industry may be subject to greater trade tensions and to regulatory and policy shifts if governments take action to establish domestic production of critical pharmaceutical supplies to safeguard public health. Finally, other shocks not included in this analysis may be more salient for some value chains. Those operating in more politically unstable regions, for example, may be more exposed to military conflict, terrorist attacks, or sudden policy changes.

[33] International Labor Organization, "Employment by sex and economic activity – ILO modelled estimates," ILOSTAT, accessed June 20, 2020.
[34] The five largest by export are petroleum products; automotive; chemicals; machinery and equipment; and basic metals; the five smallest are furniture; wooden products; glass, cement, and ceramics; transportation equipment; and medical devices.
[35] The five most traded are medical devices; communication equipment; apparel; computer and electronics; and semiconductor and components. The five least traded are fabricated metal products; glass, cement, and ceramics; wooden products; agriculture; and food and beverage.
[36] Value chains with the fewest countries responsible for 75 percent of exports or more are communication equipment; semiconductor and components; computers and electronics; aerospace; and pharmaceuticals. Value chains with the most country participation are agriculture; food and beverage; basic metals; petroleum products; and wooden products.

Today's accelerated news cycle gives the impression that supply chains are being disrupted with greater frequency—and the data bears this out. But part of that is due to the fact that multinationals are simply more exposed. As value chains have grown in length and complexity, companies based in relatively stable countries now operate and source from many more places with higher risk profiles. The previous era of globalization created intricately interconnected supply chains, data flows, financial flows, people flows, and idea flows—all of which offer more "surface area" for risk to penetrate. The following chapter examines the vulnerabilities that exist within individual companies and broader value chain structures.

2. Vulnerabilities within companies and value chains

Shocks have a way of zeroing in on vulnerabilities and exploiting them—and weak spots exist not only within individual companies but also across broader value chains. Some are inherent to the nature of a given industry and simply come with the territory. Smartphones, computers, automobiles, and airplanes are immensely intricate products with many components, which translates to complex supply chains. Because many food and agricultural products are perishable, routine production and delivery delays can easily cause spoilage even in good times. When any stressor is added, such as the possibility of Brexit's necessitating new layers of customs requirements, exporters can quickly find themselves in trouble.

However, some vulnerabilities result from intentional decisions. These include adopting lean production models to improve efficiency and margins, holding minimal inventory, sourcing from a single supplier, and making extensive use of customized inputs with few substitutes, for example. These choices can improve efficiency or quality in the immediate term, but they can have unintended consequences during a disruption. These are and remain potentially viable operating decisions; the vulnerability arises when they are applied without a counterbalancing emphasis on resilience.

One issue that affects most large companies is a lack of visibility into the deeper tiers of their supply chain. Complexity itself is not necessarily a weakness to the extent that it provides companies with redundancies and flexibility. But sometimes the balance can tip, and excessively complex networks become opaque. A single large multinational can have tens of thousands of suppliers in multiple tiers (Exhibit 5). Without full transparency, companies may not realize how heavily reliant they are on subtier suppliers in shock-prone regions halfway around the world. Vulnerability can also lurk within the balance sheet. High fixed costs, high levels of debt, and low cash on hand can make it harder to maneuver and maintain solvency in a crisis—and some of these patterns are common across broader industries. Organizational weaknesses, too, can come back to bite individual companies in a crisis.

This chapter explores several key areas of vulnerability, including demand planning, supplier networks, transportation and logistics, financial health, and product complexity.[37] An organization's supply chain operations can be a source of vulnerability or resilience, depending on its effectiveness in monitoring risk, implementing mitigation strategies, and establishing business continuity plans. Finally, we have combed through publicly available data to map the top-tier suppliers for two major corporations in the food and beverage industry and two more in computers and electronics. These real-world examples illustrate the complexity, layers, and hidden relationships that companies must sort out and manage in their supplier networks.

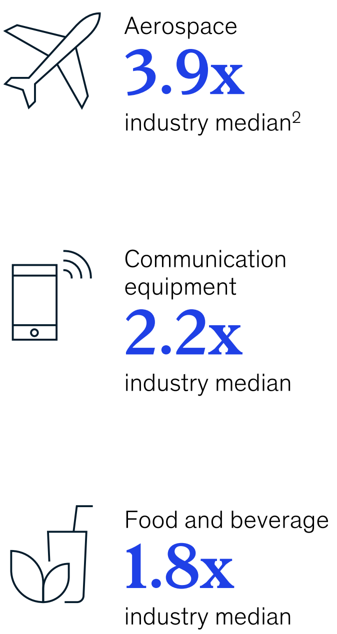
[37] Knut Alicke, Ed Barriball, Susan Lund, and Daniel Swan, "Is your supply chain risk blind—or risk resilient?," McKinsey.com, May 14, 2020.

Exhibit 5

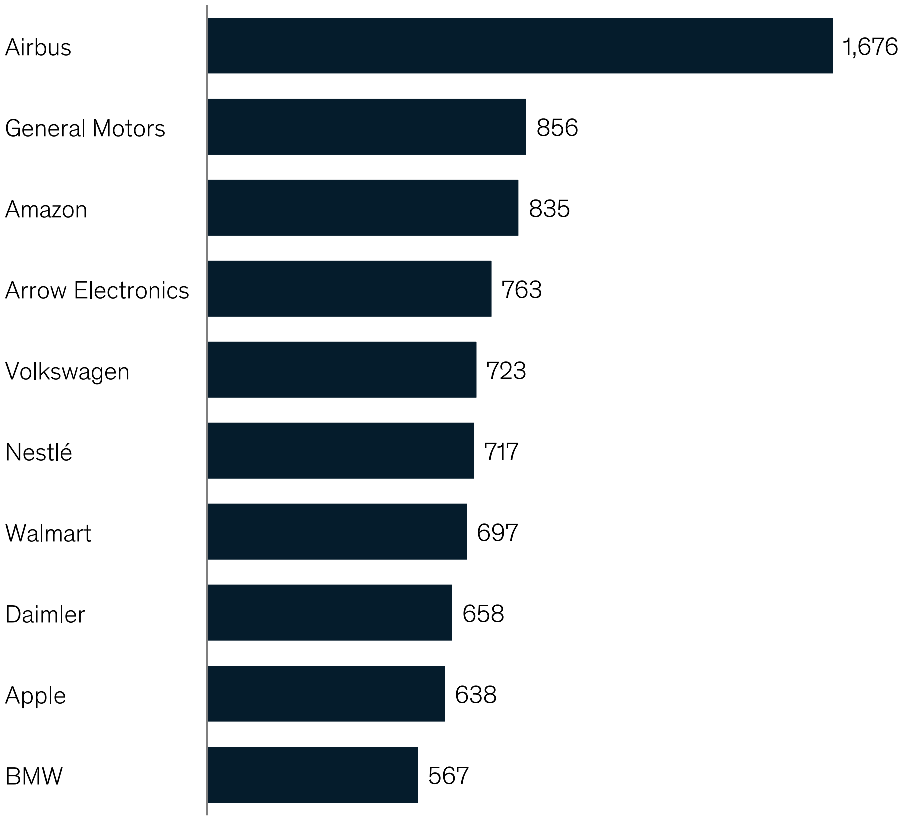
The largest companies have thousands of suppliers globally.

Number of publicly disclosed tier-1 suppliers of MSCI companies[1]

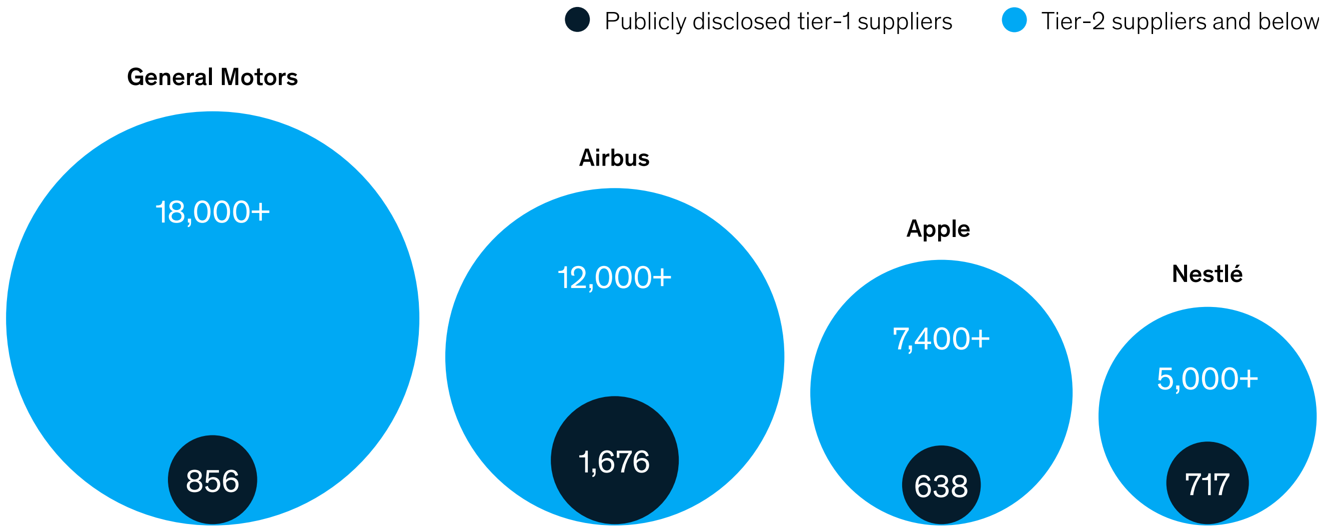
Industries with the largest number of tier-1 suppliers



MSCI companies with the largest number of publicly disclosed tier-1 suppliers



Beyond the first tier, companies rely on a network of thousands of suppliers



1. Analysis based on 668 out of 1,371 companies in MSCI index; excludes 57 companies that did not have public information available on tier-1 suppliers and 645 companies that provide services. This constitutes an incomplete estimate of customer-supplier relationships based on public disclosures. Suppliers include providers of intermediate inputs, services, utilities, software, etc.
2. Median of simple average of tier-1 suppliers for each manufacturing industry considered.

Source: Bloomberg Supply Chain database; McKinsey Global Institute analysis

At the value chain level, manufacturing of some products has become highly concentrated, creating the potential for bottlenecks

When most suppliers are concentrated in a single geography, a natural disaster or localized conflict in that part of the world can cause critical shortages that snarl the entire network. During the early weeks of the COVID pandemic, many consumer packaged goods companies found out abruptly that some critical inputs largely come from Hubei Province.

Over the past two decades, globalization has reinforced country-level specialization in some industries where clusters have formed, enabling companies to reap economies of scale and hone their expertise.[38] Industries such as computers and mobile phones have become more geographically concentrated as a result. But this can lead to bottlenecks when shocks hit. Yet the opposite has happened in industries such as medical devices and aerospace as more countries have begun to participate in the value chain (Exhibit 6). Other products may be produced in diverse geographies but have severe capacity constraints that create bottlenecks if production is disrupted. Similarly, certain products may be exported by many countries, but trade takes place within clusters of countries rather than on a global basis. In those instances, importers may struggle to quickly source from another exporter when their predominant supplier experiences a disruption. Last, diversification of production is not inherently positive, particularly if the shifts are to areas that are more exposed to shocks.

The risk of concentration affects both downstream customers, whose inputs could dry up, and upstream suppliers if those customers stop ordering. When a country is heavily reliant on one major export industry, a sharp downturn in customer markets can have devastating effects. The textile and apparel industry in Bangladesh, for instance, accounts for the vast majority of the country's exports. When consumer spending plummeted in the United States and Europe during the COVID pandemic, clothing retailers canceled billions of dollars' worth of orders. This not only squeezed Bangladeshi suppliers but created widespread hardship for garment workers whose incomes suddenly dried up.[39]

180

products exported almost exclusively by one country

Even in value chains that are generally more geographically diversified, the production of certain key products may be disproportionately concentrated. While aerospace is generally regionalized, engines, turbo propellers, and large aircraft are mainly produced in one country. Many low-value or basic ingredients in pharmaceuticals are made in China and India. For example, UN Comtrade data shows that China and India export 42 percent of global antibiotic active pharmaceutical ingredient products (by value, not volume), with China dominating export value in some specific types such as streptomycin (75 percent) and penicillin (52 percent). Semiconductors and consumer electronics also feature some regionally concentrated exports. For example, Taiwan exports 43 percent of global value in electronic integrated circuits, and South Korea exports 50 percent of global value in semiconductor memory products.[40] Mainland China exports three-quarters of all personal computers and two-thirds of all cellphones. While generally regionalized in production, some food and beverage products may also be highly concentrated. Canada exports 85 percent of global value in frozen lobsters, which are found primarily along its Atlantic coastline. In total, we find 180 products (valued at $134 billion in 2018) that are exported almost exclusively by a single country. This creates the possibility that shocks in those countries could lead to bottlenecks until alternatives can be found (Exhibit 7).

[38] See, for example, Paul Krugman, "Increasing returns, monopolistic competition, and international trade," *Journal of International Economics,* November 1979, Volume 9, Issue 4; and "Scale economies, product differentiation, and the pattern of trade," *The American Economic Review,* December 1980, Volume 70, Number 5.

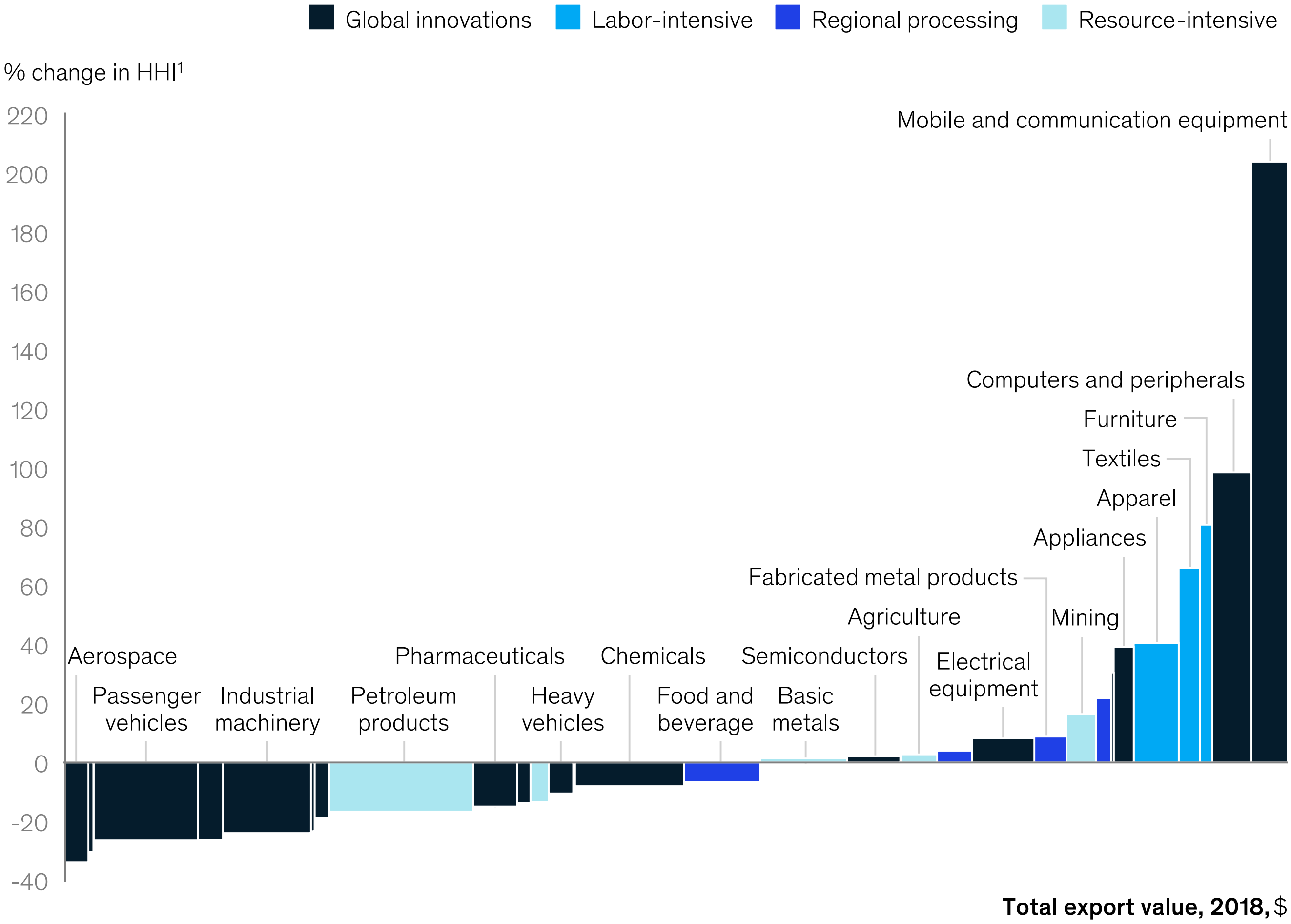
[39] Elizabeth Paton, "'Our situation is apocalyptic': Bangladesh garment workers face ruin," *New York Times,* March 31, 2020.

[40] 2018 exports for product codes HS854239 (electronic integrated circuits) and HS854232 (semiconductor memory products).

Exhibit 6

Globalization has led to diversification of production across countries in some sectors, but others have grown more concentrated.

Change in geographic concentration by sector, 2000–18, measured by change in Herfindahl-Hirschman Index of exports (HHI)[1]



1. A measure of concentration that is the sum of the square of each country's share of exports.

Note: Data includes 5,444 unique final and intermediate products from 2018 trade data. The weighted average is weighted by the share of trade for each product within each value chain. All other measurements of HHI are calculated using the raw, unweighted score.

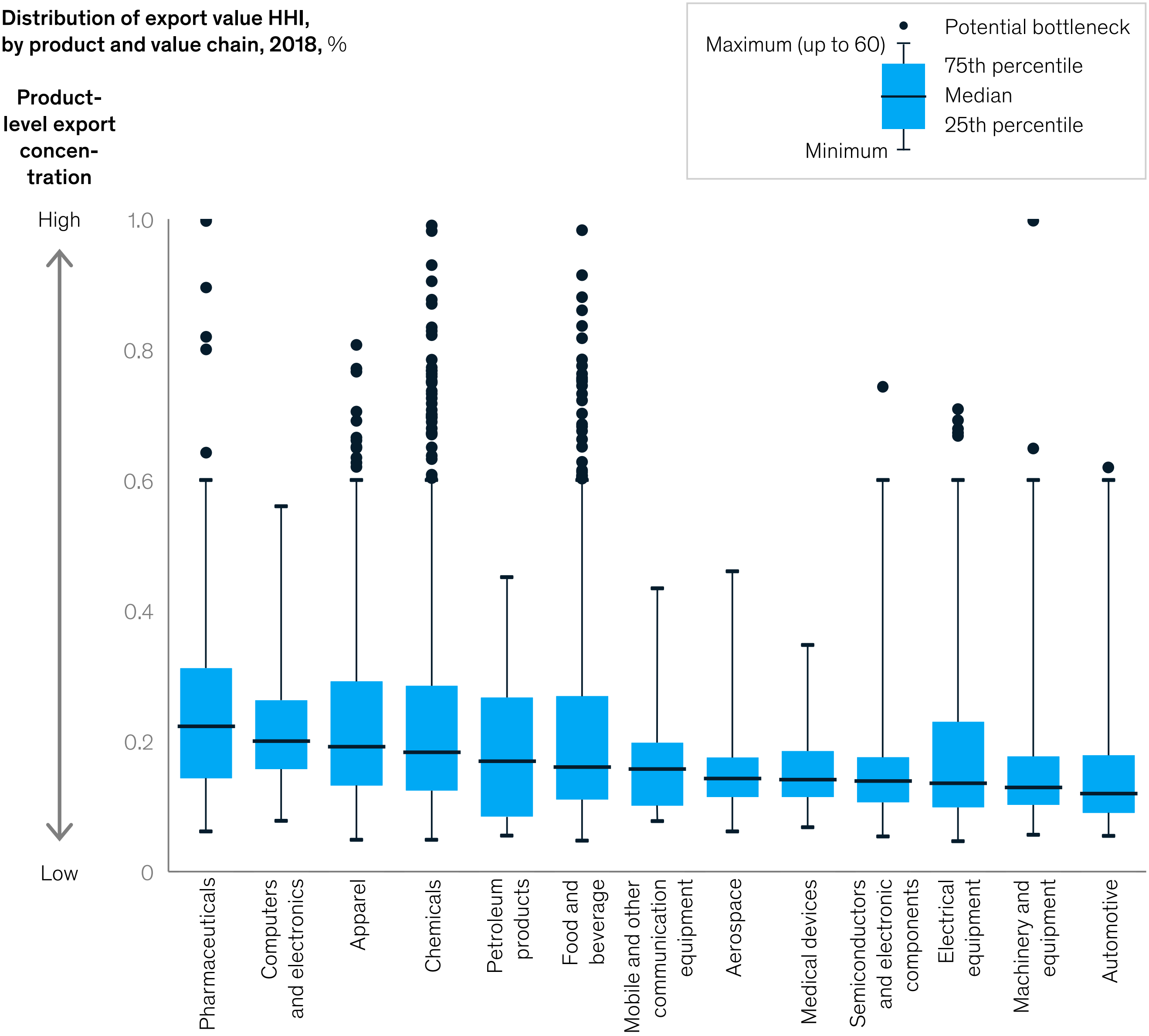
Source: UN Comtrade; McKinsey Global Institute analysis

Exhibit 7

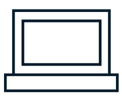
Exports of some products are significantly concentrated and can be a key source of vulnerability.

Nearly 200 products are exported almost exclusively by one country, creating potential bottlenecks

Distribution of export value HHI, by product and value chain, 2018, %

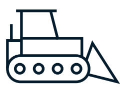


China exports
94%
of an antibiotic used to treat conjunctivitis, meningitis, typhoid fever, and other serious infections



China exports
74%
of personal laptop computers

Japan exports
76%
of cyclohexanol, a chemical used for paints, plastics, and varnishes



Germany exports
53%
of machine tools for heavy material machine operations

Source: UN Comtrade; McKinsey Global Institute analysis

At the company level, vulnerabilities can reside within five critical areas

Value chain risk exists when external shocks meet vulnerabilities in operations and supply chains. Companies therefore need to scrutinize the places where cracks tend to form. We identify at least five areas that can present vulnerabilities: demand planning and inventory decisions, the structure of supplier networks, transportation and logistics, financial fragility, and product complexity (see Box 1, "Where executives see vulnerabilities in their supply chains").

Demand planning and inventory management

Insufficient demand planning and forecasting capabilities can be a major vulnerability. Value chains differ in the extent to which demand planning is complicated by high levels of unpredictability, seasonality, and cyclicality. These characteristics are not permanently fixed. Apparel, for example, was once defined by distinct seasons with long lead times. Now much of the industry has shifted toward fast fashion, requiring rapid-fire turnaround times to keep up with fickle consumer fads that are often driven by social media influencers.[41] In electronics, short product life cycles and spikes in consumer spending during short holiday windows complicate demand planning.

Another aspect that can create vulnerability in a supplier network is inventory levels. Inventory holding patterns vary across value chains. Sectors such as medical devices with low inventory-to-sales ratios are vulnerable to disruptions, while those that tend to carry high levels of inventories, such as fabricated metal products and computers and electronics, are comparatively less exposed.

For many years, just-in-time manufacturing has been held up as the ultimate model of efficiency. This workflow methodology is predicated on highly responsive suppliers and rapid turns through each step in a production system, and one of its immediate benefits is freeing companies from the costs of carrying large inventories. As soon as a shipment of parts arrives, it is put to use and quickly sent out the door and onto the next step. But achieving perfectly lean manufacturing leaves each participant along the value chain very little margin for error. Supply disruptions can quickly spiral into bottlenecks that ripple across the network. A trend toward regionalization may, ironically, increase the speed at which disruptions are felt; when inputs are hours away by truck instead of days away by cargo ship, organizations may feel safer holding lower inventories.

[41] *The state of fashion 2019,* McKinsey & Company and the Business of Fashion, November 2018.

Box 1

Where executives see vulnerabilities in their supply chains

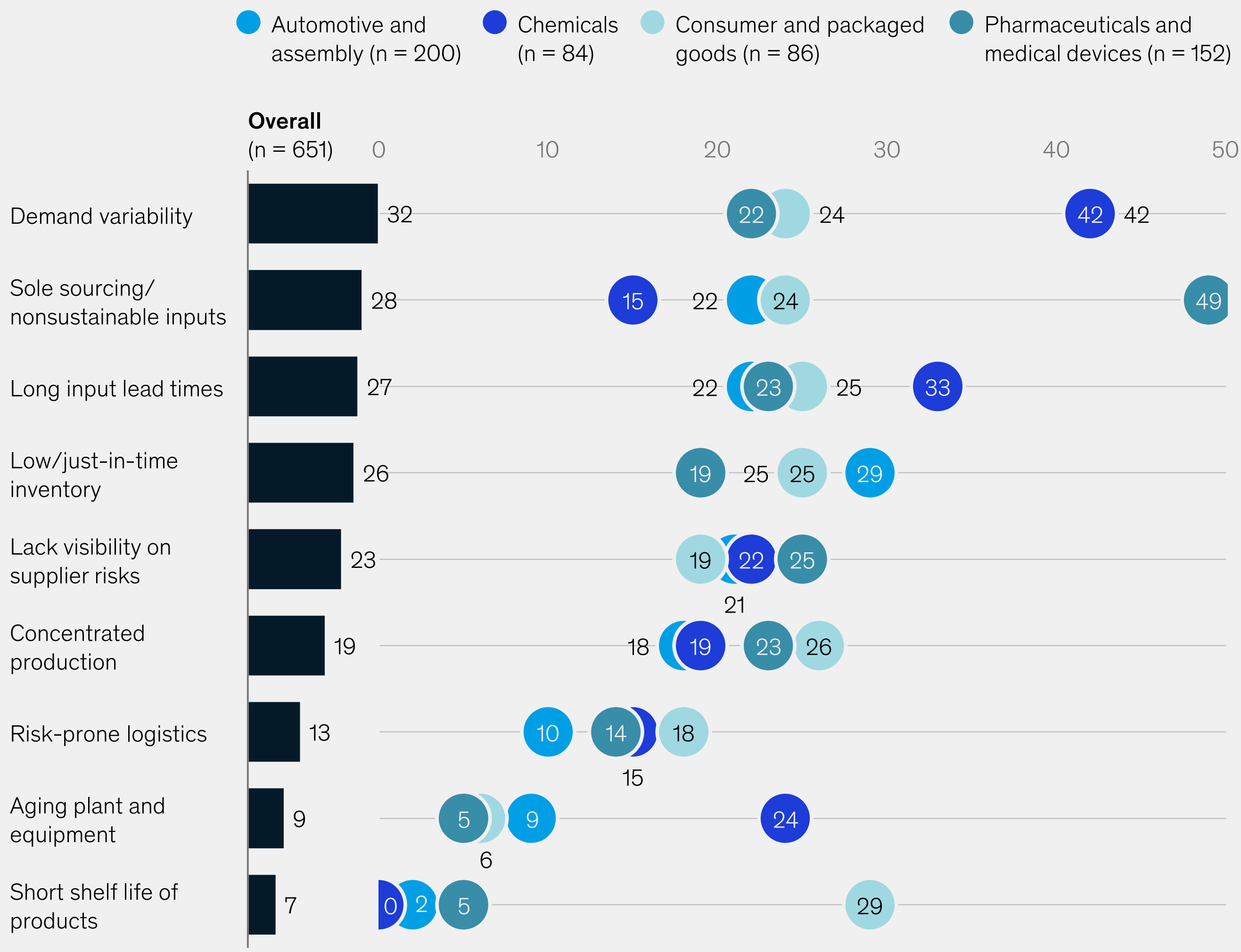
Even before COVID-19 struck, businesses were reevaluating risk. When McKinsey surveyed 600 global executives in December 2019, 70 percent of them reported that they were reconsidering their supply chain strategies and global footprint. Indeed, at the time, US–China trade tensions and the United Kingdom's pending withdrawal from the EU were major sources of uncertainty.

Since then, the COVID pandemic has led to a heightened sense of vulnerability. In a follow-up survey in May 2020, one-third of respondents cited demand variability and the difficulty of forecasting accurately as key issues (Exhibit 8). This worry was especially pronounced among respondents from the automotive and chemicals industries. Sole sourcing or the use of inputs that could not be substituted was a concern for 28 percent of all respondents—and for half of those from the pharmaceutical industry. Just over a quarter of executives pointed to long lead times for inputs and low or just-in-time inventories as vulnerabilities.

Exhibit 8

Business leaders cite multiple sources of supply chain vulnerability.

Which of the following conditions currently makes your company most vulnerable to value chain disruptions due to any cause, including COVID-19?, % of respondents



Source: McKinsey survey of business executives, May 2020; McKinsey Global Institute analysis

Supplier networks may be

7–17x

larger than tier one alone

Supplier network structure

To assess its vulnerabilities, any company has to identify all of the players in its supply chain—and that is not a trivial task. Most have some view of the potential risks in their direct tier-one suppliers but are flying blind when it comes to the subtiers of the supplier network.

Not surprisingly, our analysis of public disclosures of major customer-supplier relationships reveals that sectors that manufacture relatively complex products, such as automobiles, aerospace, and computers and electronics, have the greatest number of tier-one suppliers on average. Airbus, General Motors, and Volkswagen are among the companies with the largest number of disclosed tier-one suppliers, but this only hints at their full complexity. For example, General Motors has more than 850 disclosed tier-one suppliers in its or its suppliers' regulatory filings; the company itself, however, has stated that as many of 18,000 suppliers are part of its ecosystem, mostly from lower tiers not captured by our analysis.[42] Similarly, Airbus has 1,676 publicly disclosed tier-one suppliers but states that it works with over 12,000 suppliers.[43] As many companies move to consolidate their tier-one suppliers, their networks can also expand exponentially beyond tier one. Building on publicly disclosed data, we find that companies can have seven to 17 times as many total suppliers as in tier one.

The way a supply chain is constructed can turn out to be a source of either vulnerability or resilience—and there is no one-size-fits-all formula that will work for every company. Exhibit 9 illustrates some of these characteristics.

Having many tier-one suppliers can be challenging for procurement and operations unless the downstream company actively shapes a more coordinated and cohesive core group into which all others feed. At the same time, relying on a narrow supply chain may cede strategic leverage to key suppliers and create the possibility that one player going down can snarl the entire network. Each company will have to determine the balance that suits its management capabilities and its risk tolerance.

The depth of a supply chain refers to the number of tiers in the network, which is determined by the number of steps it takes to transform primary inputs into a finished good. Often the result of cascading outsourcing decisions, deeper supply chains with many tiers may be more opaque and harder to trace. One survey found that at least one-third of supply chain disruptions occur at the second and lower tiers.[44]

Interconnectivity is another important characteristic to examine. Suppliers that are central within production ecosystems deserve attention regardless of how much downstream companies spend with them; if they falter, they could disproportionately disrupt the broader supply chain network. Technology providers often fall into this category, functioning almost as a common utility.

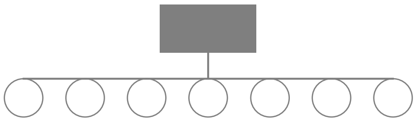
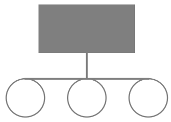
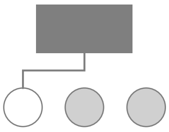
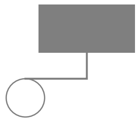
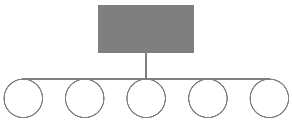
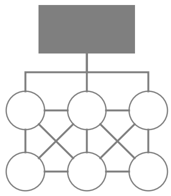
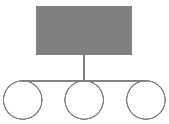
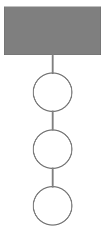
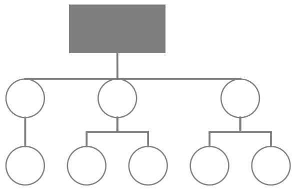
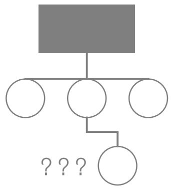
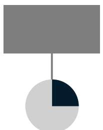
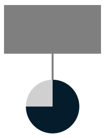
Companies also need to map their networks broadly, paying attention to both industry competitors and adjacent industries. Consider two industries that both use the same input. If supply becomes unexpectedly constrained, the smaller buyer may be squeezed out as suppliers prioritize their largest customers. Similarly, one industry may depend on the by-products of another. During the recent pandemic, ethanol production fell as gasoline sales plummeted. This drove up the prices of CO2 used by the beverage industry in carbonation—a trend that squeezed beer makers even in the face of spiking alcohol sales.[45]

The presence of dependent suppliers—that is, vendors deriving most of their revenue from a single customer—also affects the resilience of a supply chain. In automotive, for example, key suppliers are typically affiliated with a single major automaker, which typically leads to better collaboration and reporting practices. But a troubled downstream customer can have devastating financial consequences for a universe of heavily dependent suppliers.

[42] General Motors, "Our management approach to supply chain," 2018, gmsustainability.com/manage/supply.html.
[43] Airbus, "Be an Airbus supplier," airbus.com/be-an-airbus-supplier.html
[44] Rachael Elliott, Catherine Thomas, and Kamal Muhammad, *Supply chain resilience report 2019,* Business Continuity Institute, 2019.
[45] Stephanie Kelly and Lisa Baertlein, "Beer may lose its fizz as CO2 supplies go flat during pandemic," Reuters, April 18, 2020.

Exhibit 9

The structure of supply chain networks can create or reduce vulnerability.

	Creates resilience	Invites vulnerability
Concentration Density of spending with top suppliers or in single geography	 Lower likelihood that supplier disruption causes bottlenecks	 Increases dependency on single suppliers
Substitutability Extent to which suppliers are sole source of component or input	 Many substitutes Redundancies limit risk of disruption	 No substitutes Higher likelihood that supplier disruption causes bottlenecks
Interconnectivity Interconnectivity between suppliers	 Supplier disruptions unlikely to affect full network	 Supplier disruption can affect full network
Depth Layers of subtier suppliers	 Increases ability to spot risk in subtiers	 Lowers visibility into subtiers
Visibility Extent to which customer can trace spending at subtier level	 Many subtiers known Transparency	 Few subtiers known Lack of transparency
Dependence Sub-tier suppliers that are highly dependent on one customer or are SMEs	 Decreases likelihood subtier is vulnerable to financial shocks	 Higher subtier vulnerability to financial shocks

Source: McKinsey Global Institute analysis

Transportation and logistics networks

As supply chains lengthen and become leaner, they have less margin for error in getting the right inputs to the right place at the right time. Complex supply chains are inherently at the mercy of logistics to move products through each step in the process and eventually to deliver the end product to market. These services are valued accordingly: business logistics spending in the United States equaled 7.6 percent of GDP in 2019.[46] Globally, the third-party contract logistics market is valued at over $260 billion.[47]

Greater physical connectivity facilitates the movement of goods between manufacturing facilities and across borders. Since 2010, the median country experienced a 30 percent improvement in their Liner Shipping Connectivity Index, a UN Council on Trade and Development metric that shows the growing capacity and frequency of shipping services across countries.[48] At the same time, container shipping is vulnerable to both business risks (such as cargo theft, supplier bankruptcy, and even ship fires) and catastrophic events (such as storms) that physically block logistics infrastructure and routes. In a 2019 survey of global executives, 15.8 percent stated that transportation was one of the top five causes of supply chain disruptions in their network.[49]

The regionalization of global trade and supply chains may mitigate some vulnerabilities in logistics, but not all (see Box 2, "From long haul to regional"). Regional and local supplier networks are more likely to rely on ground shipping, which is more susceptible to cargo theft and localized disruptions such as blizzards. In 2019, 87 percent of cargo theft occurred during truck shipping, compared to rail or sea freight or warehousing.[50]

The World Bank assesses countries' international logistics performance on six dimensions: customs, infrastructure, ease of arranging competitively priced shipments, competence of logistics services, ability to track and trace consignments, and timeliness of shipments. In 2018, Germany ranked as the best performer. The United States ranked 14th, and China, belying its status as the world's leading exporter, ranked 26th (due in part to its lower customs scores).[51]

Financial fragility

An individual company's financial position may prove to be a vulnerability or a source of flexibility when a shock hits. Companies burdened with heavy debt loads or operating with little cash on hand may have limited room to maneuver during shocks and shutdowns.

Common financial patterns are apparent across entire value chains. Sectors such as mining are more reliant on financial intermediation services, which makes them more sensitive to financial crises; by contrast, makers of petroleum products are less dependent on the financial sector. Debt and liquidity levels also vary meaningfully by industry. Based on a review of the 2019 financials of large publicly traded global companies, the automotive, machinery and equipment, and communication equipment sectors tend to be more highly leveraged than sectors such as semiconductors and petroleum products. The pharmaceutical, semiconductor and electronic components, and petroleum products industries tend to have more cash on hand, while aerospace, automotive, communication equipment, and agriculture are less liquid.

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46 *31st annual state of logistics report,* Council of Supply Chain Management Professionals, 2020.
47 McKinsey Global Institute analysis; includes primarily air and sea freight forwarding.
48 UN Council on Trade and Development. The index is a function of the number of scheduled ship calls, deployed annual capacity, number of regular shipping services, and number of direct country connections.
49 Rachael Elliott, Catherine Thomas, and Kamal Muhammad, *Supply chain resilience report 2019,* Business Continuity Institute, 2019.
50 *BSI & TT Club cargo theft report 2020,* BSI Group and TT Club, 2020.
51 World Bank, Logistics Performance Index, 2018.

However strong the financial position of a downstream company may be, relying on many small-market-cap or financially fragile suppliers could open the door to disruptions, especially in the case of sole-source suppliers. Small automotive suppliers flirted with bankruptcy when orders dried up during the recent pandemic.[52] Many medical device companies rely on small suppliers to sterilize medical equipment; if they go down, the critical final step before sending the product to market cannot be completed. In crises, downstream companies are only as strong as their supplier networks.

Product and portfolio complexity

Product characteristics can create inherent vulnerabilities. Some products have short life cycles, for instance. Their makers can be disproportionately affected by disruptions that prevent or delay product delivery to market, since they have limited options for storing and selling products at a later date. The use of custom inputs or nonmodular manufacturing processes can also leave companies unable to find readily available substitutes or alternatives.

Product complexity can be measured by the relative level of capabilities, or skilled labor, required to manufacture that good. The Observatory of Economic Complexity developed a product complexity index based on the number of countries producing and trading a given product, which infers relative comparative advantage of production by assuming products produced in a smaller number of countries require a greater level of skill to produce, and hence are more complex by nature. [53] Analyzing these index scores across global value chains reveals that aerospace, automotive, machinery and equipment, and medical devices are the most complex products. Labor- and resource-intensive value chains, such as apparel, textiles, agriculture, and mining, are relatively less complex.

In recent decades, expanding product portfolios has created new revenue opportunities but also introduced complexity. The retail landscape has added new channels, often with their own product and packaging requirements. Consumer goods companies have rapidly expanded their product portfolios and extended existing lines in a bid to gain shelf space and capture fast-growing niche markets (such as wellness products and organic foods). This strategy can drive growth, but it also strains demand planning and supply chain management.

One McKinsey study found that product portfolio complexity costs food and beverage manufacturers as much as $50 billion in gross profit in the US market alone.[54] One global food manufacturer increased its SKU count in North America by 66 percent in a three-year period, adding line extensions and products customized as retail house brands without discontinuing any of its older products.[55] As product portfolios become bigger, they involve more unique raw inputs, limited-time offerings, small orders, specialized packaging requirements, and risk of spoilage and waste. In good times, an overly complex product portfolio can create operational drag and dilute value. But in a crisis, it suddenly becomes a real vulnerability. In response, some food and beverage companies are now developing alternative recipes in case key ingredients become unavailable, and are reducing the diversity of in-store product offerings to further streamline manufacturing and logistics.

52 Nick Carey and Ben Klayman, “May is crunch time for US auto suppliers amid coronavirus shutdown,” Reuters, April 9, 2020.

53 Jesus Felipe et al., “Product complexity and economic development,” *Structural Change and Economic Dynamics,* March 2012, Volume 23, Issue 1, pp. 36-68.

54 Christina Adams, Raphael Buck, Gary Herzberg, Janine Mandel, and Curt Mueller, “Harnessing the power of simplicity in a complex consumer-product environment,” McKinsey.com, June 2020.

55 Christina Adams, Kari Alldredge, Curt Mueller, and Justin Whitmore, “Simpler is (sometimes) better: Managing complexity in consumer goods,” McKinsey.com, December 2016.

Box 2

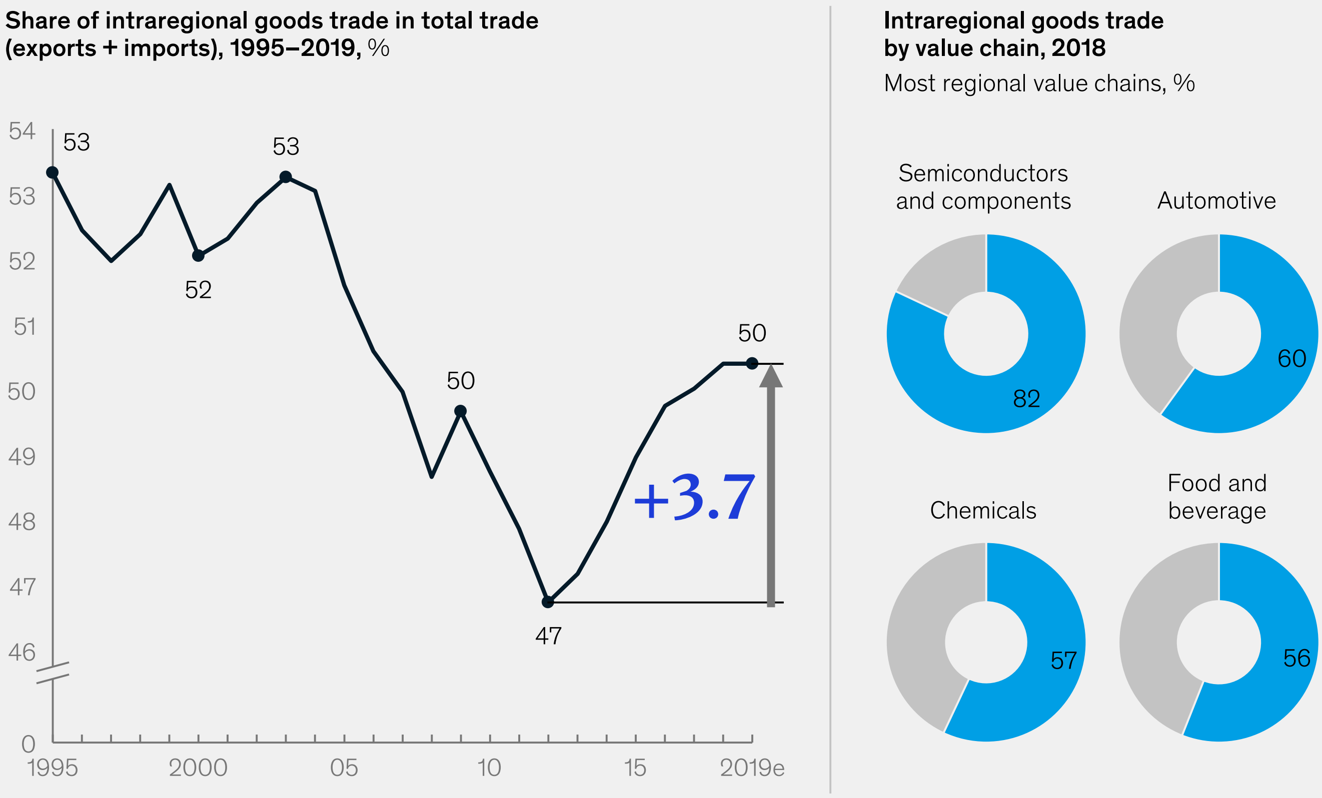
From long haul to regional

Since reaching a nadir in 2012, the share of trade occurring within the same region has begun to rebound (Exhibit 10). As the cost of labor increases in major offshoring centers, companies are realizing the advantages of bringing production closer to home, if not moving toward domestic production. Regional production networks offer the possibility of better collaboration between suppliers, greater proximity to customers, and reduced risk and cost of transportation.

In 2018, intraregional trade accounted for 56 percent of all trade in Asia–Pacific and 64 percent in Europe. Among traded goods, automotive, chemicals, and food and beverage products are commonly imported from regional partners; by contrast, goods in aerospace, medical devices, and pharmaceuticals are more likely to go through long-haul trade. Semiconductors, which are inputs to the broader electronics sector, are intensely traded within the Asia–Pacific region.

Exhibit 10

Trade is becoming more regional.

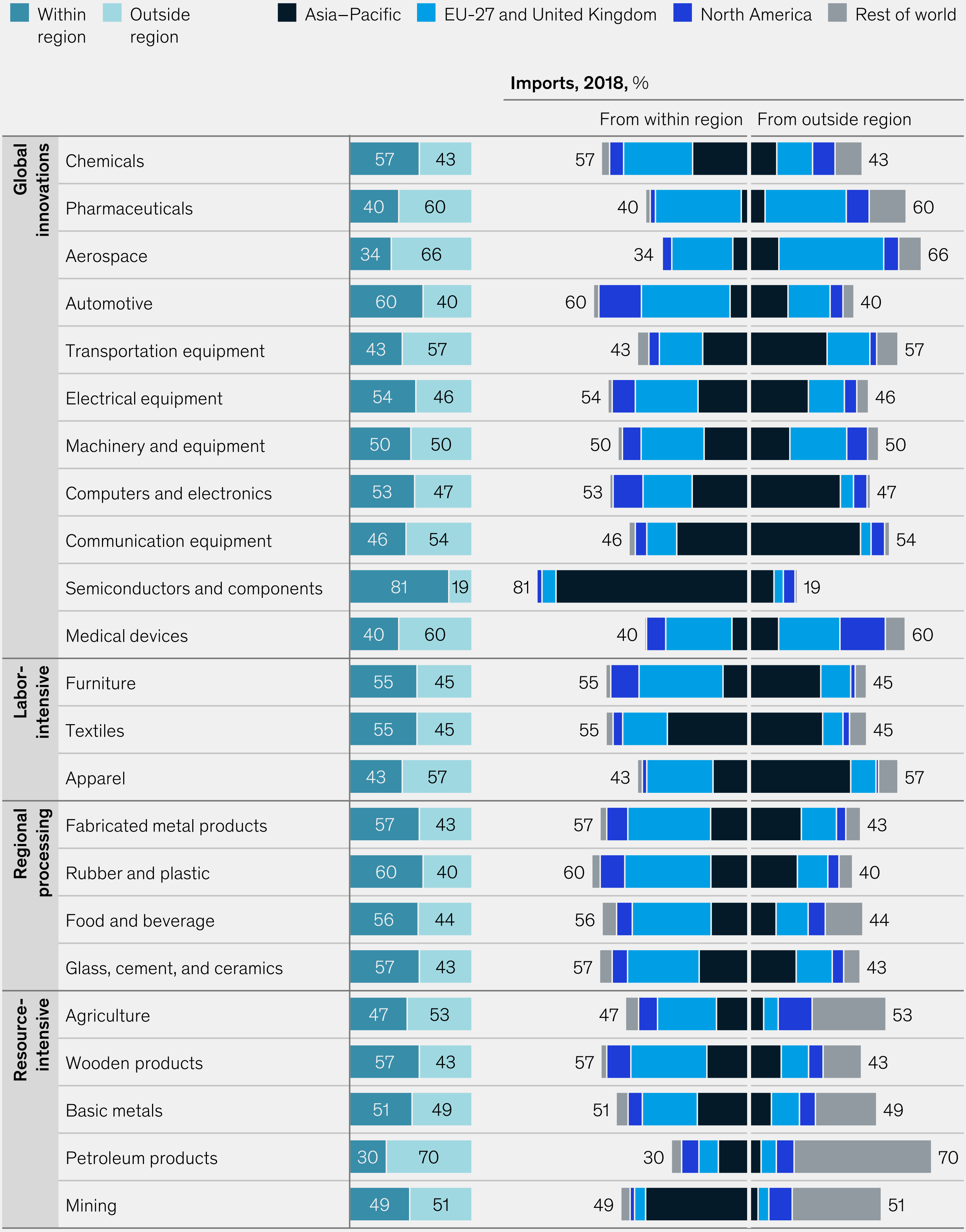


Source: ITC Trade Map; UN Comtrade; McKinsey Global Institute analysis

Exhibit 10 (continued)

Trade is becoming more regional (continued).

Intraregional imports are highest in the EU-27 and United Kingdom, followed by Asia–Pacific



Note: Figures may not sum to 100% because of rounding.
Source: ITC Trade Map; UN Comtrade; McKinsey Global Institute analysis

Network analysis can illuminate vulnerabilities for individual companies

Companies often assess their supply chain vulnerabilities exclusively based on cost, focusing on the most expensive inputs or suppliers to which they direct the largest share of spending. But a cost-only lens may miss hidden vulnerabilities in the network.

Network analysis can reveal some of the hidden dependencies lurking within supply chains.[56] To show what is possible, we illustrate the first- and second-tier supply ecosystems attached to four major Fortune 500 companies. Each one is a small universe populated by thousands of suppliers. This exercise offers a visual representation of just how complex, multitiered, and multinational these networks are—and it dispels the notion that supply chains can move and reconfigure easily. It also reveals that even within the same industry, companies may make materially different decisions about how to structure their supply ecosystems, with implications for risk.

We compare supply chain networks for two consumer electronics companies, Lenovo and Dell, and two food and beverage companies, Nestlé and Pepsi.[57] The comparison is based on publicly available data on each company's tier-one and tier-two suppliers.[58] However, these are only partial pictures. The full ecosystems, encompassing all deeper tiers back to raw materials, would be much larger, more complex, and harder to trace. Differences in business lines make it hard to compare company network structures directly: Dell's participation in the cloud computing and virtualization software markets or Lenovo's production of mobile phones may introduce additional suppliers and network dynamics.

All four companies have complex and multitiered supply chains, with 2,700 to more than 7,000 tier-one and tier-two suppliers. Like the broader industry value chain in which they operate, suppliers in the Lenovo and Dell networks tend to be concentrated in Southeast Asia. By contrast, those in the Nestlé and Pepsi networks are more globally dispersed, reflecting the more regional nature of food and beverage supply chains and more limited tradability. Nestlé has the largest share of suppliers in the European Union, while Pepsi has the largest share in the United States. Emerging economies (particularly Indonesia and countries in central Africa) play a bigger role in the food and beverage networks, supplying raw and intermediate agricultural inputs, such as palm oil.

Moving from the tier-one to the tier-two level, the geographic mix of suppliers stays relatively similar for the consumer electronics companies, but the food and beverage companies add more Chinese and South Korean suppliers. Overall, geographic concentration is marginally higher at the tier-two level (Exhibit 11).

56 See, for example, Yevgeniya Korniyenko, Magali Pinat, and Brian Dew, *Assessing the fragility of global trade: The impact of localized supply shocks using network analysis,* IMF working paper number 17/30, February 2017; Benjamin B. M. Shao et al., "A data-analytics approach to identifying hidden critical suppliers in supply networks: Development of nexus supplier index," *Decision Support Systems,* October 2018, Volume 114; Amanda J. Schmitt and Mahender Singh, "A quantitative analysis of disruption risk in a multi-echelon supply chain," *International Journal of Production Economics,* September 2012, Volume 139, Issue 1; and Petr Matous and Yasuyuki Todo, "Analyzing the coevolution of interorganizational networks and organization performance: Automakers' production networks in Japan," *Applied Network Science,* February 2017, Volume 2, Issue 1.

57 Lenovo is a Chinese multinational that sells a range of consumer electronics, including personal computers, smartphones, servers, electronic storage, and televisions. In 2019, it generated $51 billion in revenue and sold 25 percent of all personal computer units. Dell is a US multinational that sells personal computers, servers, data storage devices, televisions, and other consumer electronics. In 2019, it generated $90 billion in revenue and held 20 percent market share in personal computer unit shipments. Nestlé, a Swiss multinational, is the largest food company in the world. Its diverse product portfolio includes bottled water, coffee and tea, confectionaries, snacks, and "medical food" (products designed to meet the nutritional needs of patients with specific conditions). In 2019, it earned $92 billion in revenue. PepsiCo is a US multinational food, snack, and beverage company that earned $67 billion in revenues in 2019.

58 Data from the Bloomberg Supply Chain database, based on regulatory filings and other public disclosures. The database excludes private companies and may exclude some public companies. The results provide a relative overview of connectivity and network structure compared to other companies with similar data availability.

Lenovo and Nestlé have supplier networks that are more interconnected and centralized than those of Dell and Pepsi. The latter two companies have more clustered networks. Pepsi relies on the smallest number (89) of disclosed tier-one companies in the data set; each of them has its own relatively integrated network of related suppliers. Different network clusters correspond to steps in the value chain, such as raw inputs, manufacturing and processing, logistics, and digital infrastructure. In an integrated supply chain, the shutdown of one highly central supplier in a deeper tier can cause wider bottlenecks. In networks with multiple, relatively disconnected clusters, the disruption of a tier-one supplier could have disproportionate effects.

The number of tiers in a supply chain determine how much visibility is possible—and the degree to which downstream companies can spot problems and respond to them before events snowball. Both Lenovo and Nestlé appear to have supplier networks with more than twice as many tiers as those associated with Dell and Pepsi.

Shared suppliers can exacerbate disruptions. Analyzing the connectedness, or centrality, of each supplier across the four networks reveals some critical entities. If they encounter trouble, it is more likely to spread by impeding transactions across multiple tiers, suppliers, or both. Our analysis finds that 75 percent of Dell's 20 most connected suppliers are shared with Lenovo, and 70 percent of Lenovo's 20 most connected suppliers are shared with Dell. Foxconn, IBM, and Microsoft are hardware and software suppliers to both companies—and are highly connected in both networks. Should one become disrupted, it would not only affect Dell and Lenovo's existing operations but also limit their ability to secure alternative sourcing.

Exhibit 11

Even within the same industry, companies can have very different supply chain structures—and significant overlap.

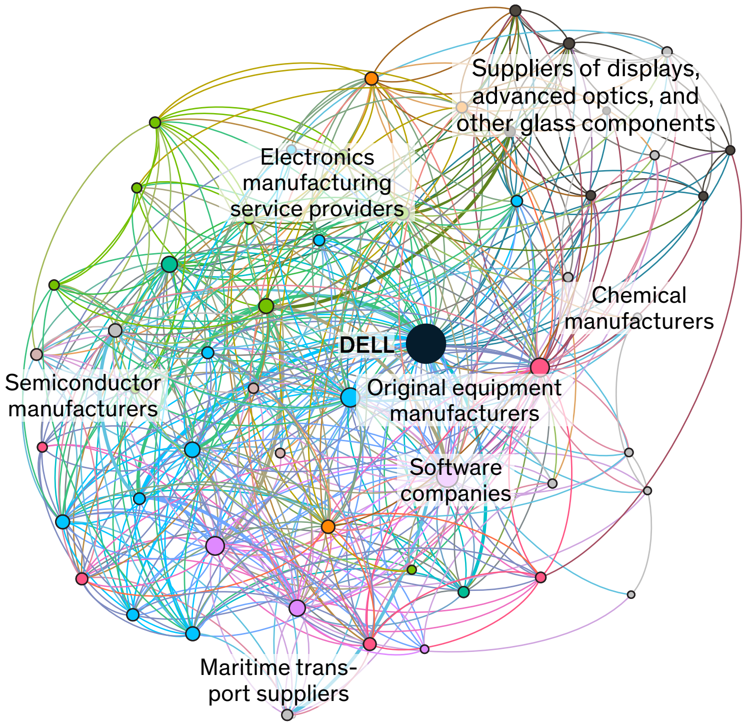
Companies rely on complex, multitiered. and interconnected networks

Example: Semiconductors, computers and electronics, and communication equipment

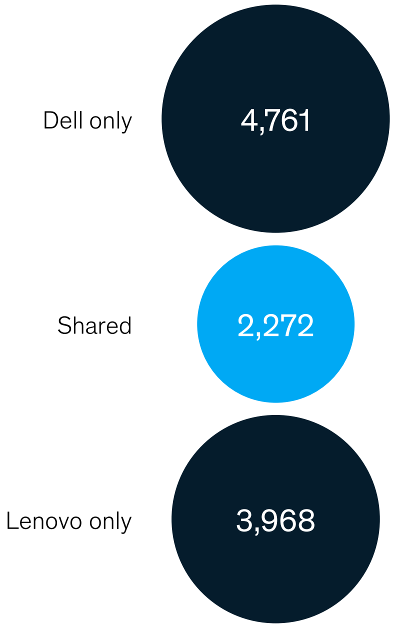
Dell

Revenue, 2019 = $90 billion

Dell's supplier ecosystem is more clustered, meaning it is potentially more exposed to bottlenecks[1]



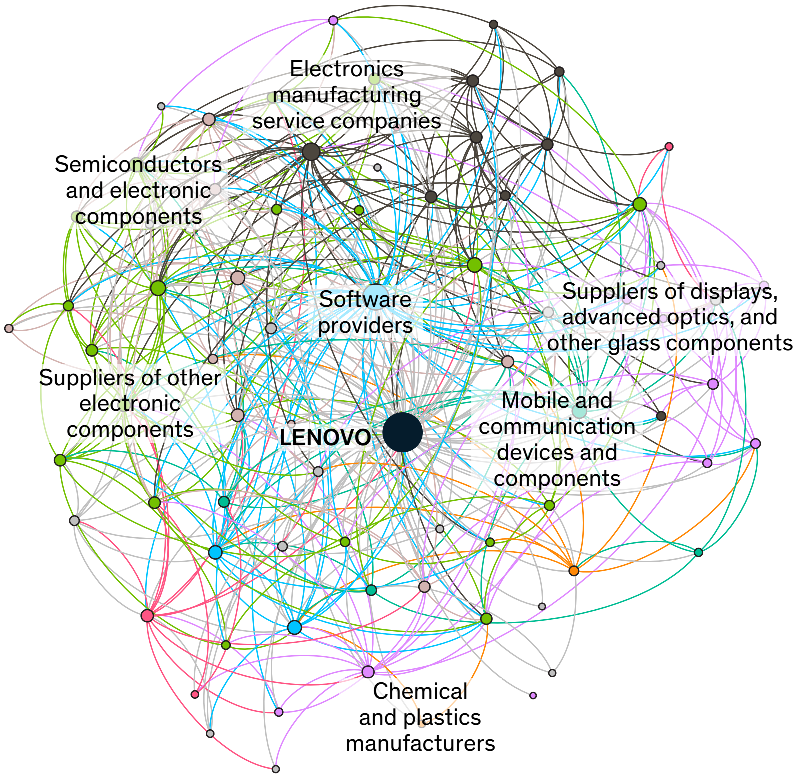
Known tier 1 and 2 suppliers



Lenovo

Revenue, 2019 = $51 billion

Lenovo's supplier ecosystem is deeper, meaning it has potentially less visibility[2]



1. Clustering is based on the clustering coefficient, which is calculated with network analysis of all supplier-customer relationships. The clustering coefficient measures the degree to which nodes cluster together and form interconnected subgroups.
2. The level of network depth is measured through the network diameter, using network analysis of all supplier-customer relationships. The network diameter is a measurement of network size that accounts for the overall structure by measuring the longest shortest path in the network.

Source: Bloomberg Supply Chain database; McKinsey Global Institute analysis

Exhibit 11 (continued)

Even within the same industry, companies can have very different supply chain structures—and significant overlap (continued).

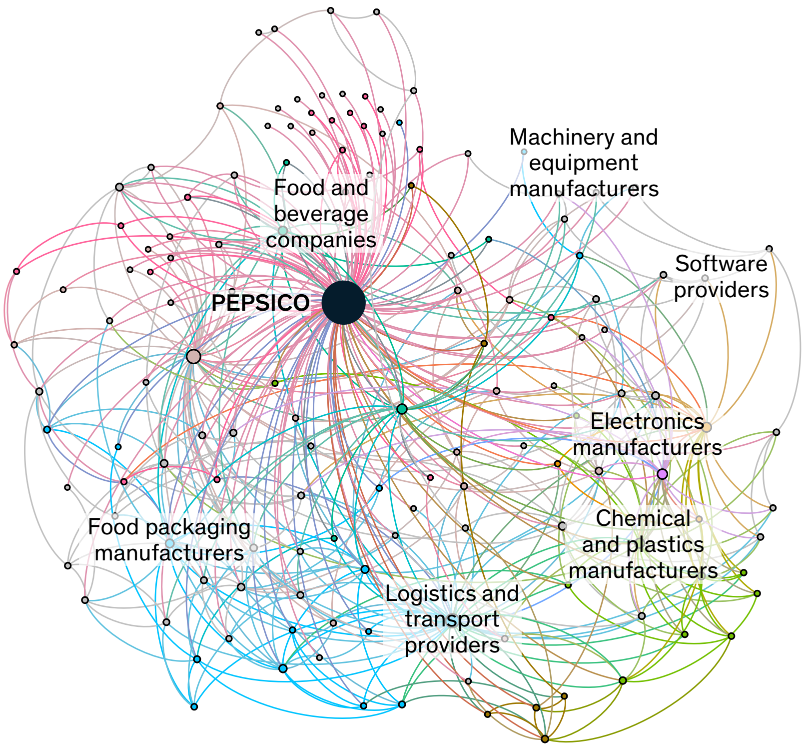
Companies rely on complex, multitiered, and interconnected networks

Example: Food and beverage, some consumer packaged goods

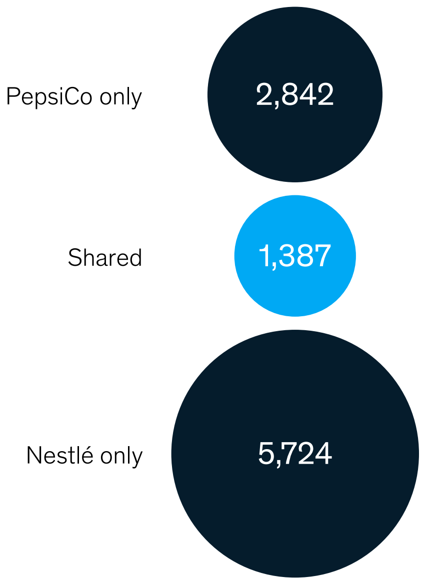
PepsiCo

Revenue, 2019 = $67 billion

PepsiCo's supplier ecosystem is more clustered, meaning it is potentially more exposed to bottlenecks[1]



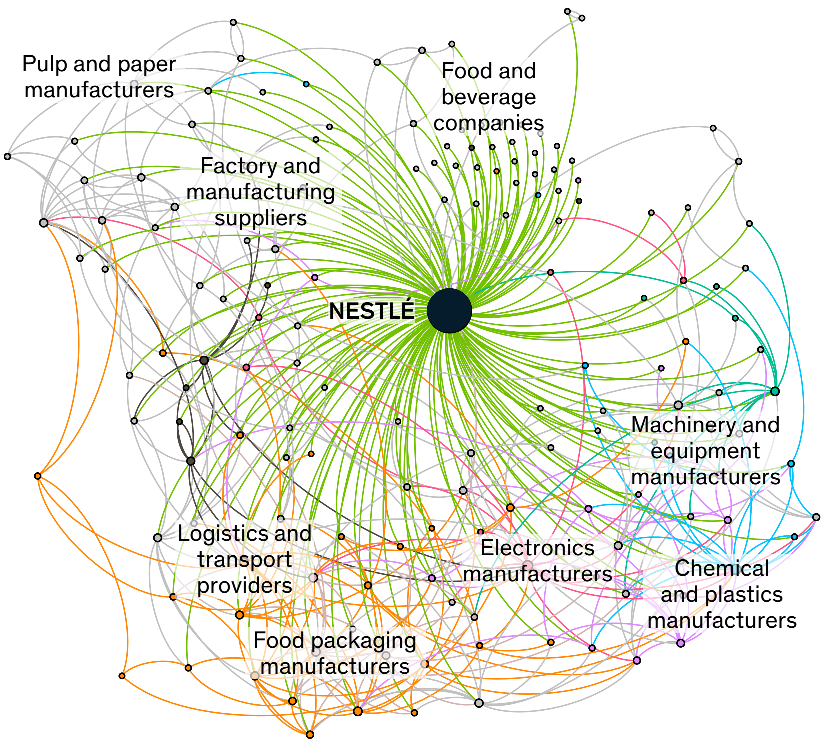
Known tier 1 and 2 suppliers



Nestlé

Revenue, 2019 = $92 billion

Nestle's supplier ecosystem is deeper, meaning it has potentially less visibility[2]



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Source: Bloomberg Supply Chain database; McKinsey Global Institute analysis

3. The high cost of disruptions

The natural disasters, industrial accidents, malicious acts, and other business disruptions described in chapter 1 leave damage in their wake—and not just on corporate balance sheets. First and foremost, many of these events can claim lives and cause physical damage to communities.

Companies will naturally want to understand the implications for their own bottom lines, but production shutdowns themselves can amplify societal harm beyond the damage caused by the initial shock itself. An inability to get products to market can lead to shortages of vital supplies in an emergency. The longer the shutdown, the greater the likelihood of lost jobs and lost tax revenue for public services.

As noted earlier in this report, disruptions are mostly unexpected but occur with regularity. An average large company will experience a month-long disruption every 3.7 years. In this chapter, we quantify the resulting financial losses, not only to help business leaders understand what to expect but also to help them weigh how to invest in resilience.

On average, companies can expect to lose approximately

45%

of a year's earnings to shocks over the course of a decade

A single prolonged disruption can destroy half—or almost all—of a company's yearly profits, depending on the industry. Based on those results and the probability of actual occurrences, we estimate that, on average, companies can expect disruptions to erase almost 45 percent of one year's profits over the course of a decade. These are not distant future risks; they are current and ongoing patterns. On top of those losses comes the additional cost of rebuilding damaged physical assets, not to mention the risk of permanently losing market share to competitors that are able to sustain operations, recover faster, or seize on a crisis to innovate successfully.

The good news is that companies can reduce those losses by taking preventive steps. We model a shock hitting two hypothetical companies: one that accepts the ongoing cost of being prepared, and one that does not. The financial results differ sharply, indicating that, in a multiyear view, the cost of prevention can pay off.[59]

[59] For example, one study found that every $1 invested in adaptation to prepare for climate change could result in $2–$10 in net economic benefits. See *Adapt now: A global call for leadership on climate resilience,* Global Commission on Adaptation, September 2019.

Supply chain disruptions strike the bottom line

We built representative income statements and balance sheets for hypothetical companies in 13 different industries, using actual data from the 25 largest public companies in each.[60] This enables us to see how they fare financially when under duress. We explore two possible scenarios:

— **Scenario 1.** A supply chain disruption that shuts down production for 100 days. In this scenario, distribution and logistics channels continue to function, so companies can still deliver goods to market. But once their safety stock of inventory is depleted, their ability to continue generating revenue halts.

— **Scenario 2.** The same conditions as in Scenario 1, but also affecting distribution channels to get products to market. This means that companies cannot sell their products even if they have inventory available.

Our choice to model a 100-day disruption is based on an extensive review of historical events.[61] In 2018 alone, the five most disruptive supply chain events affected more than 2,000 sites worldwide, and factories took 22 to 29 weeks to recover.[62] Typhoon Mangkhut was one such event, producing power outages and flooding in southeastern China's manufacturing belt.[63] The combination of heavy rains and environmental concerns over water pollution in that same year forced a major aluminum plant in Brazil to halve capacity and reduce workforce over multiple months, causing shortages and price spikes in aluminum.[64] Industrial accidents can also cause prolonged disruptions. In 2012, an explosion at an Evonik plant in Germany shut down production for six months, generating an industry-wide shortage of a specialty resin used in auto manufacturing.[65]

Modeling a shock of a 100-day duration also allows us to illustrate the differential impacts across our two scenarios due to differences in inventory holding patterns and fixed cost structures for all sectors. For shocks of shorter durations in which it is possible to sell-down safety inventory, sectors whose inventory holdings satisfy demand throughout the length of the shock will have no earnings impact. For longer shocks, having lower fixed costs has greater influence on the earnings impact.

Our scenarios show that a supply chain disruption affecting production but not distribution channels would wipe out between 30 and 50 percent of one year's EBITDA for companies in most industries. An event that disrupts both production and distribution channels would push the losses sharply higher for some (Exhibit 12).[66]

While the first stress test looks at one severe shock event in isolation, we then consider probabilities and calculate expected losses over a ten-year period (shown at the bottom of Exhibit 12). This view combines the frequency of value chain disruptions of different lengths with the financial impact experienced by companies in different industries.

60 We based their characteristics on averages from three years of financial statements from the largest 25 companies in each sector, based on the MSCI World Index.
61 See also Dmitry Ivanov, "Predicting the impacts of epidemic outbreaks on global supply chains: A simulation-based analysis on the coronavirus outbreak (COVID-19/SARS-CoV-2) case," *Transportation Research Part E: Logistics and Transportation Review,* April 2020, Volume 136.
62 Shahzaib Khan and Andrew Perez, *Eventwatch 2018 annual report,* Resilinc, 2019.
63 *A tale of two storms: supply chain risks in the aftermath of Hurricane Florence and Typhoon Mangkhut,* DHL Resilience360, 2018.
64 Terje Solsvik, "Russia, Brazil woes could lead to aluminum supply shortage: Hydro CEO," Reuters, April 16, 2018.
65 David Simchi-Levi, Willian Schmidt, and Yehua Wei, "From superstorms to factory fires: Managing unpredictable supply-chain disruptions," *Harvard Business Review,* January–February 2014.
66 In both scenarios, our model assumes no property damage, no ramp-up time after the shutdown period concludes, no seasonality in sales, and a decline in demand equivalent to 20 percent of the worst revenue hit the particular industry has experienced over the past 20 years. We assume a recovery of 25 percent of sales lost during the disruption period during the remainder of the fiscal year. See the technical appendix for additional detail.

Exhibit 12

Supply chain disruptions can have major financial consequences.

A supply chain disruption of 100 days could erase half or more of a year's earnings for companies in some industries

Better — Worse

	Impact of a 100-day disruption, % of EBITDA		Key variables		
	Scenario 1: Upstream disruption, still able to sell from existing inventory	**Scenario 2:** Disruption of both production and distribution	**Typical inventory on hand,[1]** days	**Cost of goods sold,[2]** % of revenue	**EBITDA,[2]** % of revenue
Aerospace (commercial)	-56	-90	60	78	11
Automotive	-39	-60	43	76	13
Chemicals	-38	-45	18	68	16
Computers and electronics	-50	-52	4	68	15
Electrical equipment	-50	-61	30	69	13
Food and beverage	-31	-34	11	49	25
Glass and cement	-48	-53	11	66	15
Machinery and equipment	-48	-55	17	68	16
Medical devices	-32	-53	59	43	23
Mining	-47	-53	15	78	18
Petroleum products	-52	-54	8	75	19
Pharmaceuticals	-12	-38	75	29	25
Textiles and apparel	-43	-52	22	39	20

Given the probabilities of shock frequency, companies can expect losses exceeding 40% of one year's EBITDA on average every decade

	Net present value (NPV) of expected losses over 10 years,[3] % of annual EBITDA	**NPV for a major company,[4]** $ million	**NPV of expected losses,[4]** EBITDA margin, pp
Aerospace (commercial)	66.8	1,564	7.4
Automotive	56.1	6,412	7.3
Mining	46.7	2,240	8.4
Petroleum products	45.5	6,327	8.9
Electrical equipment	41.7	556	5.4
Glass and cement	40.5	805	6.2
Machinery and equipment	39.9	1,084	6.5
Computers and electronics	39.0	2,914	5.9
Textiles and apparel	38.9	788	7.8
Medical devices	37.9	431	8.7
Chemicals	34.9	1,018	5.7
Food and beverage	30.0	1,578	7.6
Pharmaceuticals	24.0	1,436	6.0

1. Model also considers differences in revenue at risk due to a disruption and a modest demand decline (based on historical experience).
2. Based on normalized financial statements of representative global companies within the industry and expert interviews regarding what proportion of inventory is finished or semifinished. 3. Based on estimated probability of a severe disruption twice per decade (constant across industries) and proportion of revenue at risk due to a shock (varies across industries). Amount is expressed as a share of one year's revenue (ie, it is not recurring over modeled 10-year period). Calculated by aggregating cash value of expected shocks over a 10-year period based on averages of production-only and production and distribution disruption scenarios multiplied by probability of event occurring for a given year. Expected cash impact is discounted based on each industry's weighted average cost of capital. 4. Based on weighted average revenue of top 25 companies by market cap in each industry.
Source: S&P Capital IQ; McKinsey Global Institute analysis

We estimate that, on average, companies face expected losses equal to almost 45 percent of one year's profits over the course of a decade.[67] This is equal to seven percentage points of expected decline in EBITDA on average over a ten-year period. These are not just hypothetical future losses; they reflect the current and ongoing reality that companies are already experiencing. Our modeling suggests that the financial losses for companies in pharmaceuticals as well as food and beverage are lowest at the industry level. Those in aerospace, automotive, and mining stand to sustain the largest losses from disruptions. We make no assessment of the extent to which the cost of these disruptions has already been priced into valuations. Modeling a 50-day shock results in an average expected earnings impact of 35 percent of one-year's EBITDA across the industries we sampled over a ten-year period; a 25-day shock would result in an average expected earnings impact of 28 percent of one year's EBITDA over ten years.

It is important to note that individual companies within the sectors above may experience better—or worse—results than the hypothetical businesses modeled here, depending on their own exposure to shocks, the unique vulnerabilities within their operations and supply chains, and the mitigation measures they have already taken. Our analysis does not take those potential measures into account. The losses described here exclude the destruction of shareholder value, which may persist for some time after the shock.[68]

In addition, some external shocks may actually be positive for individual companies. Events that strike one company's operations and suppliers but not a competitor's can boost the latter's market share, at least temporarily but perhaps permanently. Others may seize on a crisis and innovate quickly and successfully under pressure in ways that support ongoing growth.[69]

Inventory is a critical buffer in the short term, but fixed costs come into play during longer disruptions

Companies that hold larger inventories and have lower fixed costs tend to experience relatively smaller financial losses from shocks. If a natural disaster hits a supplier but distribution channels remain open, having a sufficient inventory of safety stock becomes a key buffer. However, downstream companies that rely on their inventory to continue selling in a crisis still face a cash drain after the fact when it is time to replenish drawn-down safety stock.

How much inventory to hold is a company-specific decision, but certain holding patterns are apparent across industries in the volume and relative share of inputs and parts, semifinished goods, and finished goods.[70] For example, most inventory of finished goods in the apparel industry is held by retailers (which our analysis does not capture). Some industries can exhibit important geographic differences. European automakers typically sell through their own dealerships; they therefore have more inventory on their books than their counterparts in the United States, where independent dealers hold inventory. The computer and electronics industry may have several days' worth of inventory (or less) at any given time. By contrast, companies in the pharmaceutical industry hold several months' worth of finished goods.

These decisions reflect the complexity of production as well as the frequency of disruptions. Industries that make products with shorter shelf lives will understandably hold less inventory, for example. The cost of holding inventory as well as the ease and practicality from a physical

[67] We aggregate the cash value of expected shocks over a ten-year period, using the average cash impact from variations of Scenario 1 and Scenario 2 multiplied by a constant probability of the event's occurring in a given year based on an average of expert input for several industries. The expected cash impact is discounted based on each industry's weighted average cost of capital. For more details on our methodology, see the technical appendix.

[68] Kevin B. Hendricks and Vinod R. Singhal, *An empirical analysis of the effect of supply chain disruption on long-run stock price performance and equity risk of the firm,* November 2003.

[69] For a broader discussion, see Nassim Nicholas Taleb, *Antifragile: Things That Gain from Disorder,* New York, NY: Random House, 2014; and Yossi Sheffi, *The Power of Resilience: How the Best Companies Manage the Unexpected,* Cambridge, MA: MIT Press, 2015.

[70] To estimate inventories of finished goods, we use total inventories as reported on our sample companies' financial statements and then modify the proportion of finished versus semifinished goods based on expert interviews.

standpoint are also factors. Pharmaceutical doses are obviously easier to store in bulk than automobiles.

In more commoditized or less specialized supply chains, downstream players may be able to easily acquire inputs of comparable quality from alternate sources, creating less incentive to hold more inventory. But if they go down, the knock-on effects could touch multiple downstream companies. For example, rare earths are typically acquired on a commodity trading exchange or via commodity brokers, with no direct bilateral relationship between the supplier and the customer. A disruption in upstream production could therefore limit supply and raise prices so that all downstream companies are affected (unless they are operating under a long-term contract with price guarantees).

When a disruption outlasts the available safety stock, lower fixed costs become important to withstanding a decline in EBITDA. Industries with high fixed costs (such as pharmaceuticals) are at a disadvantage when distribution is impossible because they cannot simultaneously reduce variable costs during the disruption.[71]

It pays to be prepared

A more prepared company can reduce the losses from a shock by some

23 pp

Companies can take a number of steps to minimize the financial impact of disruptions and speed time to recovery. (See chapter 5 for a fuller discussion of possible actions.) But resilience typically requires investment or even accepting higher current operating costs today to minimize potential losses in the future. It is therefore important to consider what kind of returns those measures could yield in a crisis.

To illustrate the costs and payoff of enhanced resilience, we construct models of two imaginary firms: PreparedCo and UnpreparedCo. They take opposite approaches to dual-siting production, holding inventory, and carrying more comprehensive insurance coverage.[72] The underlying financials are based on averages for the automotive industry, which is among the most heavily exported manufacturing sectors and a pacesetter in supply chain management. But the insights hold across sectors. We subject both firms to the same 50-day shock in which property damage compromises their own production and distribution capabilities.

Our scenario assumes that a shock hits one factory from each company. But PreparedCo runs two plants to manufacture a product that accounts for half of its revenue, while UnpreparedCo relies on only one plant to do the same. The disruption therefore takes out 50 percent of UnpreparedCo's revenue but only 25 percent of revenue for PreparedCo. In addition to its lower exposure, PreparedCo then has capacity to increase output in its unaffected factory by 25 percent. The ability to flex production across sites helps to minimize the impact on revenue.

In inventory, damage to UnpreparedCo's factory destroys 50 percent of the company's stock. But because PreparedCo holds inventory at both of its factories, it loses only 25 percent. Furthermore, PreparedCo held three times as much inventory as UnpreparedCo to begin with, so it has more stock on hand to continue selling through the interruption.

Finally, PreparedCo is fully insured for its property damage, while UnpreparedCo is not. This is admittedly an extreme assumption, but we make it to illustrate the mechanics of losses in a simplified way. Insurance premiums represent higher ongoing costs for PreparedCo, which we reflect in a higher cost of goods sold and an extra insurance line item.

[71] Fixed costs reflect the inverse of the cost of goods sold (COGS) margin.
[72] These are only a few of the possible resilience measures, as we discuss in Chapter 4. In selecting these three levers, we are not asserting that they are the most appropriate for all industries. Some industries may have more opportunities to make resiliency investments that also enhance productivity. Meanwhile, the structure of other industries may make it infeasible to hold additional inventory. For more on these choices, see Florian Lücker, Ralf W. Seifert, and Işik Biçer, "Roles of inventory and reserve capacity in mitigating supply chain disruption risk," *International Journal of Production Research,* 2019, Volume 57, Issue 4.

The cost of the shock to PreparedCo is 23 percentage points less than the cost to UnpreparedCo (Exhibit 13). UnpreparedCo's cash ratio (cash balances to current liabilities) is halved by the shock, due to more extreme EBITDA losses and the company's need to rebuild its physical plant without the offsetting support of an insurance payout.

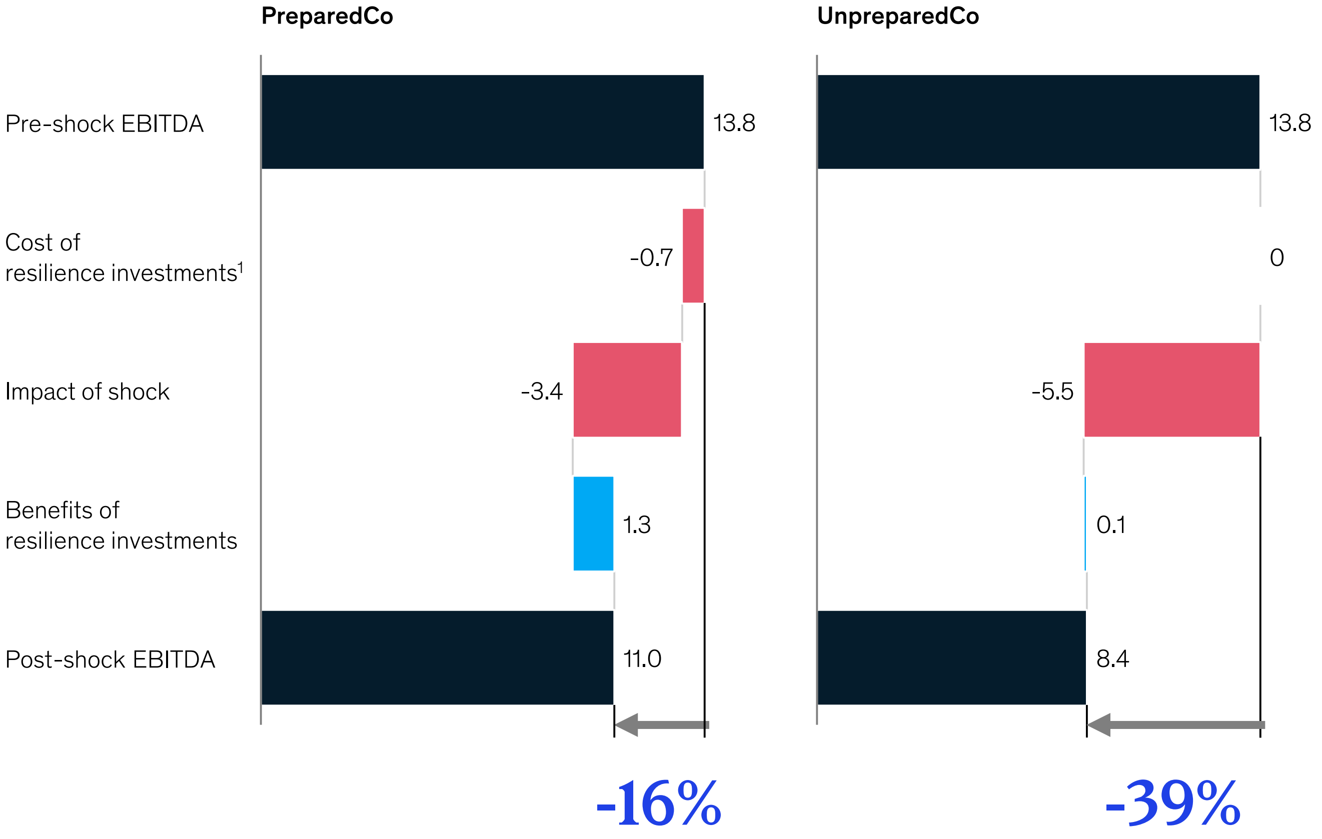
Exhibit 13

A company with a resilient supply chain can reduce the EBITDA impact of a disruption by 23 percentage points.

Impact of a 50-day supply shock with a demand hit

Analysis assumes differences in footprint, inventory patterns, and insurance

Index: Normalized to revenue = 100



1. For example, higher cost of goods sold, higher insurance expense.

Note: This analysis reflects impacts to income statement only and does not reflect balance sheet impacts. Figures may not sum to 100% because of rounding.

Source: McKinsey Global Institute analysis

As in our illustration described above, companies can conduct their own stress tests to quantify their financial risk from disruptions. Key parameters to explore could include measures of shock exposure (for example, days of disruption, number of facilities affected) and measures of supply chain vulnerability and resilience (for example, inventory levels, levels of insurance coverage, and ability to switch suppliers or ramp up production at alternate locations). Such an exercise helps companies identify the most effective preventive measures at their disposal and conduct a cost-benefit analysis of the required investment.

Some companies maintain a list of prioritized risks, and some go even further by modeling them. But they often do so by looking at these shocks as discrete events. Now analytics tools enable a more sophisticated approach that quantifies risks in the context of broader and more integrated scenarios. This makes it possible to combine extreme one-off events with knock-on effects and the ongoing business cycle, taking correlations into account. Scenarios can also integrate a range of risk mitigation strategies to test which would be most effective. The results can then inform strategic planning and capital allocation decisions.[73]

Since the cost of disruptions is high and highly probable, it is time to rethink the returns from investing in value chain resilience, which may pay off both today and over time. Our analysis indicates that an average large company could invest up to 40 percent of one year's EBITA in resilience measures and still have a positive return on investment when viewed over a decade. Chapter 4 considers one possible resilience measure that is currently garnering a great deal of speculation: moving the physical location of production. Despite the current debate, this is not always feasible, and it is only one option among many, as we outline in chapter 5.

[73] Conor Kehoe, Cindy Levy, and Matt Stone, "Stress testing for non-financial companies," McKinsey.com, June 2017.

4. Geographic rebalancing of trade flows

Even before the current pandemic, global value chains were evolving. Our 2019 report on globalization outlined a number of structural shifts taking place over the past decade:[74]

— **Trade in goods has been growing more slowly than world GDP.** This reflects the rise of consumers and supply chains in China and in other developing countries. These nations are consuming more and increasingly able to make a wider range of more sophisticated products. More of what is made in China is now sold there instead of being exported.

— **Low wages have become less important in determining where companies choose to locate production.** Overall, only 13 percent of globally traded goods are now exported from low-wage to high-wage countries.[75] Other factors matter more than labor-cost arbitrage, including access to skilled talent, proximity to major markets, supplier ecosystems, resource scarcity, and the business environment.

— **Trade flows are becoming more regionalized within Asia, Europe, and North America.** This signals that some multinational companies are deciding that nearshoring may offer the right balance of cost, speed, coordination, and resilience.

— **Cross-border data flows are the new connective tissue of the world economy.** Much of this traffic is generated by companies communicating and transacting with their global operations, overseas suppliers, and international customers. The Internet of Things, cloud computing, and data analytics are dramatically increasing global flows of data, which have grown 320 times larger since 2005.[76]

Today, with a heightened focus on risk, both business leaders and policy makers are wondering whether to expect a significant shift in the geographic structure of global value chains. This chapter attempts to answer that question from several angles. First, we consider the feasibility of relocating value chains to new countries based purely on industry economics and quantify what share of global exports could be in play. Second, we consider noneconomic factors that might influence policy interventions. Finally, we offer illustrative industry case studies to explain the complex dynamics at play and feasibility of relocation.

All told, we estimate that shifts in industry value chains could affect 16 to 26 percent of global trade, worth $2.9 trillion to $4.6 trillion annually. This is not a forecast of how much production will move, nor is it a recommendation of what should happen. It is a rough quantification of how much could move across national borders in the next five years. The dynamics of rebalancing could vary significantly across regions, however.

This chapter aims to provide critical context, considering why industry chains have evolved into their current configurations. While the share of production that could plausibly move is significant, value chains are complicated networks that cannot be uprooted and replanted easily. In fact, most global manufacturing and trade appears relatively entrenched.

[74] *Globalization in transition: The future of trade and value chains,* McKinsey Global Institute, January 2019.
[75] Defined as exports from a country whose GDP per capita is one-fifth that of the importing country or less. This share will of course vary if the ratio is set differently, but at all levels, a decline in labor-cost arbitrage is apparent.
[76] Analysis of TeleGeography data.

Some 16 to 26 percent of global trade could be subject to geographic rebalancing

Global value chains continue to evolve, but they are stickier than many people realize. As shown in chapter 2, one large multinational's supplier network alone may encompass hundreds or more of tier-one suppliers—and thousands more in the second tier and other subtiers. Hundreds of billions of dollars have been invested in establishing value chains as they exist today, and companies often work hand in hand with long-standing trusted suppliers.

We set out to estimate how much of the trade flowing through global value chains could feasibly move to new exporting countries based on industry economics alone. We then consider the extent to which policy and regulatory changes could have further impact.

To examine the business case for geographic shifts, we consider several factors:

— **Shifts already unfolding.** The market share among the top exporting countries is already shifting in some industries. Between 2015 and 2018, for instance, the share of trade produced by the three leading export countries in apparel clearly dropped. In contrast, the top three countries in semiconductors and mobile communications increased their share of trade markedly.

— **Capital intensity and economies of scale.** Highly capital-intensive value chains are harder to move for the simple reason that they represent hundreds of billions of fixed investments. These industries have strong economies of scale, making them more costly to shift.

— **Knowledge intensity and specialized supplier ecosystems.** Value chains with high knowledge intensity tend to have specialized ecosystems that have developed in specific locations, with unique suppliers and specialized talent. Deciding to move production outside of this ecosystem to a novel location is costly.

— **Access to natural resources.** Resource-intensive value chains (agriculture, mining, energy, wood products, and basic metals) are relatively fixed based on geology and the environment. This makes them very difficult to shift in the short or medium term, although in the long run, new resource discoveries and technologies can alter them.

— **Demand growth.** One of the most important determinants of where multinational companies locate production is access to consumer markets. An aging and more prosperous China, for example, will likely drive further demand for medical devices, supporting a greater presence of that industry in the country or elsewhere in Asia. Once companies establish production for China's market, they may choose to export from there as well. Indeed, in a 2019 survey of American businesses in China, 50 percent said their current model focuses on production for the Chinese market.[77]

— **Product complexity and substitutability of inputs.** Some complex products depend on inputs that are made by only one or two suppliers in the world. This severely reduces possibilities for moving production or sourcing. We use the product complexity index from the Observatory of Economic Complexity, which measures whether a product is produced in a few locations or many, as a proxy for the capabilities required to produce that product.[78] More complex products require a greater level of capabilities to produce and are more likely to be concentrated in a smaller number of countries with a relative comparative advantage.

[77] *2020 China Business Climate Survey report,* American Chamber of Commerce in the People's Republic of China (AmCham China), 2020.
[78] Jesus Felipe et al., "Product complexity and economic development," *Structural Change and Economic Dynamics,* March 2012, Volume 23, Issue 1, pp. 36-68.

- **Regionalization of the value chain.** Regional production networks that have formed near major consumer markets allow companies to increase the speed at which they can get products to market and more nimbly respond to shifts in demand. Value chains that already have comparatively low levels of intraregional trade may be more likely to move geographically as firms seek to shorten transportation times and production cycles.

- **Trade intensity.** Value chains that are not highly traded (that is, with predominantly local production and consumption) are less likely to shift. This may be due to the weight or perishability of the product. Shifts in these value chains will largely be based on consumer demand.

In addition to looking at the business case, we also consider three noneconomic factors that could cause policy makers to take steps to boost domestic production:

- **National security.** Some nations have become more intent on protecting their industrial base and safeguarding technologies with dual-use (civilian and military) implications. This could lead governments to intervene in value chains such as semiconductors and communication equipment (particularly as 5G networks are built out).

- **National competitiveness.** Governments may deem some industries important to their national competitiveness and economic development strategies. Some have announced major industrial policies intended to capture leading shares of emerging technologies ranging from quantum computing and artificial intelligence to renewable energy and electric vehicles. This, too, has the potential to reroute value chains.

- **Self-sufficiency.** The COVID pandemic has driven home the importance of self-sufficiency across a range of fundamental areas, including food, pharmaceuticals, and certain medical equipment.

16–26%

of global exports could conceivably move to different countries in the medium term

Exhibit 14 presents metrics on many of these dimensions for individual value chains and summarizes their estimated potential to move across borders in the next five years. We find that 16 to 26 percent of 2018 exports, worth $2.9 trillion to $4.6 trillion, could be in play. We emphasize that this is not a forecast. It is a rough estimate of how much global trade *could* relocate rather than an assertion that it actually will.

Labor-intensive value chains (such as textiles, apparel, and furniture) can feasibly move for economic reasons but are less likely to be subject to policy pressures. In contrast, resource-intensive value chains (such as mining, agriculture, and energy) have very limited economic potential to shift in the medium term. But policy considerations may encourage new exploration and development that can shift value chains at the margins.

The value chains in the global innovations category (semiconductors, automotive, communications, and pharmaceuticals) are subject to the most scrutiny and possible intervention from governments, although the feasibility of moving them based on the economics alone varies.

Exhibit 14

The potential for value chains to shift across borders over the next five years depends on economic and noneconomic factors.

Feasibility of geographic shift: Low ○ ◑ ● High

Value of exports with shift feasibility (annual exports)[1]: Low → High

Drivers of economic shift feasibility: Low → High

	Value chain	Feasibility of geographic shift: Economic factors	Feasibility of geographic shift: Noneconomic factors[2]	Value of exports with shift feasibility: Range, $ billion	Value of exports with shift feasibility: Share of value chain exports, %	Total exports, 2018, $ billion	Top 3 exporter share change, 2015–18, pp	Capital intensity,[3] %	Knowledge intensity,[4] %	Product complexity[5]	Intraregional trade,[6] %
Global innovations	Chemicals	○	◔	86–172	5–11	1,584	-1.4	72	26	5	57
	Pharmaceuticals	◔	●	236–377	38–60	626	0	58	41	5	40
	Aerospace	◔	◑	82–110	25–33	333	-2.9	53	40	5	34
	Automotive	◔	◑	261–349	15–20	1,730	-1.6	51	16	5	60
	Transportation equipment	◕	◔	60–89	29–43	209	0	48	18	5	43
	Electrical equipment	◕	◔	213–319	23–34	928	-2.5	43	23	5	54
	Machinery and equipment	◑	◔	271–362	19–25	1,455	-2.2	36	19	6	50
	Computers and electronics	◕	◔	165–247	23–35	708	-1.9	47	57	5	53
	Communication equipment	◔	●	227–363	34–54	673	9.5	51	45	5	46
	Semiconductors and components	○	●	92–184	9–19	995	10.5	62	39	5	81
	Medical devices	◑	◕	100–120	37–45	268	0.1	47	29	5	40
Labor intensive	Furniture	●	○	37–74	22–45	164	-5.7	40	15	4	55
	Textiles	●	○	67–134	23–45	297	-3.2	34	15	4	55
	Apparel	●	◔	246–393	36–57	688	-8.1	30	18	3	43
Regional processing	Fabricated metal products	◕	◔	94–141	21–32	440	-3.5	33	16	5	57
	Rubber and plastic	◕	◔	97–145	20–30	488	-2.7	40	16	5	60
	Food and beverage	◔	○	63–125	5–11	1,149	-1.1	57	14	4	56
	Glass, cement, and ceramics	◑	○	22–45	11–21	209	-4.5	48	15	5	57
Resource intensive[7]	Agriculture	◔	◑	112–149	20–26	568	0.4	24	10	4	47
	Wooden products	○	◔	8–17	5–11	155	0.9	43	11	4	57
	Basic metal	○	◔	77–153	6–12	1,250	-3.6	54	16	4	51
	Petroleum products	○	◔	212–423	9–18	2,414	1.3	81	32	3	30
	Mining	◔	○	29–57	6–13	452	3.8	72	16	3	49
		Total	Low	2,900	16						
			High	4,600	26						

1. Low-end sizing = global imports from outside importing country's region average of economic and noneconomic feasibility. High-end sizing = global imports from outside importing country's region maximum of economic and noneconomic feasibility. 2. Noneconomic factors take into account goods deemed essential or targeted for national security or economic competitiveness considerations, based on proposed and enacted government policies and definitions of essential goods. 3. Amount of capital compensation as a share of gross output. 4. Defined as share of labor with a tertiary education. 5. Product Complexity Index measures the relative substitutability of production across sites of products in value chain. 6. Percent of total trade that takes place within same region as its importer. 7. Dependent on access to resources that are geographically determined.

Source: Federal Reserve Bank of St. Louis; Observatory of Economic Complexity; UN Comtrade; US Bureau of Economic Analysis; US Bureau of Labor Statistics; World Input-Output Database; McKinsey Global Institute analysis

Four case studies illustrate the way value chains have evolved and how complex geographic rebalancing would be

Below we look at how four industry value chains are structured, the risks they face, how they have responded to shocks in the past, and how they might evolve in the future. They were chosen to represent a diverse range of industries, with varying economics and policy pressures.

Pharmaceuticals: A globally diversified value chain in the political spotlight

Overall, the pharmaceutical value chain has become less concentrated and more globally dispersed over the past 20 years (Exhibit 15). But the COVID pandemic has highlighted the fact that the manufacturing of some specific products is highly concentrated. Many countries are concerned about securing their own access to vital treatments—and, eventually, a vaccine. Industry economics alone point to only a modest possibility of shifts, but policy interventions could redraw the map of pharmaceutical manufacturing more profoundly.

In rough terms, this heavily traded, knowledge-intensive value chain breaks down into two complementary camps: one specializing in simpler small-molecule products (such as antibiotics, aspirin, and other anti-inflammatories) and the other focusing on cutting-edge large-molecule drugs or biologics that treat complex diseases such as cancer and multiple sclerosis. Both types include intermediate production of active pharmaceutical ingredients as well as finished dose forms of drugs.

Looking through the lens of value, exports of both intermediate ingredients and dosage-ready drugs are dominated by advanced economies, including Germany, Switzerland, the United States, and Ireland. One reason is that newer large-molecule therapies are under patent and command higher prices per dosage. Collectively, they account for 30 percent of pharmaceutical exports by value.[79]

Many small-molecule products are older and no longer under patent, lending themselves to cheaper generic formulations. Mostly developed in the 1980s or earlier, small-molecule products include medications such as ibuprofen, ACE inhibitors for high blood pressure, over-the-counter cold remedies, antibiotics, and generic forms of many drugs that have gone off patent. As these products became commoditized, investment in new manufacturing capacity shifted toward lower-cost locations where it is cheaper to build and operate new plants. Much of this production occurs in hubs such as China, India, Singapore, and Ireland, which offer some combination of lower overhead expenses, tax advantages, and clusters of expertise. Some US manufacturing shifted to Puerto Rico. These locations typically implemented tax and regulatory regimes and other policies specifically designed to attract pharmaceutical manufacturing and create specialized industry clusters.

Some specific products are manufactured almost exclusively by one or two countries. While China and India export a relatively small share (3 percent each) of overall pharmaceutical products by value, they are the world's key producers of active pharmaceutical ingredients and small-molecule drugs.[80] In some categories, such as antibiotics, sedatives, ibuprofen, and acetaminophen, China is the world's dominant producer, accounting for 60 percent or more of exports. India is the world's leading provider of generic drugs, accounting for some 20 percent of global exports by volume.[81] But it relies on China for most of the active pharmaceutical ingredients that go into them. When the flow of these ingredients dried up in the early stages of the COVID pandemic, India temporarily placed export controls on dozens of essential drugs, including antibiotics.[82]

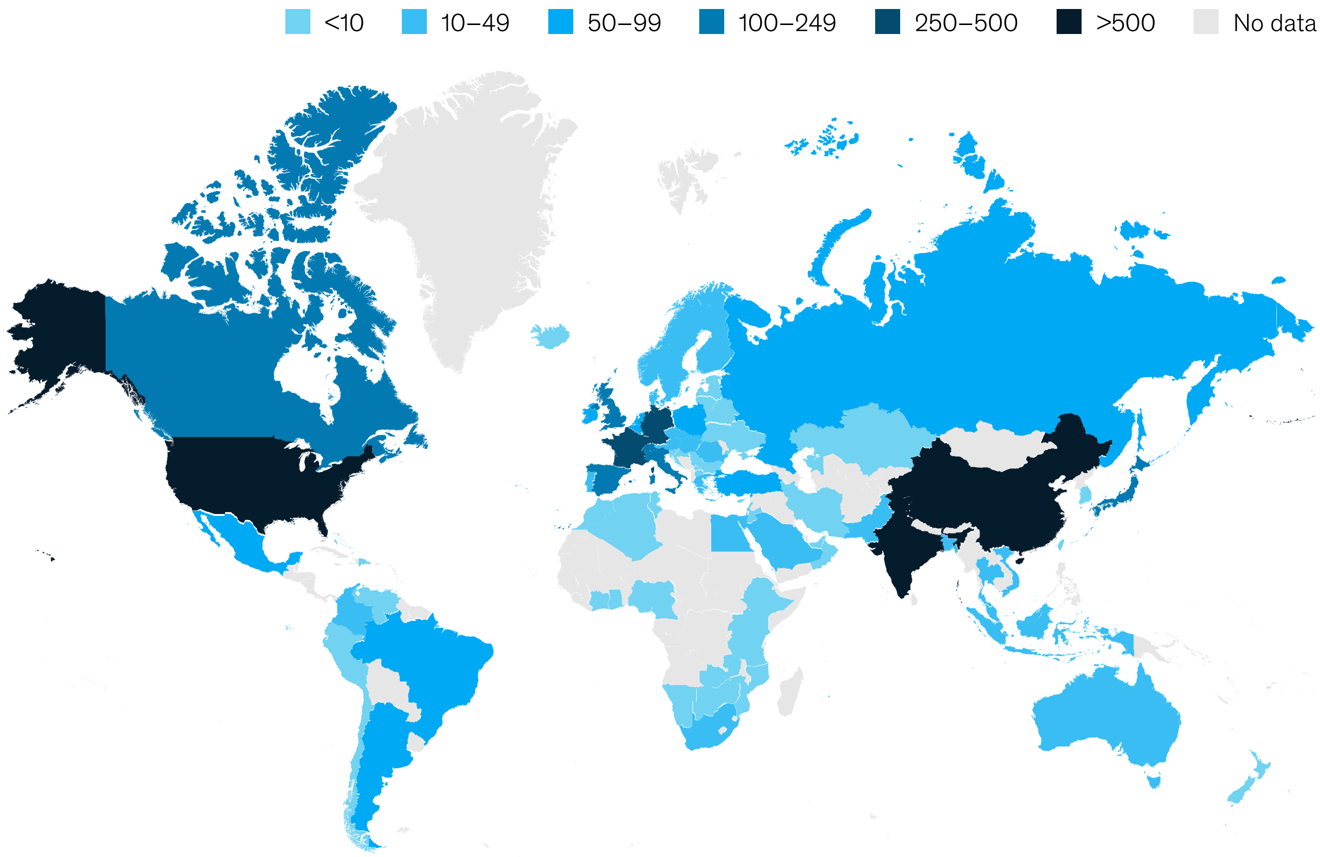
[79] Large-molecule therapies include blood products and vaccines.
[80] UN Comtrade, 2018.
[81] *Pharmaceuticals,* India Brand Equity Foundation, 2019, ibef.org/download/Pharmaceuticals-June-2019.pdf.
[82] Vindu Goel, "As coronavirus disrupts factories, India curbs exports of key drugs," *New York Times,* March 3, 2020.

Exhibit 15

Pharmaceutical manufacturing is global, with countries specializing by product.

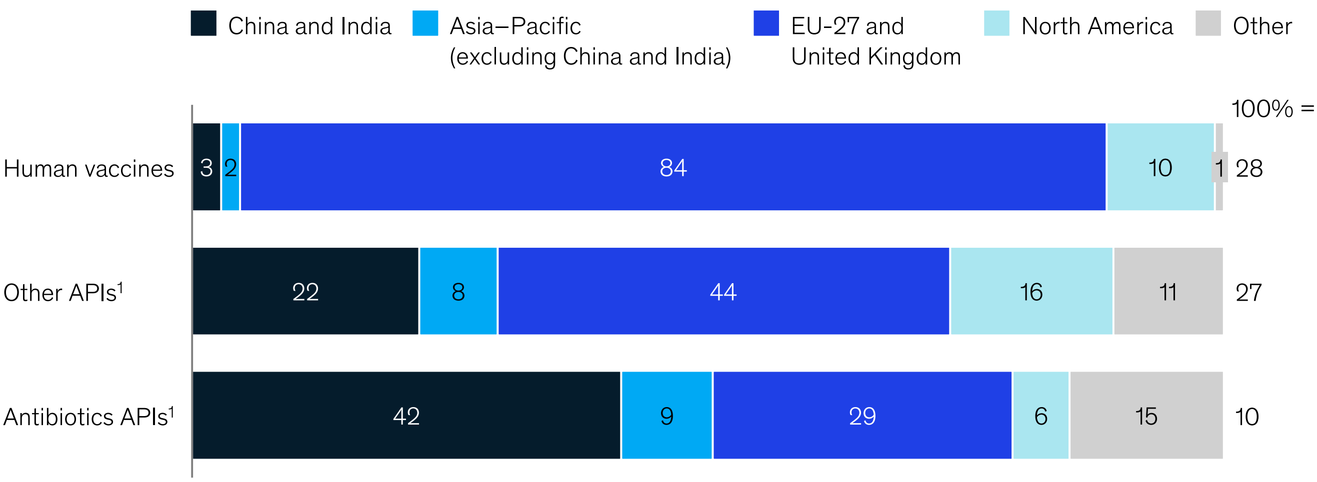
Pharmaceutical production is concentrated in the United States, Europe, India, and mainland China

Number of manufacturing facilities (including contract manufacturers)



Regions specialize in select types of pharmaceutical products

Global export value, select products, 2018 (%; $ billion)



1. Active pharmaceutical ingredients, the building blocks of medicines and vaccines. Other APIs include alkaloids, hormones and steroids, vitamins, and other chemical components not used in vaccines or antibiotics.

Note: The boundaries and names shown on this map do not imply official endorsement or acceptance by McKinsey & Company. Figures may not sum to 100% because of rounding.

Source: McKinsey/United Nations (disputed boundaries); PharmSource; UN Comtrade; McKinsey Global Institute analysis

Based on economics alone, there is little reason to believe that pharmaceutical production will shift unless it responds to the rise of new consumers in developing countries or to changes in tax policies or other incentives. But in the wake of the pandemic, many governments are revisiting whether they need to restore domestic production of some key medicines (as well as medical equipment) to ensure public health. As a result, we estimate that 38 to 60 percent of the pharmaceutical value chain could shift geographically in the coming years. If governments choose to take action, they could do so through changes in tax policy, public purchasing, a push to advance new technologies, or incentives for new plants and modernization of existing plants. Additionally, pharmaceutical companies themselves may shift production to avoid trade disputes or strengthen existing supply chain networks.

Production of small-molecule drugs would likely need to be digitized and automated to be viable in advanced economies; otherwise, the higher costs of doing business might lead to higher drug prices. Beyond requiring local production, governments can bolster national resilience through other strategies, such as the regionalization of supply chains, maintaining national stockpiles, or requiring pharmaceutical companies themselves to increase inventory.

Automotive: Regionalized value chains in flux

The auto industry has some of the most intricate value chains in the global economy, and the most regionalized. Global auto exports amount to $1.7 trillion each year, of which roughly 59 percent circulates within three broad regions: Asia, Europe, and North America. Automotive is a prized industry from the standpoint of jobs, innovation, and competitiveness, and nations have historically enacted policies to try to attract and retain auto manufacturing. Policy, in addition to risk management, could drive future moves and additional regionalization.

$44 billion

China's annual exports of auto parts

Although some parts may be sourced from suppliers halfway across the globe, the automotive industry is characterized by regional clusters of production networks (Exhibit 16). The United States, Germany, Japan, South Korea, and China are the world's largest hubs of automotive production. They primarily source from suppliers in their immediate regions. The US auto industry is integrated with Mexico and Canada; Germany has production networks in Eastern Europe; and Japan and South Korea source from China as well as Thailand and Malaysia. Regional clustering occurs in part because auto parts and vehicles are bulky and heavy, making shipping expensive.

National policy and regulation have played a large part in influencing where production is located. Virtually all countries impose tariffs and other trade restrictions on the automotive industry due to its high value added and its ability to spur supporting activity in other types of manufacturing and services. Local content requirements and unique safety and environmental standards also tend to promote local production. Automotive production in China relies on very few imported parts; the industry imported $40 billion worth of intermediate inputs compared to nearly $600 billion in total car sales in 2018.[83] In North America's new USMCA trade agreement, 75 percent of a vehicle's parts must be produced within the region to qualify for free trade, an increase from the previous 62.5 percent.[84]

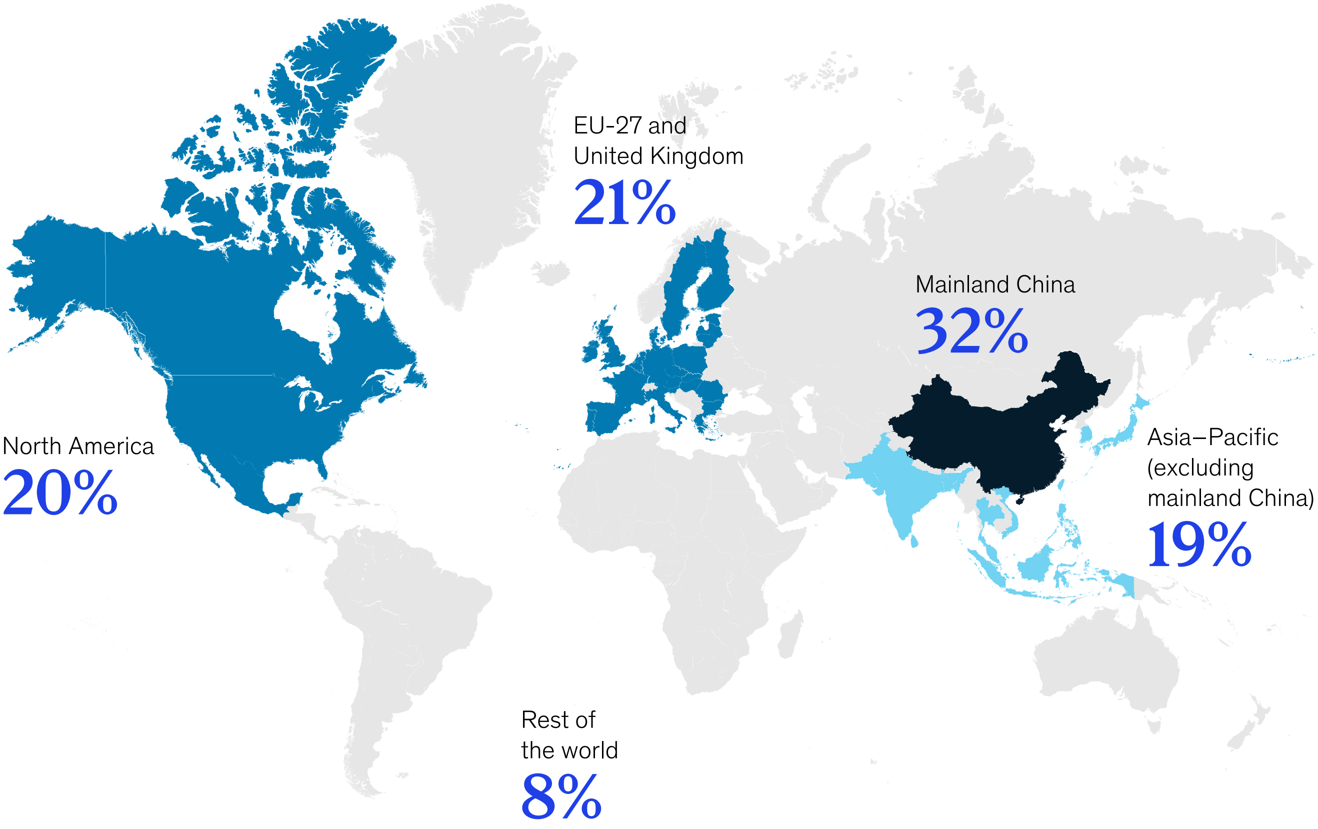
[83] UN Comtrade export data, 2018; and China National Bureau of Statistics, 2018.
[84] *Agreement between the United States of America, the United Mexican States, and Canada 12/13/19 text,* Office of the United States Trade Representative, 2019.

Exhibit 16

Automotive production is widely distributed across regional hubs.

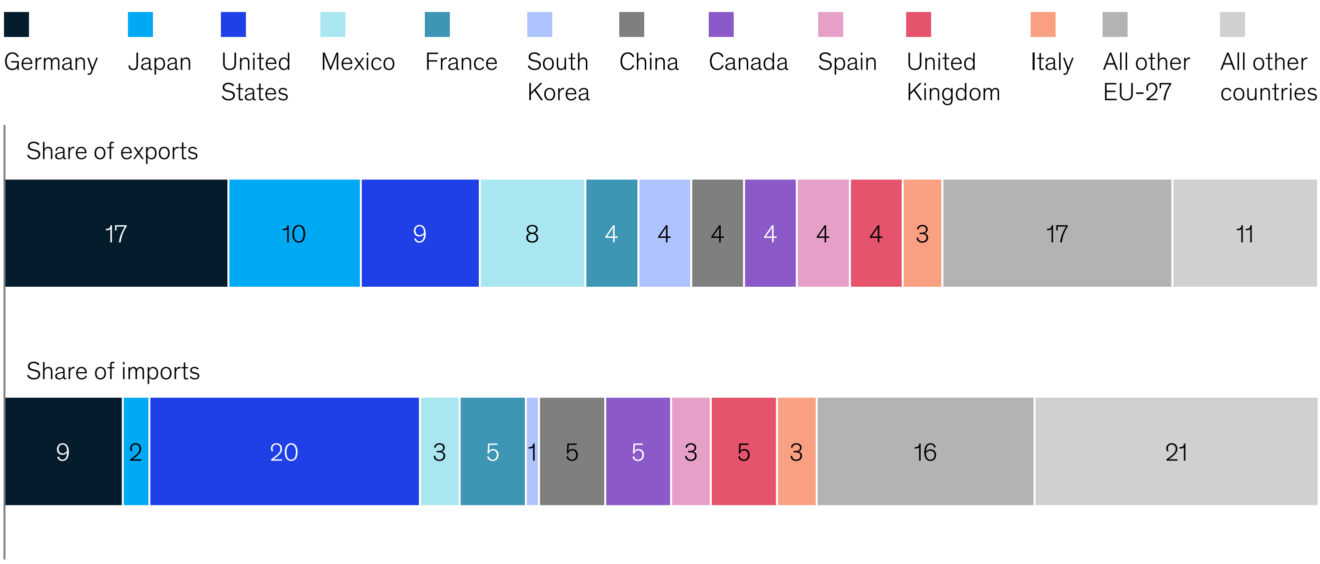
Clusters in North America, Europe, and China produce most of the world's parts and vehicles

Share of global exports and gross output of intermediate and final goods, 2018, %



Automotive imports and exports are relatively distributed among the top countries, pointing to regionalization

Intermediate and final goods, 2018, %



Note: The boundaries and names shown on this map do not imply official endorsement or acceptance by McKinsey & Company. Figures may not sum to 100% because of rounding.
Source: IHS Markit; McKinsey/United Nations (disputed boundaries); UN Comtrade; McKinsey Global Institute analysis

Despite the largely regional nature of automotive production networks, OEMs in other parts of the world still rely on some imported Chinese parts. In 2018, China exported $44 billion worth of automotive parts and inputs globally, of which $17 billion went to North America, $8 billion to the EU, and $13 billion to the rest of Asia. Because of these dependencies, the initial COVID outbreak centered in Hubei Province quickly produced global ripple effects in the industry. Typically, a just-in-time manufacturing approach gives companies between two and 12 weeks of buffer inventory. The impact of Chinese factory shutdowns was moderated by excess inventory purchases that had only recently been made in anticipation of the Chinese New Year holiday. Nevertheless, purchasing managers scrambled to find alternative suppliers within and outside of China for critical parts, even if those parts had to be air shipped at greater cost. Shortages of Chinese parts quickly snowballed, forcing the shutdown of assembly lines from Brazil and Mexico to Europe and South Korea in February 2020. Hyundai and Kia, for example, were not only more reliant than other automakers on Chinese parts but tended to hold lower inventory of those parts.[85]

The automotive industry has historically led the way in productivity-enhancing manufacturing and logistics innovation—and it is now at the cutting edge of attempting to marry resilience and productivity. Toyota, an early creator of lean manufacturing systems, has already addressed lessons learned after the 2011 tsunami (see chapter 5). Trade disputes are an ongoing concern, leading companies to build in more flexibility and redundancy. We estimate that a relatively modest share of auto exports, between 15 and 20 percent by value, has the potential to shift, driven predominantly by noneconomic factors.

Semiconductors: Highly specialized production hubs

Semiconductor components are lightweight, modular, and high-value-added products. This combination lends itself to a heavily traded global value chain. But high barriers to entry also make the industry entrenched. While the United States designs many advanced chips, production is highly concentrated in South Korea and Taiwan, although the United States, mainland China, and other regions also manufacture some chips and electronic components (Exhibit 17). Economies of scale and existing advantages leave very little room for semiconductor production to shift on its own. But national security and competitiveness concerns could lead governments to take action, potentially shifting an estimated 11 to 22 percent of trade flows.

Building a semiconductor fab can cost

$10+ billion

Complex manufacturing of advanced chips is not easy to scale up. A semiconductor fabrication plant can cost $10 billion or more to build, creating high barriers to entry. The industry requires specialized suppliers and contractors as well as large numbers of highly educated engineers with unique expertise. Two dominant hubs have emerged for making the most advanced chips: Incheon Industrial Park in South Korea, and Hsinchu Science Park in Taiwan. However, different stages of production have clustered in different geographies depending on the skills and labor required. For example, while Asia–Pacific has nearly 80 percent of global wafer manufacturing capacity at an aggregate level, the United States and Europe do have a significant amount of power semiconductor and CPU manufacturing. Exports of electronic integrated circuits, meanwhile, tend to be concentrated in South Korea and Taiwan, although this may not provide a complete picture of production for domestic consumption or trade of subcomponents across the United States, Europe, and Asia–Pacific prior to final assembly. Outsourced semiconductor assembly and testing capacity is the final and most labor-intensive stage, which has migrated to low-cost countries. The Asia–Pacific region accounts for more than 95 percent of this capacity.

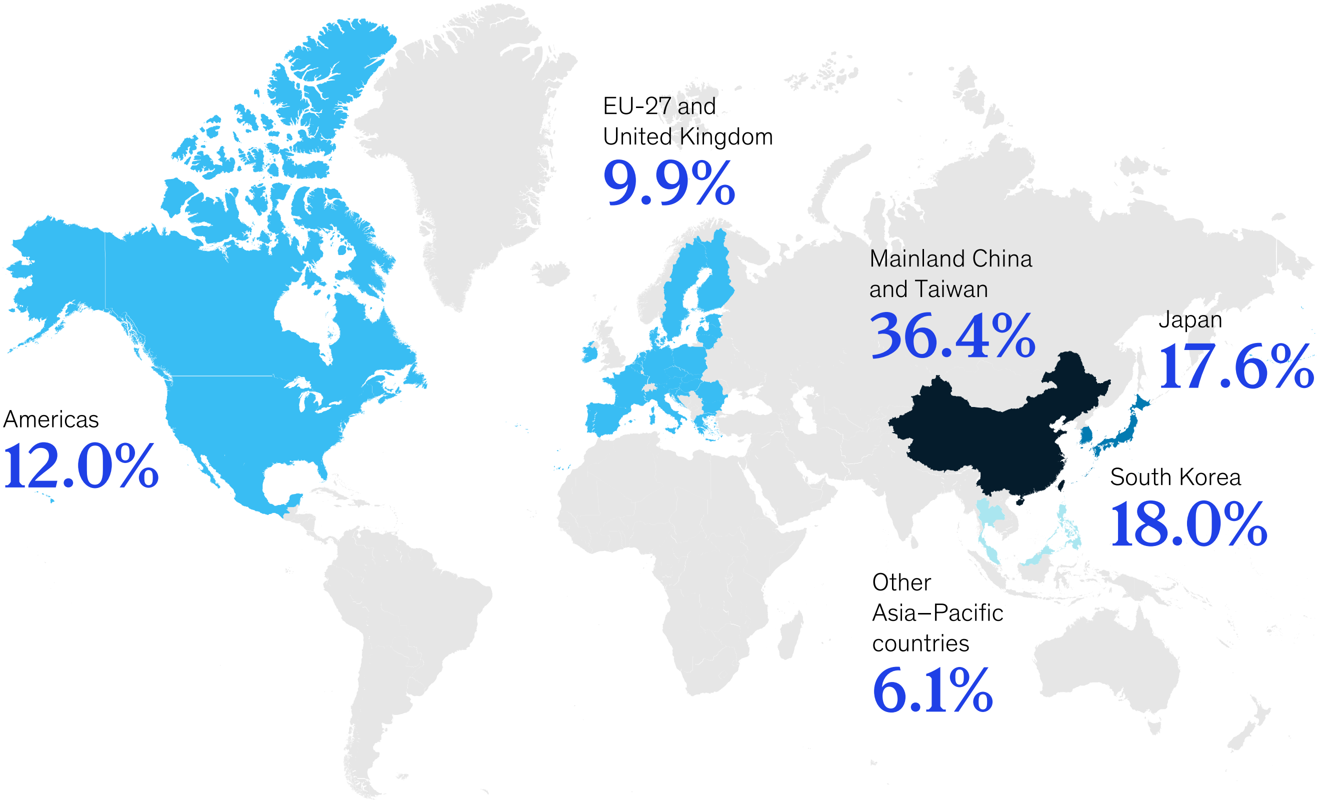
[85] Joyce Lee and Hyunjoo Jin, "Hyundai halts Korea production as coronavirus causes parts shortage," Automotive News Europe, February 4, 2020.

Exhibit 17

Semiconductor production is highly concentrated in Asia–Pacific.

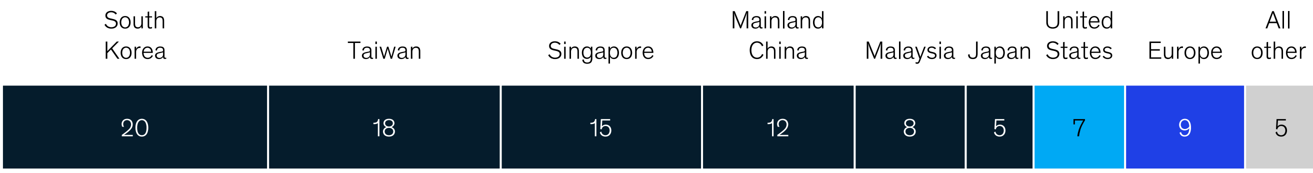
Nearly 80% of the world's semiconductor production is located in various Asia –Pacific regions

Installed global wafer capacity, 2019, % (wafers per month)[1]



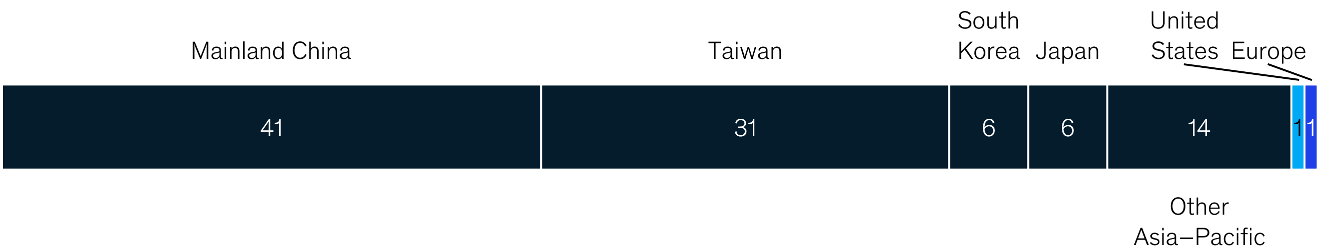
Exports of electronic integrated circuits

% of global total by region, 2019



70% of the industry's capacity for outsourced assembly and testing is in mainland China and Taiwan

% of global total by region, 2016



1. Export figures are a proxy for production concentration and exclude production for domestic consumption as well as trade at more fine-scale levels of production due to lack of data availability.

Note: The boundaries and names shown on this map do not imply official endorsement or acceptance by McKinsey & Company. Figures may not sum to 100% because of rounding.

Source: Gartner; Harmonized System Code 8542 (electronics); McKinsey/United Nations (disputed boundaries); Semiconductor Industry Association, *State of the semiconductor industry report*, 2020; UN Comtrade; McKinsey Global Institute analysis

This kind of geographic concentration brings potential risks. Previous MGI research has found that companies sourcing advanced chips from South Korea, Japan, Taiwan, and other hubs in the western Pacific can expect that hurricanes severe enough to disrupt suppliers will become two to four times more likely by 2040.[86] Other dynamics can also invite potential complications. A single firm leads production of lithographic machines, which place circuits on the wafers.

Moreover, national policy priorities and trade tensions could reshape the semiconductor global value chain in ways that market forces alone might not. Having announced plans to become self-sufficient in chips to feed its growing computer and electronics and communications industries, China is rapidly building its own semiconductor industry. The United States has its own concerns about the competitiveness and national security of its semiconductor industry. Despite the high costs of building a fabrication plant outside of the established economic cluster in Taiwan, Taiwan Semiconductor recently announced plans to construct one in Chandler, Arizona, with unspecified public support.[87] Similarly, Japan recently imposed national security restrictions on the export of key chemicals used in the manufacture of chips and displays to South Korea, leading some South Korean manufacturers to turn to domestic suppliers.[88]

While the stable and deeply integrated trade flows in this value chain are unlikely to shift meaningfully in the near future, the convergence of government intervention and growing awareness of risk among the makers of semiconductors could possibly produce greater geographic diversification and new roles for participants in the longer term.

Textiles and apparel: Significant value chain shifts are already under way

Apparel and textiles are heavily traded, labor-intensive value chains with regional production hubs. China has long been the dominant player, and it still accounts for some 29 percent of apparel sold globally.[89] But its role is evolving. Today it is pursuing ambitions to upgrade and modernize its apparel manufacturing capabilities to move into higher-value production—and its wages are rising relative to the rest of the emerging world. At the same time, the burgeoning Chinese middle class is flexing its new spending power. China is now one of the world's biggest markets for fashion, and it can use its vast production capabilities to serve its own soaring domestic demand. In 2005, China exported 71 percent of the finished apparel goods it produced. By 2018, that share was just 29 percent. Industry economics will continue to drive shifts in these value chains, propelled by labor arbitrage as well as proximity to markets to reduce production lead times and shipping costs. Manufacturing of final apparel goods is expected to shift marginally more than textile production, and national security needs for PPE could cause some footprint changes as well.

Although no other country has China's scale and footprint, the apparel trade is on the rise in other emerging economies—and recent technology advances in apparel manufacturing have even opened the door for some types of global production to take place in higher-wage countries, albeit in more automated form (Exhibit 18).

This value chain starts with agricultural inputs, which are processed into intermediate textiles and then made into final products.[90] Textile production is highly concentrated, with China accounting for 35 percent of all exports (followed by India, at only 6 percent) and more than half of all exports of specific products such as synthetic and cotton fabrics.

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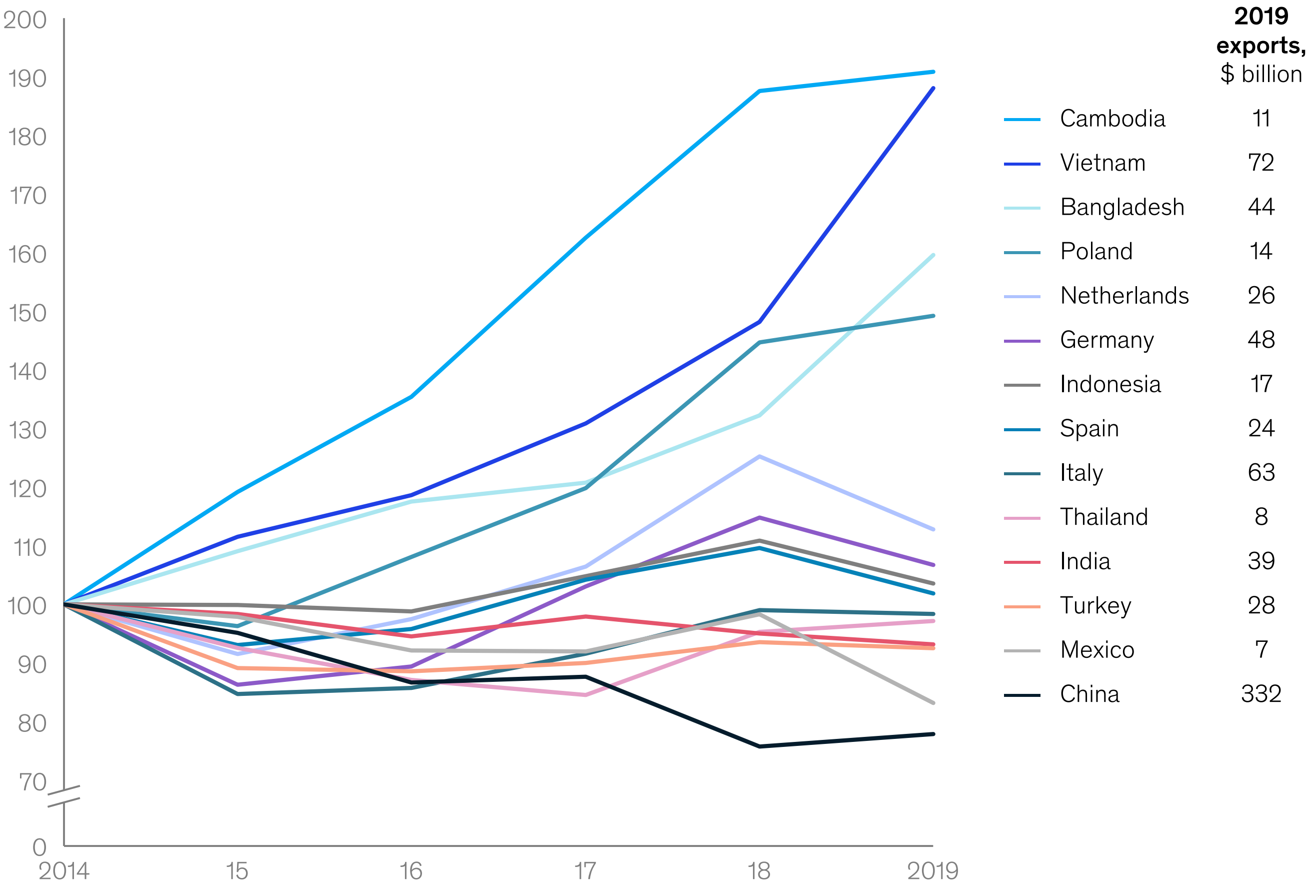
86 *Could climate change become the weak link in your supply chain?,* McKinsey Global Institute, June 2020.
87 Will Knight, "The US will help a Taiwan firm build a chip plant in Arizona," *Wired,* May 15, 2020.
88 Kotaro Hosokawa and Ten Umekuni, "Korea Inc. ditches Japan chipmaking materials for homegrown supply," *Nikkei Asian Review,* May 23, 2020.
89 UN Comtrade, 2018 intermediate and final good exports.
90 According to 2018 UN Comtrade data, 72 percent of textile trade is in intermediate goods, whereas 97 percent of apparel trade consists of final goods.

Exhibit 18

As China's exports of textiles and apparel have declined, other emerging markets have gained market share.

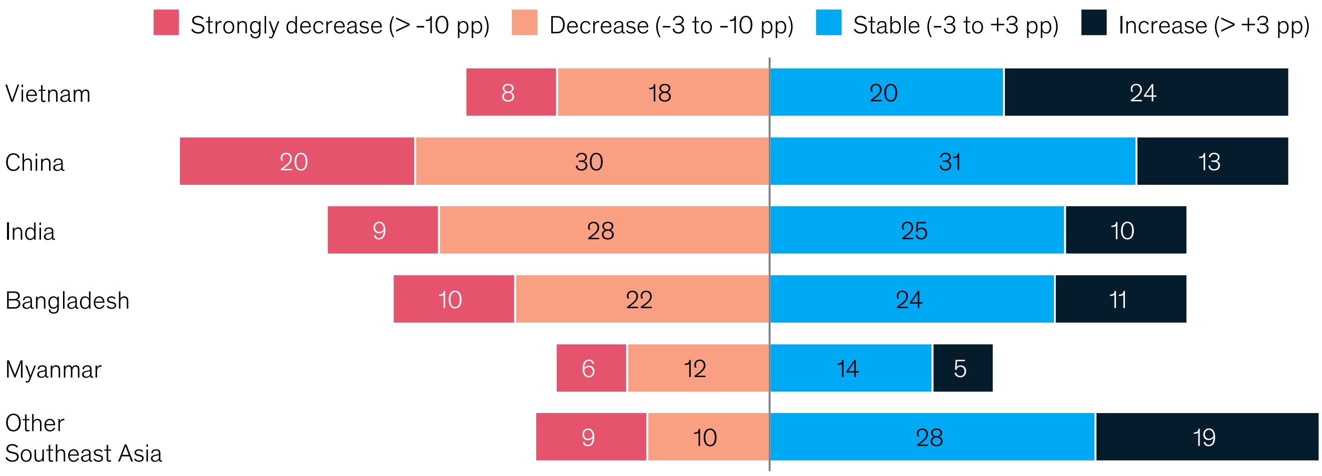
Growth rate, 2014–19, %[1]

Index: 100 = 2014



Procurement executives in the apparel industry expect more business to shift to Vietnam and elsewhere in Southeast Asia

Anticipated near-term change in share of apparel sourcing from select Asian countries[2]



1. Rest of world represents $284 million in export value and experienced -1 percent growth from 2014 to 2019.
2. Based on a 2019 McKinsey survey of global procurement executives from fashion retailers and brands (n = 116).
Note: Figures may not sum to 100% because of rounding.
Source: ITC Trade Map; UN Comtrade; McKinsey Global Institute analysis

Apparel manufacturing is growing more diverse. As China's exports have plateaued, other developing nations with lower wages are stepping in. Apparel exports from Bangladesh, Vietnam, and Ethiopia have risen sharply over the past decade. Turkey is also a major producer of clothing that is exported to Europe. In a 2019 McKinsey survey, 72 percent of chief procurement officers at US and EU apparel companies said they were planning to diversify their sourcing away from China in the near to medium term, turning to places such as Bangladesh, Ethiopia, Myanmar, and Vietnam.[91]

The fashion industry's reliance on textile manufacturers in developing countries makes it particularly vulnerable to natural disasters and idiosyncratic risks. In 2013, the Rana Plaza collapse in Bangladesh killed more than 1,100 garment factory workers and injured thousands more.[92] The disaster spurred the industry toward more active supply chain management and transparency about working conditions.

During the COVID pandemic, clothing manufacturers initially faced the prospect of factory shutdowns and worker illnesses because of the virus itself. But even as the outbreak receded in Asia, the pandemic hit suppliers from another direction. The closure of retail stores in the West and a sharp drop in consumer spending on apparel led to widespread cancellation of purchase orders.[93] A McKinsey survey of executives from fashion retailers and brands found that at least one-quarter of suppliers were in financial distress, and many expect this proportion to grow in the coming months. In response to the issue of financially fragile suppliers, further consolidation is expected.[94]

The pandemic could accelerate trends that were already under way in the fashion industry, such as a shift from transactional to long-term supplier partnerships, an emphasis on multicountry and nearshoring supply chain strategies, shorter lead times, smaller order sizes, and digitization. Digitization offers multiple paths to reducing costs, analyzing market trends, connecting with customers, and even advancing personalization. It can also make supply chains more transparent, traceable, and agile. While digitizing involves up-front costs and a learning curve, it can improve margins over the longer term—a critical imperative in a world where consumers have come to expect low prices.

Relative to all other value chains, textiles and apparel feature the highest percent of trade that could feasibly shift (36 to 57 percent in apparel and 23 to 45 percent in textiles). This represents a range of $67 billion to $393 billion in value. While some apparel production may nearshore to US and EU markets, the majority is expected to shift to Southeast Asian countries due to their comparative advantage in labor and overhead costs. But companies will need to mitigate against climate-related and pandemic shocks in these geographies.

91 McKinsey US and EU CPO survey, 2019.
92 Tansy Hoskins, "Reliving the Rana Plaza factory collapse: A history of cities in 50 buildings, day 22," *Guardian,* April 23, 2015.
93 Jon Emont, "Retailers canceling apparel orders amid coronavirus torments clothes makers," *Wall Street Journal,* May 5, 2020.
94 Achim Berg, Lara Haug, Saskia Hedrich, and Karl-Hendrik Magnus, "Time for change: How to use the crisis to make fashion sourcing more agile and sustainable," McKinsey.com, May 2020.

5. Building resilience

Today, much of the discussion in advanced economies about resilience revolves around the idea of reverting to domestic production as a "flight to safety." The geographic footprint of production and supply chains does need to be reevaluated periodically as the environment changes, and heavy dependence on one geography can be a vulnerability. But companies and countries have a wide range of options at their disposal. Increasing local production is only one of them—and it is not a guarantee of robustness in and of itself, nor is it always feasible.[95] The toolbox is much bigger than the current debate would seem to indicate.[96]

Practical strategies for making supply chains more transparent and resilient have been widely discussed for years, yet only a small group of leading companies have taken decisive action. Cautionary tales about past disasters have rarely spawned industry-wide changes. As the old saying goes, everyone talks about the weather, but nobody does anything about it.

Yet this time really might be different. The price tag associated with disruptions has been growing. Now the world finds itself living out a genuine worst-case scenario as the COVID pandemic deals the global economy a major blow.

Companies not only have a renewed sense of urgency about addressing risk; they also have a new way forward. The pandemic occurred at a moment when technology is leapfrogging forward. Global manufacturing has only just entered a new era encompassing a range of technologies such as analytics and artificial intelligence, the Internet of Things, advanced robotics, and digital platforms. Companies now have access to new solutions for running scenarios, assessing trade-offs, improving transparency, accelerating responses, and even changing the economics of production.[97]

The confluence of these trends may produce a more dramatic wave of change than discrete disasters have spurred in the past. When companies understand the magnitude of the losses they could face from supply chain disruptions, they can weigh how much to invest in mitigation—and technology is now challenging old assumptions that resilience can only be purchased at the cost of lean operations. Some manufacturing companies will no doubt seize the moment in the current crisis and come out on the other side as more agile and innovative organizations. One of the biggest opportunities would be scaling up new digital manufacturing approaches to encompass the entire value chain rather than isolated pilot plants.

95 Sébastien Miroudot, "Resilience versus robustness in global value chains: Some policy implications," in *COVID-19 and Trade Policy: Why Turning Inward Won't Work,* Richard Baldwin and Simon Evenett, eds., VoxEU, April 2020.

96 A large body of literature addresses resilience in supply chains. See, among others, Ana Beatriz Lopes de Sousa Jabbour et al., "Sustainability of supply chains in the wake of the coronavirus (COVID-19/SARS-CoV-2) pandemic: Lessons and trends," *Modern Supply Chain Research and Applications,* June 2020; Masoud Kamalahmadi and Mahour Mellat Parast, "Developing a resilient supply chain through supplier flexibility and reliability assessment," *International Journal of Production Research,* 2016, Volume 54, Issue 1; Masoud Kamalahmadi and Mahour Mellat Parast, "A review of the literature on the principles of enterprise and supply chain resilience: Major findings and directions for future research," *International Journal of Production Economics,* January 2016, Volume 171, Part 1; and Christopher Martin and Helen Peck, "Building the resilient supply chain," *International Journal of Logistics Management,* July 2004, Volume 15, Issue 2.

97 See, for example, Katy George, Sree Ramaswamy, and Lou Rassey, "Next-shoring: A CEO's guide," *McKinsey Quarterly,* McKinsey.com, January 2014; and Kevin Goering, Richard Kelly, and Nick Mellors, "The next horizon for industrial manufacturing: Adopting disruptive digital technologies in making and delivering," McKinsey.com, November 2018.

Below, we look at a range of approaches that fit into three categories (Exhibit 19). The first set includes foundational measures to build robust risk management capability and gain better visibility into supply chains. The second category is about minimizing exposure to shocks. The final set of actions is focused on building the operational and financial muscle to respond and recover quickly when disruptions hit.

Exhibit 19

Companies can adopt a broad range of resilience strategies.

Strengthen supply chain risk management and transparency

Minimize exposure to shocks

- Diversify supplier network and geographic footprint
- Build alternatives in transportation and logistics systems
- Strengthen critical suppliers or bring key production in-house
- Simplify product design
- Harden physical plant and infrastructure

Improve financial and operational capacity to respond and recover

- Increase inventory/safety stock
- Flex production across suppliers, sites, and channels
- Create cash-flow and balance sheet buffers
- Build supplier financial health

Source: McKinsey Global Institute analysis

All of these potential actions should be considered in light of the costs and benefits they deliver. These will vary for each company, given its own set of opportunity costs. Some actions, such as adopting 3-D printing, have the potential to enhance productivity and resilience at the same time (in this case, by unlocking the value of mass customization while reducing some of the complexity of SKU proliferation that exists today). Other actions are principally about reducing expected disruption-related costs. Finally, some options may create intangible benefits. These could include advancing sustainability and ethical sourcing goals, building goodwill in the community, and making reliability part of the brand.[98]

Strengthen supply chain risk management and improve end-to-end transparency

It was not until after the 2008 financial crisis that the world's major banks began to conduct rigorous annual stress tests of their balance sheets to determine whether they could withstand a severe recession. Today such stress testing is the norm.[99] Now, in the wake of a series of shocks that have disrupted businesses around the world, many manufacturing and industrial companies are considering similar approaches to supply chain risk.[100]

98 Seren Morris, "FEMA 'Waffle House Index': What the closure of Waffle House says about COVID-19 response," *Newsweek*, March 25, 2020.
99 Christopher Mazingo, Theodore Pepanides, Aleksander Petrov, and Gerhard Schröck, "Introducing a holistic approach to stress testing," McKinsey.com, June 2014.
100 Conor Kehoe, Cindy Levy, and Matt Stone, "Stress testing for nonfinancial companies," McKinsey.com, June 2017; and Sven Heiligtag and Susanne Maurenbrecher, "Applying stress tests beyond banking," McKinsey.com, December 2017.

Only the largest and most advanced global companies have built permanent supply chain risk management teams that proactively monitor for risk, assess the potential impact of various scenarios, and establish robust business continuity plans to keep critical operations running in the event of a disruption.[101] All of these areas require periodic review to ensure that preparedness reflects how risks are evolving over time. Well before a shock hits, the risk management team needs to ensure that key assets are protected and engage in drills and ongoing employee education. If disaster does strike, a centralized nerve center can coordinate all facets of response and recovery, from ensuring that employees are safe to monitoring logistics routes (see Box 3, "How Biogen got ahead of Hurricane Maria").

Box 3

How Biogen got ahead of Hurricane Maria

When Hurricane Maria decimated Puerto Rico in 2017, it struck a cluster of pharmaceutical plants that at the time produced 10 percent of the US drug supply. The hurricane crippled the island's power supply for months, hampering production of 17 major drugs sold in the United States.

An effective risk management system at Biogen enabled the company to activate its response days before the storm arrived. Drawing on experience with Hurricanes Irma and Harvey, Biogen's global risk team set up a natural disaster "war room" to run scenarios and identify threats to its production facilities and its supply chain as well as downstream clinical trials. As a result, Biogen was able to relocate essential materials and shift some production from Puerto Rico to sites in Kentucky. It also contacted alternative procurement sources ahead of the hurricane's landfall, executing a $1.3 million purchase for items at risk of shortages.[1]

As a result, Biogen's stock price recovered only two weeks after the hurricane hit. Not all of its competitors fared as well. Many Puerto Rican plants remained down well into 2018. One of the most pronounced effects was a widespread shortage of IV bags in US hospitals, since the island supplied roughly half of the nation's supply.[2]

The island's entire pharmaceutical cluster absorbed some critical lessons from the storm. When the supply of gases that are essential for maintaining sensitive biologics ran dangerously low, companies set aside competition to work together on sourcing and share resources. In the years since, they have strengthened their connectivity and communication systems, repositioned backup supplies, and added more generators. Some have even built their own cogeneration plants.[3]

1 *Biogen & Resilinc case study: Proactive risk mitigation in hurricane season,* Resilinc, February 2018, info.resilinc.com/hubfs/Biogen%20Case%20Study:Proactive%20Risk%20Mitigation%20in%20Hurricane%20Season.pdf.
2 "FDA Commissioner Scott Gottlieb, MD, updates on some ongoing shortages related to IV fluids," US Food and Drug Administration news release, January 16, 2018.
3 Karen Langhauser and Meagan Parrish, "Puerto Rico pharma: Battered but unbroken," *Pharma Manufacturing,* September 2018; and Lisa Jarvis, "Hurricane Maria's lessons for the drug industry," *Chemical and Engineering News,* September 2018, Volume 96, Issue 37.

101 See Knut Alicke and Anna Strigel, "Supply chain risk management is back," McKinsey.com, January 2020.

Map your value chain in detail

One key to identifying risks, predicting disruptions, and responding to them is to know your supply chain in detail. But most large firms have only a murky view beyond their tier-one and perhaps some large tier-two suppliers. Many are surprisingly unfamiliar with suppliers of critical components in deeper tiers.[102] Full transparency across the whole value chain, from the production of raw materials to the customer, remains a holy grail for even the most advanced companies.

Working with operations and production teams to review each product's bill of materials can reveal if critical inputs are sourced from high-risk areas and lack ready substitutes. A risk index for each component and commodity, based on uniqueness and location of suppliers, can be a useful tool.

Creating a comprehensive view of the supply chain through detailed subtier mapping is a critical step to identifying hidden relationships that invite vulnerability. Companies can work more closely with their tier-one suppliers to create transparency; after all, those suppliers are likely to have similar concerns about their own vendors. However, some may lack visibility themselves or may consider their sourcing to be proprietary information.[103] In these situations, risk management teams may have to do some sleuthing or guesswork by triangulating from a range of information sources and business data providers.[104]

After mapping upstream suppliers, companies need to understand the production footprint and financial stability of each participant in the value chain. Many are starting to do so: in one recent survey, two-thirds of respondents reported asking key suppliers whether they have business continuity plans in place.[105]

Use the full potential of digital to monitor, connect, and collaborate across the supply chain

For years, the manufacturing world has been hearing about the promising convergence of technologies such as analytics, AI, robotics, connected sensors and controls, tracking technologies, and augmented reality. These have the potential to make industrial settings hyperefficient and reliable—and, eventually, they can connect the entire value chain with a seamless flow of data.[106]

Consumer goods giant Procter & Gamble has invested heavily in digitizing its facilities and its supplier network to achieve both efficiency and resilience. In the past, hundreds of international facilities would make their own disaster planning and response decisions. Today, a centralized control tower system gives a company-wide view of geographies and products. It integrates multiple types of real-time data, from inventory levels to road delays and weather forecasts, for its own plants as well as suppliers and distributors. When a problem occurs, the system can run scenarios to identify the most effective solution.[107] In addition, P&G has invested in more efficient and flexible production facilities. In its plant in the Czech Republic, flexible machinery can be reconfigured to turn out different products at the touch of a button, improving responsiveness.[108] The company has also deepened its use of automation

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[102] Thomas Y. Choi, Benjamin B. M. Shao, and Zhan Michael Shi, "Hidden suppliers can make or break your operations," *Harvard Business Review*, May 2015; and Benjamin B. M. Shao et al., "A data-analytics approach to identifying hidden critical suppliers in supply networks: Development of nexus supplier index," Decision Support Systems, October 2018, Volume 114.

[103] Knut Alicke, Ed Barriball, Susan Lund, and Daniel Swan, "Is your supply chain risk blind—or risk resilient?," McKinsey.com, May 2020.

[104] Knut Alicke, Xavier Azcue, and Edward Barriball, "Supply-chain recovery in coronavirus times—plan for now and the future," McKinsey.com, March 2020.

[105] *Supply chain resilience report 2019,* Business Continuity Institute, 2019, thebci.org/uploads/assets/e5803f73-e3d5-4d78-9efb2f983f25a64d/BCISupplyChainResilienceReportOctober2019SingleLow1.pdf.

[106] For more on next-generation manufacturing technologies, see *Global Lighthouse Network: Insights from the forefront of the Fourth Industrial Revolution,* World Economic Forum, December 2019; *The great re-make: Manufacturing for modern times*, McKinsey & Company Manufacturing Practice, June 2017; and *Digital manufacturing: Escaping pilot purgatory,* McKinsey & Company, July 2018.

[107] Emma Cosgrove, "How P&G created a 'ready-for-anything' supply chain," *Supply Chain Dive,* June 3, 2019.

[108] Barrett J. Brunsman, "P&G's second-oldest plant called 'factory of the future,'" *Cincinnati Business Courier,* September 11, 2018.

technologies in its megasize “factory of the future” in West Virginia and in a high-productivity, fully “lights-out” facility in Taicang, China, in which machines work unattended by people.[109]

General Motors uses a geographic information system that combines data from GM plants, tier-one and tier-two suppliers, and logistics hubs with 24/7 incident monitoring. The system maps the flow of parts and interactions between thousands of locations and players. When a disruption hits, the company is able to trace where an affected part was set to move upstream and which vehicle model it would affect. If the bottleneck appears serious, a crisis management team can apply its contingency plans much sooner.[110]

Minimize exposure to shocks

In a world where disruptions are increasing in both frequency and severity, companies cannot afford to be purely reactive. Investing in targeted measures to shore up vulnerabilities *before* an event occurs can mitigate the impact of a shock or speed time to recovery.[111] Some of the options include diversifying supplier networks, strengthening critical suppliers, building more robust transportation and logistics options, designing products for modularity and shared components, and hardening physical structures and assets. The right set of actions will depend on each company’s specific exposures, although some patterns are apparent across broader industries (see Box 4, “Supply chain leaders on resilience”).

Diversify your supplier network and geographic footprint
Many companies have come to rely on a single source for critical components or raw materials. In some cases, they do so because they found only one supplier with the unique capabilities to make the input they need. But in others, companies were aiming to streamline purchasing or negotiate better pricing by going with a single supplier despite the fact that others were available. This can be a major vulnerability, even if that supplier is domestic. It creates the possibility of bottlenecks if that supplier goes down; it may also become a constraint to ramping up to meet sudden spikes in demand.

Even if a company relies on multiple supplier firms, they may be concentrated in a single geography because of the way specializations have developed. For instance, just five regions (mainland China, Taiwan, South Korea, Singapore, and the United States) account for three-quarters of global exports in semiconductors. China, Vietnam, the United States, the Netherlands, and South Korea account for three-quarters of exports in telecommunication equipment. Overall, we find 180 traded products, worth $134 billion in 2018, that were overwhelmingly produced in just one country.

Companies can diversify their supplier network to build in more flexibility and redundancy. Sourcing from multiple or lower-risk geographies can minimize the odds that an isolated natural disaster in one place can bottleneck the entire value chain.[112] Taking the time to identify, prequalify, and onboard backup vendors can provide much-needed capacity when a crisis strikes, shortening interruptions and avoiding the need for hasty decisions under pressure. There is a cost associated with screening new suppliers and working with multiple sources, but the end result is that companies are better able to shift production across vendors, factories, and countries as circumstances dictate—and they can bounce back from shocks faster than others.[113] Indeed, this is why dual sourcing was the planned action cited most frequently by supply chain executives responding to a recent McKinsey survey.

[109] Alexander Coolidge, “P&G promises mega ‘factory of the future’ as it shuts down old sites,” *Cincinnati Enquirer,* July 26, 2018; and “44 of the most advanced manufacturing factories in the world are lighting the way as learning beacons,” World Economic Forum, July 2019, weforum.org/our-impact/advanced-manufacturing-factories-light-the-way-as-learning-beacons.
[110] Yasaman Kazemi, “How GM maps and manages supply chain risk,” *WhereNext Magazine,* Esri, November 15, 2018; and *2018 sustainability report,* General Motors, 2019.
[111] Knut Alicke, Ed Barriball, Susan Lund, and Daniel Swan, “Is your supply chain risk blind—or risk resilient?,” McKinsey.com, May 2020.
[112] Sébastien Miroudot, “Resilience versus robustness in global value chains: Some policy implications,” in *COVID-19 and Trade Policy: Why Turning Inward Won’t Work,* Richard Baldwin and Simon Evenett, eds., VoxEU, April 2020.
[113] Tom Linton and Bindiya Vakil, “Coronavirus is proving we need more resilient supply chains,” *Harvard Business Review,* March 5, 2020.

As companies audit and diversify, they can move closer to the goal of zero-carbon supply chains with minimal environmental impact. In addition to focusing on sustainability, companies can also take this opportunity to raise labor standards and transparency throughout their supply chains and to increase opportunities for minority- and women-owned businesses.[114]

Diversification in sourcing does not necessarily point to a radical restructuring of value chains, however. As discussed in chapter 4, their current configuration reflects economic logic, hundreds of billions of dollars' worth of investment, and long-standing supplier relationships. Companies with operations around the world have also chosen those locations to serve local markets; exports may be only a secondary consideration. Many multinationals with a presence in China are there to sell to its fast-growing industries and rising middle class, not to produce goods and ship them to European or North American customers. However, the need to diversify and move closer to end consumers is prompting companies to rethink where to invest in new capacity or add backup sourcing.

Strengthen critical suppliers or bring production of key components in-house

Just as large companies need to build resilience in their own operations, they need to ask whether their critical suppliers are prepared for all eventualities. These companies, too, must focus on risk monitoring and planning, diversifying their own supplier bases, building financial buffers, and investing in demand planning capabilities.

Large companies may consider investing to develop their suppliers' capabilities or collaborate alongside them on key components. Apple, for example, has invested $450 million in Corning to support the development of glass used in its iPhones. The money comes from the company's $5 billion advanced manufacturing fund, which provides suppliers with capital for R&D and upgrades; in return, Apple locks in supplies and favorable prices.[115]

Vertical integration is the ultimate way to ensure continuity of a key input. In 2018, the iconic British fashion brand Burberry acquired a major Italian supplier, CF&P, to ensure the delivery and quality of leather goods. In the automotive industry, demand is growing for electric vehicles, but automakers have faced difficulties in securing sufficient supplies of batteries. This has led Volkswagen to invest €1 billion into its own state-of-the-art battery-making plant in Germany and to acquire a 20 percent stake in Chinese battery maker Guoxuan.[116] The make-versus-buy question is a complicated trade-off but one worth exploring, particularly in cases where companies depend on scarce or unique inputs.

Another option many companies are also considering is co-locating more of their supply chain in the same place to maximize their ability to collaborate, shift production across sites, and reap the benefits of economic clusters and ecosystems. These benefits include improved information flows and innovation in crisis times and in normal times; a larger pool of specialized talent; and the emergence of service providers and other suppliers geared toward a particular industry. However, the benefits of co-location have to be carefully weighed against the risks of geographic concentration, and the ecosystem must have built-in safeguards.

Build alternatives in transportation and logistics

When port facilities are damaged, roads are impassable, or flights are stopped, vital parts and finished products can be stranded. In the COVID pandemic, it was difficult to transport goods into lockdown areas. Many cargo flights were canceled, and trucking companies ran short of drivers. Every form of logistics became snarled.

Avoiding this kind of scenario depends on having the right relationships in place and alternatives mapped out well in advance. Companies can contract with multiple logistics services and identify backup providers for every key route. One company that supplies apparel to brands such as Hugo Boss and Nike, Esquel, found itself unable to export fabric

[114] Verónica H. Villena and Dennis A. Gioia, "A more sustainable supply chain," *Harvard Business Review,* March–April 2020.
[115] Stephen Nellis, "Apple awards iPhone supplier Corning $250 million from US manufacturing fund," *US News & World Report,* September 17, 2019.
[116] Alex Davies, "VW will make its own batteries to power an electric future," *Wired,* May 15, 2019; and Julie Zhu and Yilei Sun, "Volkswagen to buy 20% of Chinese battery maker Guoxuan amid electric push," Reuters, January 16, 2020.

from China to its factories in Vietnam during the initial COVID outbreak. But the company activated its backup plan and pivoted to shipping through Hong Kong to keep production going.[117] When logistics providers are treated as partners over the long term, they can become invaluable in a crisis when it comes to rerouting and expediting critical shipments.

Land O'Lakes turned to FourKites to implement a new model of selling excess capacity in its own logistics and delivery fleet.[118] This maximizes utilization in good times and can also become a lifeline for participating companies in a crisis. Digital platforms that offer real-time visibility into available shipping capacity can provide dynamic matching, applying sharing-economy principles to manufacturing logistics.

Move toward modular product design with standardized inputs

One way to achieve supply chain resilience is to design products with common components and cut down on the use of custom parts for different product offerings. Nissan, for example, fared better than some of its competitors in the aftermath of Thailand's 2011 flooding because it used common parts. When its Thai suppliers were inundated, the company was able to tap other global suppliers to get replacement parts into Thailand and resume production.[119]

Indeed, reducing the number of input SKUs has been an ongoing priority for many companies. Makers of consumer packaged goods in particular have accelerated those efforts during the pandemic. By streamlining product portfolios, they have been able to focus their resources on ramping up production of their best sellers, although it is not clear if that strategy will become permanent.

Harden physical assets to withstand natural disasters

Companies will consider the likelihood and frequency of weather- and climate-related events when they are selecting a site to add new capacity or choosing a new supplier. But factories are rigid assets with high sunk costs. When risk exposure rises near an existing factory, adapting and shoring up the facility itself can be a more cost-effective solution than moving it.[120]

In regions that are vulnerable to hurricanes and storm surges, companies can install bulkheads, elevate critical machinery and utility equipment above the maximum anticipated flood line, improve waterproof sealing, and rework drainage and valves.[121] Plants located in earthquake-prone areas may need seismic retrofitting and bracing. Many factories in developing countries are not air-conditioned today. But as temperatures rise and heat waves become more intense, cooling systems will be increasingly important for keeping workers healthy and productive as well as protecting sensitive components.[122]

In addition to examining their own physical assets, companies are exposed to risk if public infrastructure fails. Preparing for blackouts and power outages has long been necessary for companies in developing countries. Now, with aging power grids, intensifying storms, and growing cyberthreats, facilities in advanced economies have to prepare to keep operations running if power is out for an extended period. Companies can work closely with local authorities to identify and address vulnerabilities in transportation, logistics, energy, communications, and health infrastructure. Many of these systems need to be hardened to withstand more extreme weather. In some cases, private investment in modernizing infrastructure may pay off. Another option is participating in industry coalitions and public-private partnerships to address these issues.[123]

[117] Edmund L. Andrews, "How to survive the disruption in global supply chains," *Fast Company,* April 21, 2020.
[118] FourKites, "Supply chain visibility: Beyond the expected," blog entry by Naomi Newman, April 11, 2019.
[119] Janet Pau et al., *Building resilience in business and supply chains in Asia,* Asia Business Council, February 2018.
[120] One study found that every $1 invested in adaptation to prepare for climate change could result in $2–$10 in net economic benefits. See *Adapt now: A global call for leadership on climate resilience,* Global Commission on Adaptation, September 2019.
[121] *Climate risk and response: Physical hazards and socioeconomic impacts,* McKinsey Global Institute, January 2020.
[122] E. Somanathan et al., *The impact of temperature on productivity and labor supply: Evidence from Indian manufacturing,* Becker Friedman Institute for Economics at the University of Chicago, working paper number 2018-69, August 2018.
[123] *Could climate become the weak link in your supply chain?,* McKinsey Global Institute, June 2020.

Box 4

Supply chain leaders on resilience

McKinsey conducted a survey of 60 supply chain executives at leading global companies in May 2020. With the disruptions of the COVID pandemic fresh in their minds, an overwhelming 93 percent reported that they plan to take steps to make their supply chains more resilient. In another survey, 44 percent said they would prioritize resilience over short-term profitability.

Overall, 53 percent of respondents plan to diversify their supplier network by qualifying more vendors and building in redundancies. Forty-seven percent plan to hold more inventory of critical inputs. Forty percent plan to nearshore their supply base, and 38 percent plan to regionalize their supplier network—both strategies enable companies to build a more collaborative production network and spot bottlenecks in production more quickly (Exhibit 20).

Exhibit 20

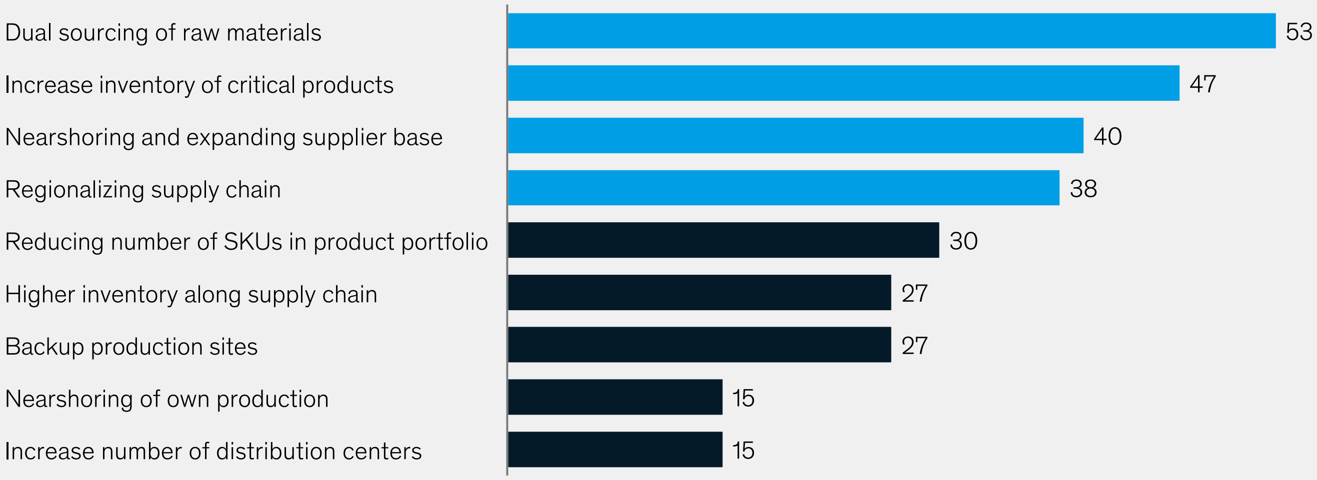
Surveyed business leaders are increasing resilience in supply chains and production through multiple strategies.

93% of global supply chain leaders are planning to increase resilience[1]

44% would increase resilience even at expense of short-term savings[2]

Planned actions to build resilience

% of respondents[1]



1. McKinsey survey of global supply chain leaders, May 2020.
2. McKinsey survey of business executives, May 2020.

Source: McKinsey survey of global supply chain leaders, May 2020 (n = 60); McKinsey survey of business executives, May 2020 (n = 605); McKinsey Global Institute analysis

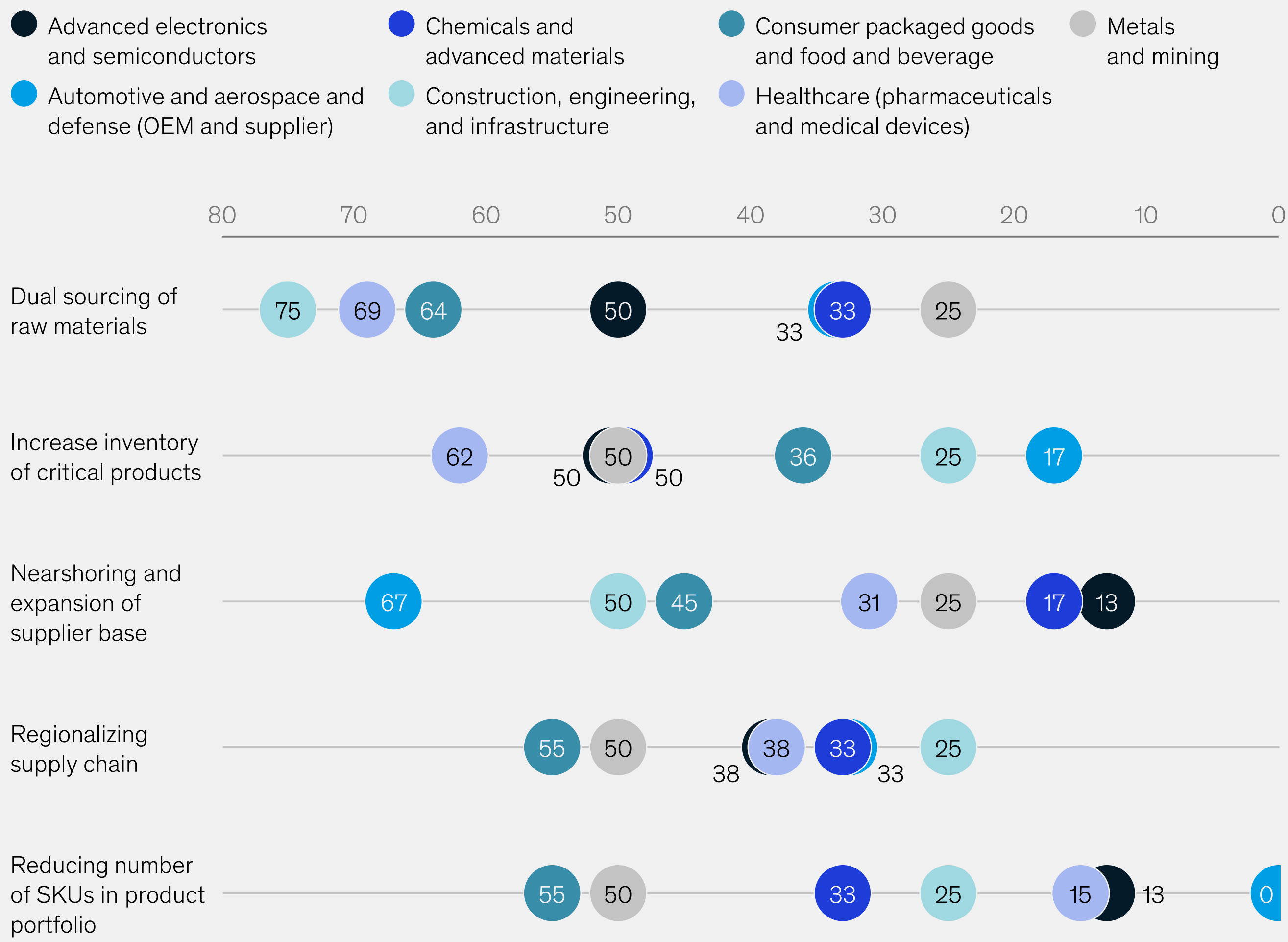
Looking across industries, some key differences emerge. For instance, more than one-third of all companies plan to build regional supplier networks for better coordination. But very few companies in the semiconductor and advanced electronics industry plan on nearshoring. This reflects the fact that this industry is well entrenched, with strong economies of scale. The costs of replicating it in another location would be prohibitive. In contrast, two-thirds of automotive companies plan to nearshore suppliers. Companies in the consumer and packaged goods industry are more focused on simplifying their product portfolios and regionalizing their supply chains. Construction and engineering firms predominantly view dual sourcing as the way to reduce their vulnerability (Exhibit 21).

Exhibit 21

The major resilience strategies vary by industry.

Most cited options to improve supply chain resilience

% of respondents per industry sector (with at least 5 respondents)



Source: McKinsey survey of global supply chain leaders, May 2020 (n = 60); McKinsey Global Institute analysis

When a shock does hit, companies need the ability to respond

Some disruptions are unavoidable or occur on such a large scale that the effects are pervasive. When such an event occurs, companies need to be able to respond quickly and effectively.

Increase inventory and safety stock

The shift to just-in-time and lean production systems first engineered by Toyota in the 1980s has helped companies improve efficiency and reduce their need for working capital, raising profitability along the way. But a supply chain built for maximum efficiency may be more fragile. Many companies—including Toyota—are now striking a new balance between just in time and "just in case" (see Box 5, "How Toyota strengthened its supply chain"). Our models show that having sufficient backup inventory of key parts and safety stock is a critical buffer that can minimize the financial impact of disrupted supplies. It can also position companies to meet sudden spikes in demand.

Box 5

How Toyota strengthened its supply chain

Toyota is often credited with inventing the concept of lean manufacturing, as the principles underlying its famous Toyota Production System spread around the world.[1] But the company has updated its approach in the wake of major disruptions. After a magnitude-9 earthquake and tsunami hit Japan in 2011, all of Toyota's domestic operations shut down for nearly two months. Production in the United States declined by 30 percent due to a shortage of parts produced in Japan.[2] Profits plunged, and Toyota vowed to revamp its supply chain.

To become more resilient, the company used a combination of four different tactics. First, it standardized some components across vehicle models so that inventory could be shared globally and production could be shifted flexibly across various sites. Second, Toyota built a comprehensive database of thousands of its suppliers and the hundreds of thousands of parts they held in inventory so it could quickly identify how to shift components across sites when needed. Third, the company regionalized its supply chains, so that disruptions at one location would not affect global operations. Finally, Toyota identified roughly 1,000 parts that came from hundreds of single-source suppliers and asked those vendors to disperse production of those parts to multiple sites or hold extra inventory—several months' worth in the case of specialized parts that cannot be produced in multiple locations.[3]

These moves appear to have paid off. When earthquakes struck Japan in 2016 and 2019, Toyota kept production stoppages to two weeks or less and avoided disruptions in its worldwide operations.[4]

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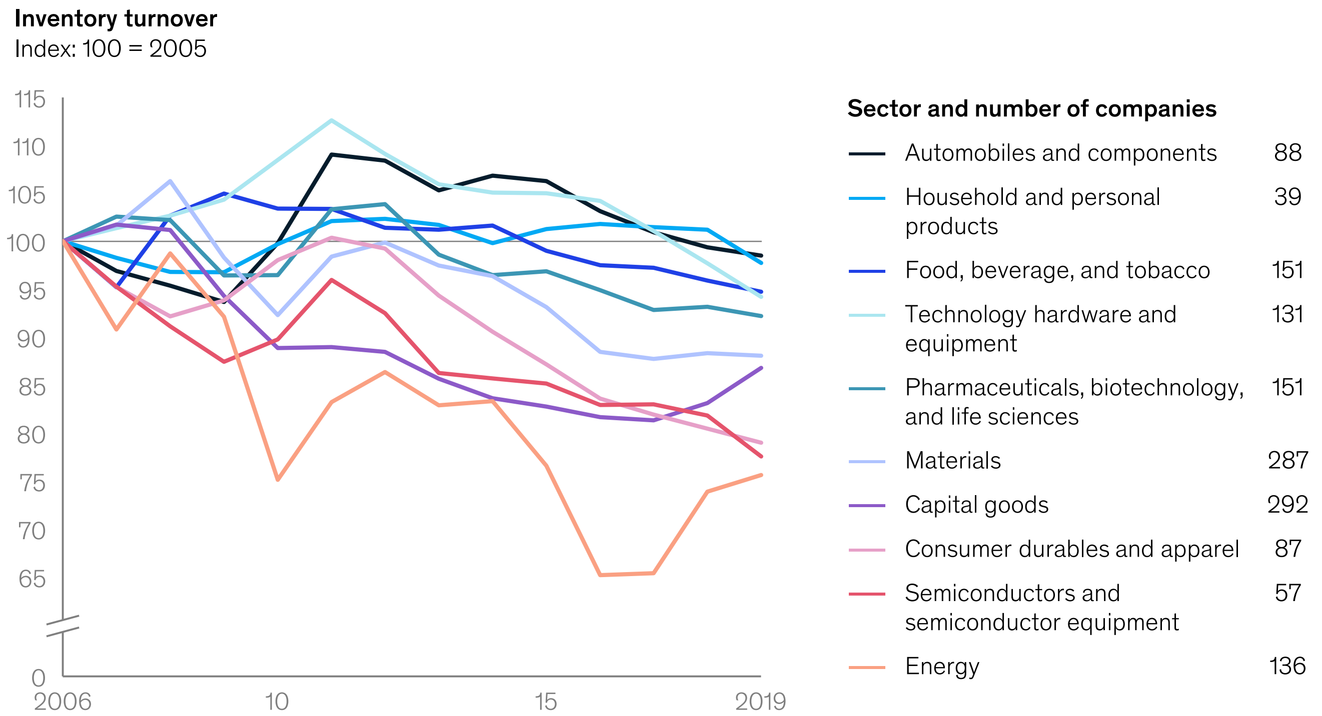
1 See James P. Womack, Daniel T. Jones, and Daniel Roos, *The Machine That Changed the World: The Story of Lean Production,* New York, NY: Free Press, 2007.
2 Bill Canis, *The motor vehicle supply chain: Effects of the Japanese earthquake and tsunami,* US Congressional Research Service report R41831, 2011.
3 Hirofumi Matsuo, "Implications of the Tohoku earthquake for Toyota's coordination mechanism: Supply chain disruption of automotive semiconductors," *International Journal of Production Economics,* March 2015, Volume 161; and "Toyota taking massive effort to reduce its supply chain risk in Japan," *Supply Chain Digest,* March 2012.
4 Chang-Ran Kim, "Toyota: supply chain will be ready by autumn for next big quake," Reuters, March 2, 2012; and Yoko Kubota, "Japan earthquakes rattle Toyota's vulnerable supply chain," *Wall Street Journal*, April 19, 2016.

In a world where shocks are growing in frequency and intensity, companies may need to revisit past calculations about how much inventory stock to carry. There are signs that this is already under way. From 2017 to 2019, most value chains had lower inventory turnover than they did in the period from 2010 to 2012 (Exhibit 22).

Exhibit 22

A trend toward holding more inventory is already under way.

Two-year moving average of inventory turnover across global MSCI sectors has declined since 2006[1]



1. Implying higher inventories relative to sales.
Source: S&P Capital IQ; McKinsey Global Institute analysis

Flex across suppliers, production sites, and customer channels

The ability to reroute components and shift production across sites can keep companies going in the wake of a shock.[124] Auto manufacturers are perhaps the most advanced in this regard, having implemented manufacturing platforms that share components across product lines and production sites.[125] This type of modular approach not only reduces the number of items that can become bottlenecks; it also enables carmakers to shift production dynamically if they need to respond to tariffs or natural disasters.

To flex production, companies first need to have robust digital systems in place for real-time tracking of inventory and shipments. They also need the analytics muscle to run scenarios based on different responses. Nike, for example, has invested heavily in digitizing its operations and supply chain, using RFID tagging to track goods from end to end. The company relies on fully outsourced manufacturing, utilizing more than 500 factories across 40 countries. To manage this complexity, Nike built an "express lane" manufacturing system for visibility, speed, and flexibility. When the COVID pandemic hit, consumer demand plummeted, leaving retailers with major inventory buildups. Predictive analytics helped Nike quickly assess inventory relative to expected demand and selectively mark down goods and reduce production early on to minimize impact. The company was also able to reroute

[124] Yasuyuki Todo, Kentaro Nakajima, and Petr Matous, "How do supply chain networks affect the resilience of firms to natural disasters? Evidence from the Great East Japan Earthquake," *Journal of Regional Science,* March 2015, Volume 55, Issue 2.
[125] David E. Zoia, "Massive retooling readies Toyota Georgetown for another 30 years," *Wards Auto,* July 10, 2017.

products originally destined for brick-and-mortar stores across China to warehouses for e-commerce sales instead. At the same time, the company used its Nike Training Club app to accelerate growth of its direct-to-consumer online sales, particularly in Greater China. As a result, Nike sustained a smaller drop in sales than some of its competitors.[126]

Some companies are willing to shoulder the costs of excess manufacturing capacity that can be ramped up in the event of a disruption or a surge in demand. Other brands outsource their manufacturing and may reserve or quickly purchase excess capacity as needed. This can involve adopting a strategy made famous by Apple and outsourcing in full, or outsourcing the manufacturing of specific specialized product lines.

Create cash flow and balance sheet buffers—for suppliers, too

$74 trillion

global nonfinancial corporate debt at the beginning of 2020

Firms with strong balance sheets are better prepared to withstand shocks; highly leveraged companies have little room to maneuver when revenue suddenly dries up. As our ongoing debt and deleveraging research has documented, nonfinancial corporate debt has been mounting for years.[127] At the beginning of 2020, it stood at an all-time high of $74 trillion—which means that many companies were in a precarious state on the eve of the COVID pandemic.[128] Some major players have already filed for bankruptcy, and more are teetering on the brink.

During good times, companies can strengthen their balance sheets by reducing debt, building reserves, and securing adequate credit lines.[129] Recent McKinsey research analyzed the performance of 1,000 publicly traded companies and found that about 10 percent of them materially outperformed the rest during the Great Recession and the years that followed. One of the characteristics that set them apart was moving to create a financial safety buffer before the financial crisis hit, which helped them shift into acquisition mode at the first sign of recovery, using their cash to acquire assets that their competitors were divesting in order to survive.[130]

Other steps may help them guard against some known financial risks. Airlines, for example, hedge against oil prices, while agricultural companies hedge against commodity price fluctuations. Periodically reevaluating insurance coverage is also important.

When disaster strikes, companies have to be laser focused on cash management. But those at the top of a value chain also have a vested interest in preserving the supplier networks they depend on, prioritizing assistance for the suppliers that are most critical and hardest to replace. During the global financial crisis and the Great Recession, some companies accelerated payments or guaranteed bank loans to give key vendors a lifeline. Intel helped suppliers create financial plans, find other customers or investors, and even provided liquidity or took equity stakes in some cases.[131]

Companies have numerous strategies available to mitigate risks and minimize disruptions. But the time to commit to them is well before an event occurs. Once a crisis is in motion, the options are much more limited for implementing a new technology system or finding an alternative supplier. Investing in resilience takes discipline and a long-term view, but in an increasingly volatile world, preparing for a wide range of eventualities is becoming a must.

[126] "NIKE, Inc. reports fiscal 2020 third quarter results," March 24, 2020, news.nike.com/news/nike-inc-reports-fiscal-2020-third-quarter-results.
[127] *Rising corporate debt: Peril or promise?* McKinsey Global Institute, June 2018.
[128] Bank for International Settlements data, Q4 2019, total credit to nonfinancial corporations.
[129] Michael Birshan, Arno Gerken, Stefan Kemmer, Aleksander Petrov, and Yuri Polyakov, "The secret to unlocking hidden value in the balance sheet," McKinsey.com, March 2020.
[130] Martin Hirt, Kevin Laczkowski, and Mihir Mysore, "Bubbles pop, downturns stop," *McKinsey Quarterly,* May 2019.
[131] Yossi Sheffi, "The financial crisis and the money supply chain," *Supply Chain Quarterly,* December 2015.

Technical appendix

This appendix details the data sources and methodology used to conduct several key pieces of analysis in this report.

- Determining each value chain's level of exposure to different types of shocks
- Calculating the financial loss that an individual company could sustain in a prolonged disruption
- Comparing financial outcomes for companies with different levels of preparedness
- Estimating the share of global trade that could move to new geographies

Determining each value chain's level of exposure to different types of shocks

We constructed an index that measures the forward-looking exposure of 23 value chains to six different types of shocks: pandemics, cyberattacks, climate events including heat stress and flooding, geophysical natural disasters (such as earthquakes), and trade disputes. The results are shown in Chapter 1, Exhibit 4. In selecting these shocks, we sought to analyze those with high cost and little advance warning, those with high cost and longer lead times, and those with moderate cost and longer lead times. While idiosyncratic business risks (such as power outages and supplier bankruptcies) are the most common disruptions in most value chains, we omit them from this analysis because their impact is often at the level of specific companies rather than the entire value chain.

Each column of the exhibit ranks value chains in order of their relative exposure to particular shock, with 1 being most highly exposed and 23 being least exposed. For example, digital- and capital-intensive value chains like electronics rank among the most highly exposed to cyberattacks, while less digital-intensive industries such as textile, apparel, and wooden products are less susceptible.

To make these assessments for each shock, we begin by ranking each industry on a set of constituent variables. We then average the results for the overall ranking for that shock.

We further create an overall exposure ranking by averaging each industry's exposure ranking across all six shocks. We do not weight them by severity, and we acknowledge that doing so, or assessing additional shocks, might change this result.

Because value chains are ranked, the score of the most exposed industry is always 23, based on the number of industries we assessed. If we had normalized relative to the maximum value of any particular variable, the variance between the most and least exposed value chain would differ based on the dispersion of the underlying metric. In other words, even if the underlying variable scores range from 90 to 100, we generate a ranking of 1 to 23. This should not be read as a statement that the most exposed value chain is always 23 times more exposed than the least.

For each shock, we combine the following factors and sources:

— **Pandemics.** This reflects the value chain's geographic footprint (based on country share of exports (as reported by UN Comtrade), its exposure to pandemics (using data from INFORM, a global open-source risk assessment tool established jointly by the United Nations and European Commission), and people inflows (using UN World Tourism Organization data). We also consider the labor intensity of production, because pandemics prevent people from working in crowded factory settings, and the effect on demand (as measured by the change in enterprise value of publicly listed companies in each value chain in the first quarter of 2020 in response to COVID-19). Labor intensity is sourced from the US Bureau of Economic Analysis for value chains in our global innovations archetype; the World Input-Output Database is used for others.

— **Cyberattacks.** We determine the potential for disruptions in each value chain based on its knowledge intensity, level of digitization, footprint in countries with high levels of cross-border data flows, and capital intensity. We use the share of the workforce with a bachelor's degree or higher in each value chain as a proxy for its knowledge intensity, relying on data from the US Bureau of Labor Statistics and MGI's own LaborCube database. For the level of relative digitization, we rely on the MGI Digitization Index, which measures digital assets, utilization of technology, and use of digital tools by the labor force.[132] For the industry's presence in countries with high levels of cross-border data flows, we use data from TeleGeography, a telecom research service. Our inclusion of capital intensity reflects a forward-looking perspective that companies will increasingly incorporate the Internet of Things into their plants and equipment, making them more vulnerable to cyberattacks.

— **Heat stress.** For heat stress, we look at the labor intensity of different value chains, how much work is done outdoors or with exposure to extreme temperatures required (based on O*Net and US Bureau of Labor Statistics data), and how much of the value chain exists in places that are highly exposed to rising temperatures (based on workability indicators in MGI's prior research on climate risk).[133]

— **Acute flooding events.** For flood risk, we consider how much of the value chain exists in geographies with high flood vulnerability as reported by the World Resources Institute's 2030 average urban damage due to riverine flooding score.

— **Geophysical natural disasters.** This reflects the extent of a value chain's geographic footprint in geographies with a history of more frequent earthquakes and tsunamis as reported by the INFORM database. We also consider each industry's capital intensity.

— **Trade disputes.** This reflects each value chain's trade intensity relative to its output and its product complexity (as reported by the Observatory of Economic Complexity). The latter is used as a proxy for substitutability. These choices reflect the assumption that trade disputes, which historically occurred in labor-intensive sectors such as agriculture, now seem to be shifting into more complex value chains such as electronics and pharmaceuticals as countries seek to minimize their dependence on imports and enhance national security. The product complexity index is based on the ubiquity of the product and the diversity of other products produced by the producing country; that is, products that are produced by comparatively few countries that produce diverse goods will score as higher complexity.

It is important to note that our assessment of exposure to each of these shocks is based on each value chain's physical footprint today; we make no assumption about how it might shift in the future. It does not reflect the vulnerabilities within individual companies or broader value chains, such as the propensity of companies in that industry to hold little inventory or the relative financial strength of industry players. Nor does it consider any measures

[132] See the following McKinsey Global Institute reports: *Digital America: A tale of the haves and have-mores,* December 2015; *Digital Europe: Realizing the continent's potential,* June 2016; and *Digital China: Powering the economy to global competitiveness,* December 2017.
[133] *Climate risk and response: Physical hazards and socioeconomic impacts,* McKinsey Global Institute, January 2020.

that companies within the value chain may or may not have taken to inoculate themselves against risk. It also excludes views on the quality of infrastructure or emergency services in the nations where they are sited.

We use the value of exports as the basis for its geographic weighting, although we acknowledge that value does not always correspond with the criticality of a component. For instance, while active pharmaceutical ingredients account for relatively little of the value of all final pharmaceutical exports, the latter cannot be produced without the former. This implies that our assessment of a pharmaceutical value chain's exposure may understate its susceptibility to disruptions since the production of active pharmaceutical ingredients and other lower-cost, foundational inputs are concentrated in China and India.

Calculating the financial loss that an individual company could sustain in a prolonged disruption

To understand the financial impact of shocks on companies in different industries, we undertook an extensive modeling exercise. To begin, we created synthetic companies in each industry, basing their characteristics on averages from three years of financial statements from the 25 largest companies, based on listings in the MSCI World Index for each sector. We then put these hypothetical companies through a two-scenario stress test.

The first scenario assumes a 100-day disruption to production, but distribution and sales are still possible to the extent that companies have finished or semifinished inventory on hand. The second scenario assumes the same production shutdown but adds disruption to distribution channels as well, so that companies cannot earn revenue by tapping safety stock. Revenue at risk and inventory assumptions were derived from a panel survey of industry experts as well as actual company financials.

In both scenarios, our model assumes no property damage, no ramp-up time after the shutdown period concludes, no seasonality in sales, and a decline in demand equivalent to 20 percent of the worst revenue hit the particular industry has experienced over the past 20 years. We assume the shock puts 50 percent of revenue at risk and that variable costs are 50 percent of the costs of goods sold (fixed costs being the residual and other line items such as sales and general and administrative expenses). We assume a recovery of 25 percent of sales lost during the disruption period during the remainder of the fiscal year. Inventory rebuilding to pre-shock levels is assumed to take place over a three-year period, stretching the cash flow impact.

The model's mechanics affect income, cash flow, and balance sheet statements.
The mechanics of the model begin with revenue. Revenue impact is derived by calculating the total length of the shock net of days of safety stock (under the first scenario, in which distribution remains possible). Days of lost revenue are multiplied by the value of revenue at risk per day; the total lost revenue figure is grossed down given the assumption that some sales are recovered later in the year. After the decline in revenue, the cost of goods sold declines on the assumption that half of those costs are variable. Other expenses, such as administration and research and development costs, do not decline as revenue falls.

Changes in cash flow are based on the change in EBITDA; changes in cash items, such as rebuilding finished goods inventory; changes in taxes due to decreased earnings; interest; and changes in non-cash working capital. The latter is based on non-cash changes in current assets minus changes in current liabilities. Changes in non-cash current assets is based on changes in account receivables, which decline proportionately with revenues) and changes in inventory (which declines proportionately with cost of goods sold). Changes in current liabilities are based on account payables, which decline proportionately with account receivables. The ending cash balance is calculated as the beginning cash balance minus free cash flow. It assumes no changes in dividend payouts or debt profile.

We then combine the expected frequency of value chain disruptions of different lengths with the financial impact experienced by companies in different industries to calculate expected losses over a ten-year period from supply chain shocks. The net present value of expected losses is calculated by aggregating the cash value of expected shocks over a decade. This uses the average cash impact from variations of both scenarios, multiplied by a constant probability of the event occurring in a given year (based on an average of expert input for several industries). The expected cash impact is discounted based on each industry's weighted average cost of capital.[134]

Real examples allowed us to back-test the model. For example, we looked at the 40-day shutdown caused by a labor dispute at General Motors in 2019, which cost approximately $4 billion during the fiscal year.[135] We modeled a similar 40-day disruption with one-third of revenue at risk due to disruption (consistent with General Motors's experience) and found that our financial model produced a result consistent with the automaker's actual experience.

As with any model, ours has important limitations. First, the stress test makes no assumptions about a company's relative vulnerability beyond the financial and inventory metrics used as inputs to the model. Second, the model does not consider levers that companies might deploy to mitigate the impact of a disruption, such as reducing overhead costs. Third, we assume that a company will continue as a going concern and do not model second-order financial effects such as the breach of covenants or inability to raise capital.

Comparing financial outcomes for companies with different levels of preparedness

To illustrate the costs and returns associated with enhanced resilience, we construct models of two hypothetical firms: PreparedCo and UnpreparedCo. The two companies take opposite approaches to dual sourcing, inventory levels, and more comprehensive insurance coverage.

Apart from the use of these mitigation levers and assumptions regarding property damage, the mechanics of the model used for this analysis are the same as that for the first scenario described above. We assume production is disrupted but companies can continue selling existing finished and semifinished goods until their inventory is exhausted. However, while the analysis described above simulated a 100-day shock, this analysis assumes a 50-day shutdown.

The underlying financials used for the model are based on the automotive industry, but similar outcomes would be observed regardless of sector. We assume that only a portion of each company's revenue is at risk due to the disruption; that is, we do not assume that a single site is responsible for all of a company's production, which is consistent with the automotive industry in reality. Our assumption for the value of property damage is based on the industry's property, plant, and equipment, and proportional to the revenue at risk.

The three mitigation levers we model are: insurance coverage on the property that is damaged; PreparedCo holding three times more inventory than UnpreparedCo; and PreparedCo splitting production across two sites, one of which is unaffected by the shock and able to increase its output by 25 percent. We account for the cost of these decisions by assuming that PreparedCo has roughly 5 percent lower EBITDA going into the event (modeled in the form of higher costs of goods sold and a line item for insurance coverage based on average rates for property insurance).

When the shock hits, PreparedCo has more inventory on hand to continue selling goods for longer. Increased output from its twin plant further reduces the impact of unfulfilled sales. From a cash flow perspective, PreparedCo will experience a smaller drop attributable to

[134] The assumptions for each industry are the following percentages: aerospace, 8.6; automotive, 8.7; chemicals, 8.5; computers and electronics, 10.4; electrical equipment, 9.7; food and beverage, 7.7; medical equipment, 8.1; mining, 7.4; petroleum products, 8.5; pharmaceuticals, 7.7; textiles and apparel, 8.8; glass, cement, and ceramics, 8.6; and mechanical equipment, 8.8.

[135] Michael Wayland, "UAW strike cost GM up to $4 billion for 2019, substantially higher than estimated," CNBC, October 29, 2019.

operations. Since we assume its damaged property is fully insured, it does not have the same need to deploy cash for reconstruction that UnpreparedCo experiences.

These mitigation levers are not exhaustive, nor are they necessarily the most appropriate for every industry. They were selected for their broad applicability and clearly translatable model mechanics. Alternative mitigation levers might include investment in organizational effectiveness and redundancies in transportation and logistics. If the former were used, the model might assume slightly higher costs of goods sold in return for fewer days of downtime for PreparedCo. Similarly, if we were to model transportation and logistics impact, we might assume that PreparedCo can begin selling down its safety stock instantaneously, whereas UnpreparedCo would experience a delay of several days before it could begin selling, amplifying its cash flow issues.

Estimating the share of global trade that could move to new geographies

This analysis estimates the extent to which value chains could move to different countries due to a combination of economic and noneconomic factors in the next five years. We emphasize that this is not a forecast of what *will* move.

We consider eight economic factors that could influence the propensity of a value chain to shift:

— **Shifts already unfolding.** Value chains in which top exporting nations have recently experienced higher change (in absolute terms) of market share are considered more likely to continue doing so in the future. Data on market share is based on the top three exporting nations from 2015–18, reported in absolute value of percentage points, and sourced from UN Comtrade.

— **Capital intensity and economies of scale.** Highly capital-intensive value chains are harder to move for the simple reason that they represent hundreds of billions of fixed investments. These industries have strong economies of scale, making them more costly to shift. Capital intensity is based on US Bureau of Economic Analysis data as a proxy for global innovations value chains (those producing the most intricate and knowledge-intensive goods), and the World Input-Output Database, which defines the metric as the amount of capital compensation as a share of gross output, for all other industries. In cases where WIOD does not report at a disaggregated level, we used data on the value of property, plant, and equipment relative to revenue from the US Federal Reserve Bank of St. Louis as a directional guide for disaggregation.

— **Knowledge intensity and specialized supplier ecosystems.** Value chains with high knowledge intensity tend to have specialized ecosystems that have developed in specific locations, with unique suppliers and specialized talent. Deciding to move production outside of this ecosystem to a novel location is costly. Knowledge intensity is defined as the share of labor with a tertiary education, using data from the US Bureau of Labor Statistics and MGI's own LaborCube as a proxy for global industries.

— **Access to natural resources.** Resource-intensive value chains (agriculture, mining, energy, wood products, and basic metals) are relatively fixed based on geology and the environment. This makes them very difficult to shift in the short or medium term, although in the long run, new resource discoveries and technologies can alter them.

— **Demand growth.** One of the most important determinants of where multinational companies locate production is access to consumer markets. Industries may reconfigure production in geographies experiencing higher rates of economic growth to serve these markets more efficiently.

— **Product complexity and substitutability of inputs.** Some highly complex products depend on inputs made by only one or two suppliers in the world. This severely reduces possibilities for moving production or sourcing. We use the product complexity index from the Observatory of Economic Complexity, which measures whether a product is produced in a few locations or many, as a proxy for the capabilities required to produce that product.[136] More complex products require a greater level of capabilities to produce and are more likely to be concentrated in a smaller number of countries with a relative comparative advantage.

— **Regionalization of the value chain.** Over the past decade, production networks have become more contained within distinct regions (as opposed to reliant on long-haul trade). This trend has more room to continue playing out in value chains that still have comparatively low levels of intraregional trade today as firms seek to shorten transportation times and production cycles. To determine the share of intraregional trade, we use UN Comtrade figures for 2018, looking at the share of imports into any region from outside the importing region relative to total trade in the value chain.

— **Trade intensity.** Value chains that are not highly traded (that is, with predominantly local production and consumption) are less likely to shift. This may be due to the weight or perishability of the product. Shifts in these value chains will largely be based on consumer demand. Trade intensity is based on the World Input-Output Database.

Value chains that score higher on propensity to shift across most of these individual factors will consequently have a higher overall score.

In addition to considering industry dynamics, we separately consider noneconomic factors that could cause some production to move. We base this assessment on expert interviews, considering three factors:

— **National security.** The extent to which experts believe that countries may use national security justifications to induce or mandate domestic production.

— **National competitiveness.** The extent to which experts believe that countries may prioritize certain industries in their economic development strategies and seek to increase local production.

— **Self-sufficiency.** The extent to which experts believe that countries are concerned with self-sufficiency in some products and may take steps to induce or mandate local production. As an example, value chains such as pharmaceuticals may shift above and beyond their economic rationale if countries seek to develop domestic production capabilities in response to their experience with COVID.

In reviewing these noneconomic factors, we make no assessment of the merits of domestic production in a given country. Nor do we assess the instruments or costs involved in creating these outcomes (which may include subsidies, public investment, quotas, tariffs, regulatory changes, and other measures).

We arrive at our low-end estimates by discounting the value of extraregional trade (i.e., all imports outside the region of the importing country) in a value chain by the average of the economic and noneconomic scores. We come to the high-end estimate by discounting the value of extraregional trade by the maximum of the economic or noneconomic score for each value chain.

[136] Jesus Felipe et al., "Product complexity and economic development," *Structural Change and Economic Dynamics,* March 2012, Volume 23, Issue 1, pp. 36–68.

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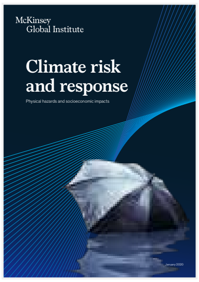

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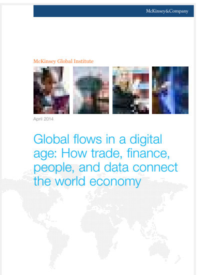
This report discusses how the relationship between China and the rest of the world is changing, and a great deal of value could be at stake, depending on whether there is more or less engagement. Businesses will need to adjust to the uncertainty ahead.



Global flows in a digital age: How trade, finance, people, and data connect the world economy (April 2014)

The movement of goods and services, people, and finance has reached previously unimagined levels. Global flows are creating new degrees of connectedness among economies—and playing an ever-larger role in determining the fate of nations, companies, and individuals.

Jobs lost, jobs gained: Workforce transitions in a time of automation (December 2017)

This report explains that as many as 375 million workers around the world may need to switch occupational categories and learn new skills. Winner of the Gluck Knowledge & Capability Award 2018 in the category "Best Published Perspective".

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