

Building a more competitive US manufacturing sector

Discussion paper

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Summary of findings

The COVID-19 pandemic has underscored manufacturing's role in providing products that are critical to health, safety, national security, and the continuity of multiple industries. It has also revealed the extent to which global supply chains are exposed to shocks and disruptions. All of this has occurred at a moment when new technologies, process innovations, input trends, and demand patterns are reshaping manufacturing worldwide, creating opportunities in many cases.

These events have deepened the urgency for the United States to build on an agenda that recognizes the importance of domestic manufacturing for a strong economy and national resilience, both today and in the future. But it will be important to pursue this agenda with a clear view of global competition, since many countries, including China, are continuing to expand their capabilities and compete on dimensions beyond labor costs.

Drawing on MGI's years of research on all aspects of manufacturing, including supply chains, global trade, productivity, growth, and technology, this paper focuses on the industries that can help the United States meet its economic and resilience goals.¹ It examines the microeconomic factors and competitive dynamics associated with key manufacturing activities and outlines the challenges that a competitiveness strategy would need to address. Our analysis indicates that revitalizing growth and competitiveness in 16 key manufacturing industries could boost the sector's annual GDP by more than 15 percent over baseline forecasts and add up to 1.5 million jobs both directly and indirectly.

Our key findings include the following.

- **A healthy manufacturing sector is vital for the nation's economic health and resilience.**² In the United States, manufacturing accounts for \$2.3 trillion of GDP, employs 12 million people, and supports hundreds of local economies. Although it represents just 11 percent of US GDP and 8 percent of direct employment, it drives 20 percent of the nation's capital investment, 30 percent of productivity growth, 60 percent of exports, and 70 percent of business R&D. Its spillover effects generate even broader economic activity and employment in related sectors, including some service sectors. Many manufactured goods are important to other industries, infrastructure systems, national defense, public health, or emergency preparedness. All of these attributes make manufacturing uniquely positioned to help the United States meet four important goals: productivity and economic growth; jobs and incomes for workers and communities; innovation and competitiveness; and national resilience.
- **Sixteen manufacturing industries stand out for their economic and strategic contributions.** Starting from a list of 30 manufacturing industries, we identify 16 that can advance at least one (and typically more than one) of the four goals listed above. The industries with strong growth prospects include semiconductors, medical devices, communications equipment, and electronics; industries that drive productivity include communications equipment, autos and parts, and precision tools. The industries with the greatest potential to support jobs and incomes for workers and communities are autos and parts, metals, and machinery; collectively, they employ 3.4 million workers and involve

¹ See the following McKinsey Global Institute reports: *Risk, resilience, and rebalancing in global value chains*, August 2020; *Making it in America: Revitalizing US manufacturing*, November 2017; *Globalization in transition: The future of trade and global value chains*, January 2019; *Playing to win: The new global competition for corporate profits*, September 2015; and *Manufacturing the future: The next era of global growth and innovation*, November 2012. See also *Global lighthouse network: Reimagining operations for growth*, World Economic Forum and McKinsey & Company, March 2021.

² We rely on the NAICS definition of manufacturing industries as establishments engaged in production activity of both finished and intermediate goods. For some analyses, we expand the definition of manufacturing to related activities such as scientific R&D services, computer systems design, and wholesale trade to consider the profits and wages of factory-less goods producers.

75,000 suppliers. Pharmaceuticals, electronics, semiconductors, and medical devices have high intensities of R&D spending, which underpins innovation and competitiveness. All 16 industries and their supply chains are important to national security, resilience, or emergency preparedness. If these industries become more competitive, the direct and indirect effects could boost annual GDP by \$275 billion to \$460 billion over baseline forecasts, while adding up to 1.5 million jobs. The multiplier effect would be felt across a far wider and more diverse geographic area than an equivalent GDP gain in tech or finance. Renewing the capital stock in these industries could get billions of dollars of investment flowing, setting off a virtuous cycle of increased economic activity in communities that sorely need it.

— **Amplifying the contributions of these industries starts with regaining lost ground.**

Although absolute output has grown, the past two decades have been marked by declines in the US shares of global manufacturing GDP and gross sales. In real value-added terms, growth has slowed dramatically over the past three business cycles, from 4.9 percent in the 1990s to 1.4 percent in each of the last two decades—and much of that recent growth has been driven by design, services, and software activities rather than actual production. Today there are roughly 25 percent fewer US manufacturing firms and plants than there were in 1997, reflecting not only closures but also fewer manufacturing startups. From 1999 to 2009, 5.8 million manufacturing jobs were lost, compared to 1.3 million added from 2010 to 2019. Although US shares of global manufacturing GDP, output, and exports all stabilized during this decade, the US trade deficit in manufactured goods more than doubled, reaching \$833 billion. Increased import dependence has left some key US manufacturing supply chains exposed to greater global risks.³

— **Beneath the industry view, it is also important to apply a new lens to competition dynamics in key manufacturing activities.**

We see four major activity types in manufacturing, each with distinct factor inputs, operational characteristics, investment profiles, personnel mix, and competitive dynamics.⁴ A given industry (or even an individual manufacturing company) may contain a mix of these activities, and that mix may evolve over time. First, scale-based and standardized activities (exemplified by auto parts and metal foundries) involve large investments in physical capital, high plant utilization, and standardization of parts and processes; they may have long supply chains that extend economic impact over a wide area. Second, learning-curve activities (seen in semiconductor fabs and the production of lithium-ion batteries) invest time, capital, and engineering to achieve exponential process improvements. Each successive product generation drives productivity gains. Third, R&D- and design-driven activities (such as the development of new pharmaceutical biologics, or the design of next-generation digital devices) draw on large investments in research, intellectual property, design, software, and other intangibles to create differentiated and market-leading products, although their actual production is often outsourced. Finally, flexible and customizable activities (seen in aerospace parts and medical devices) use increasingly digital production technologies to reduce the scale necessary to be profitable, making it possible to produce smaller lot sizes. This paves the way for business models built around customization, distributed production, rapid order fulfillment, and after-sales services.

— **US performance has been mixed across these activity types.** Over the past 25 years, the US share of global manufacturing GDP in R&D- and design-based activity rose by four percentage points. However, the nation has lost six percentage points of its global share in scale-based activity, a trend that has widened the trade deficit and hollowed out some domestic industries. In learning-curve activities, the United States excels at conceiving new process innovations but struggles to scale them up as broadly as some other countries; its share of global GDP in this segment has fallen by 11 percentage points. The semiconductor industry is a microcosm of these trends. The United States is

³ For more on this topic, see *Risk, resilience, and rebalancing in global value chains*, McKinsey Global Institute, August 2020.

⁴ See the main body of this report as well as the technical appendix for more detailed definitions of these archetypes as well as the occupational mix and other metrics used to distinguish how industries fit within them.

a world leader in chip design but has fallen behind on producing the next generation of seven- and five-nanometer chips; its share of global production capacity has fallen from 37 percent in 1990 to 10 percent today. The US share of flexible activity, too, is down by four percentage points.

- **Investor expectations and the relative costs of capital have added to the challenge at a time when manufacturing is under economic pressure worldwide.** Simply put, US manufacturing companies are expected to produce higher returns on capital than their competitors in the OECD and China. The largest have managed to do so, but often through cost cutting that has depressed capital investment and wage growth, squeezed suppliers, or shifted production to lower-cost areas. In scale-based activities, large US manufacturers average returns of 12 to 14 percent, versus 7 to 9 percent for European companies and 5 to 7 percent for Asian counterparts. R&D- and design-based activities are more profitable overall, which has led US companies to gravitate to this part of the value chain and offshore some less profitable activities. Although demand continues to rise, the sector is under pressure worldwide, with the average profit for a dollar of capital investment in manufacturing falling by 80 percent over the past two decades. In this environment, even small differences in currency valuations, compliance costs, or input costs can make or break a manufacturer—and most of these trends have not favored the United States. Some scale-based and learning-curve activities (such as production of medical PPE, rare earth metal processing, electrical equipment manufacturing, consumer electronics assembly, and semiconductor fabrication) struggle to be economically viable in the United States; a dollar of capital in these industries may return only 70 to 80 cents.
- **Despite these challenges, the United States has opportunities to improve its competitiveness.** Recent crises have highlighted the importance of shoring up US manufacturing, and several factors could make this goal reachable. Labor costs have been equalizing over time. The United States matches OECD peers such as Japan and Germany in productivity-adjusted labor costs, while Chinese wages are catching up. Similarly, a decline in energy costs between 2008 and 2011 brought the United States closer to cost parity. Technological advances and changing industry structures are also creating opportunities.⁵ Industry 4.0 technologies, for example, can raise productivity by up to 40 percent and shift some scale-based activity to flexible production. As US manufacturers reassess supply-chain resilience and focus on speed to market, there is room to increase domestic sourcing. Peer countries tend to meet 80 to 90 percent of domestic demand with regional production, but only 70 percent of US domestic demand is met with locally produced goods. Electric vehicles are already spurring learning-curve activities and their corresponding effects, as well as new supply chains; the United States cannot afford to miss out on this type of growth market.
- **An effective manufacturing strategy should reflect the competitive realities for companies engaged in the activity types described above.** An integrated plan with a long-term outlook can provide the certainty businesses require to invest. It would need to address several major issues, starting with capital investment. Public spending, or other ways to aggregate investment, may be needed where returns are not attractive in the near term. Mechanisms to stimulate or guarantee demand are an option for jump-starting or scaling up activities. Second, the United States needs more specialized talent such as process engineers, production technicians, and industrial operations managers. Third, it will take improved productivity and know-how for US companies to catch up with global leaders in technology adoption and process improvements. Fourth, US industries need healthy domestic supply chains to innovate with partners close at hand and reduce exposure to complex and growing global risks.
- **Investment and talent issues will require responses tailored to the challenges inherent in each activity type.** In scale-based manufacturing, we estimate capital investment needs of \$15 billion to \$25 billion annually over the next decade to upgrade

⁵ *Globalization in transition: The future of trade and value chains*, McKinsey Global Institute, January 2019.

aging plants and equipment with Industry 4.0 technologies—and capital needs to flow to some 120,000 small and medium-size enterprises. A mechanism such as a national industrial finance corporation is one potential option for handling this challenge. The investment needs differ in learning-curve activities. It can take \$20 billion to build a single new large-scale five-nanometer semiconductor fab, for instance, with the cost doubling every two to four years across succeeding product generations and a very long investment horizon. Other countries subsidize 40 to 50 percent of up-front costs for one or two large companies so that private capital can earn a return once concepts bear out. As for talent, the R&D- and design-based activities that can boost future output growth and competitiveness require more scientists, product designers, and software developers. Learning-curve activities need specialized engineers, production technicians, and industrial operations managers, all continually building on their existing know-how and experience. Meanwhile, scale-based activity is becoming more digitized and automated, which calls for higher-level skills—and upgrading existing jobs to attract the next generation of workers, perhaps from other industrial sectors. Private companies should be able to shoulder their own workforce training, and they will be in a better position to do so once their underlying economic health improves.

- **The United States can benefit from examining the range of active approaches to industrial support taken by peer countries and adapting some ideas to its own context.** Germany's technical assistance program for small manufacturers, for instance, is far larger and better funded than the comparable US federal program. European and Asian manufacturers can access long-term capital through institutions like Germany's KfW and the Japan Finance Corporation, but nothing similar is available to US manufacturers. In some industries, foreign competitors are directly subsidized in ways that US manufacturers are not. In other countries, cross shareholdings between industrial OEMs, suppliers, and even banks tend to promote technology sharing and long-term financing; in the United States, OEM-supplier relationships remain more arms-length and transactional. The United States can adapt these and other examples from other countries as well as developing its own approaches.
- **To turn intentions into focused action, business leaders and policy makers will need to address key implementation questions.** One set of questions concerns investment. What mechanisms and vehicles can marshal sufficient capital and ensure that it flows to the activities and businesses that need it most? How should public spending figure into this agenda? Another set of questions focuses on ensuring that investment leads to better outcomes. Could demand guarantees and public procurement accelerate scale and learning-curve effects? What role could corporate governance play? A third major area for debate is whether the United States is prepared to subsidize production of some critical goods if they do not produce returns for private investors. Another set of questions relates to jobs and the workforce. How can the United States quickly address the need for more specialized high-skill talent in roles that require years of training—particularly as a generation of senior technical experts approaches retirement? What targeted changes to education and immigration policy might be needed? Can US manufacturing raise wages and improve the quality of jobs? Finally, a set of questions revolves around how to revitalize the domestic supplier base. How much of this can large US manufacturers achieve on their own?

The stars could be aligning for US manufacturing. There is both public- and private-sector resolve to shore up a sector that has long been an important pillar of the economy. This momentum, combined with technology trends and market opportunities, offers a rare chance to change the existing trajectory—and give the United States a powerful driver for economic recovery, inclusive growth, resilience, and the capabilities of the future.

1. The imperative to make US manufacturing more competitive

When the COVID-19 pandemic disrupted global supply chains, it also delivered a stark reminder that manufacturing capabilities matter—not only to fuel the economy in good times but also to keep it functioning in moments of crisis.

Now, addressing the long-term health of the manufacturing sector can lend momentum to the economic recovery. Manufacturing remains an important force that drives growth, innovation, and employment. Its erosion in the United States over the past two decades has weakened the broader economy and created vulnerabilities. Perhaps most important, it has undermined the middle class and sapped the vitality of many small communities across the country.

US manufacturing has to be globally competitive to be sustainable, and that challenge is steeper than ever before.⁶ The past two decades have radically reshaped the competitive landscape—and the decade ahead will see further changes wrought by industry dynamics and the advent of new technologies, materials, processes, and business models.

The United States has an opportunity to change the narrative. We identify 16 manufacturing industries that could propel the US economy forward in the decade ahead, boosting GDP by \$275 billion to \$465 billion annually, adding up to 1.5 million direct and indirect jobs, and making the nation more productive, competitive, and resilient.

This chapter explores the current state of US manufacturing and its long-term challenges, as well as the industries that could lead a competitive comeback. Subsequent chapters examine the specific areas and issues that need to be addressed and detail how a new approach could further the nation's economic and security goals.

Manufacturing capabilities matter—not only to fuel the economy in good times but also to keep it functioning in moments of crisis.

⁶ Competitiveness can be defined as the degree to which a nation can, under free and fair market conditions, produce goods and services that meet the test of international markets while at the same time maintaining or expanding the real incomes of its citizens.

US manufacturing makes outsized economic contributions

A healthy manufacturing sector is critical for inclusive growth and competitiveness.⁷ In the United States, manufacturing accounts for \$2.3 trillion of GDP, employs 12 million people, and is the main economic activity in hundreds of counties. These GDP and job gains, along with strong multiplier effects, are spread over a wider geographic area than those associated with industries such as tech or finance. Manufacturing is a mobility ladder for workers and households all over the country.

Relative to their GDP and employment shares, manufacturing industries make disproportionate contributions to national competitiveness (Exhibit 1). Although the sector represents roughly 10 percent of US GDP and jobs, it drives 20 percent of the nation's capital investment, 30 percent of productivity growth, 60 percent of exports, and 70 percent of business R&D expenditure. Manufacturing remains the main economic engine and primary employer in some 500 counties across the nation.

Exhibit 1

Manufacturing creates outsized economic impact in the United States.

US manufacturing directly accounts for ...



8%

of the US workforce



11%

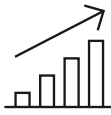
of US GDP

... but makes disproportionate contributions to the US economy



20%

of net capital stock



35%

of productivity growth



55%

of patents



Spurs demand in related industries that provide services and inputs



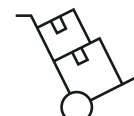
60%

of exports



70%

of R&D spending



Supports local economies and small suppliers across the country

Source: US Bureau of Economic Analysis; US Bureau of Labor Statistics; McKinsey Global Institute analysis

⁷ We rely on the NAICS definition of manufacturing industries as establishments engaged in production activity of both finished and intermediate goods. For some analyses, we expand the definition of manufacturing to related activities such as scientific R&D services, computer systems design, and wholesale trade to consider the profits and wages of factory-less goods producers.

Moreover, manufacturing has significant spillover effects that ripple through other parts of the economy. It spurs demand and employment in industries that supply inputs as well as related sectors such as logistics, wholesale, retail, and services. Academic research has consistently confirmed manufacturing's strong multiplier effect.⁸

In addition to more quantifiable indicators, manufacturing reflects the nation's technical prowess and innovative capacity—its ability to bring great ideas to life in physical form and continuously improve both products and the way they are made. The capabilities associated with making one type of product can translate to others, making manufacturing operations uniquely adaptable.⁹ The cluster of designers, suppliers, distributors, and financiers in an industrial ecosystem makes it easier to bring the next innovation to market quickly and at scale.¹⁰ US leadership in science and technology is closely linked to the nation's manufacturing base.

The sector supports an R&D ecosystem that routinely turns out new and improved products, services, materials, and technologies. Its contribution to productivity growth has held down the price of durable goods in the United States, giving households more spending power and putting better products within their reach. Over time, manufacturing innovation has made it possible to add new safety features in cars and trucks, more sophisticated functionality in smartphones, and real-time responsiveness in medical monitoring devices.

A strong manufacturing sector offers an economy a measure of stability. For largely service-based economies, it provides important diversification. It is also critical for national security and resilience. Having a weak industrial base leads to overreliance on imports, which increases vulnerability to exchange-rate fluctuations and supply-chain disruptions.¹¹

While this paper focuses on turning around the long-term erosion of US manufacturing, it is important to place those trends in a broader context. The United States is still the world's number-two manufacturing nation in the dollar value of sales, GDP, and exports. It remains an attractive destination for foreign investment. In fact, it has a more diverse sector than most peer economies, with a large presence in industries ranging from aerospace to petrochemicals to food processing. The massive US market is an asset, since 75 to 80 percent of manufacturing value added globally is captured close to the end market. The nation has a vibrant ecosystem for innovation as well as deep, flexible capital and labor markets. While US manufacturing has been through a rocky period, these advantages remain formidable—and they could form the basis for a new wave of growth.

⁸ See, for example, Enrico Moretti, "Local multipliers," *American Economic Review: Papers & Proceedings*, May 2010, Volume 100, Number 2; Josh Bivens, *Updated employment multipliers for the US economy*, Economic Policy Institute, January 2019; and Abbas Valadkhani, "Cross-country analysis of high employment-generating industries," *Applied Economics Letters*, 2005, Volume 12, Number 14.

⁹ César A. Hidalgo et al., "The product space conditions the development of nations," *Science*, July 2007, Volume 317, Issue 5837.

¹⁰ Suzanne Berger, *Making it in America*, MIT Press, 2013.

¹¹ Martin Neil Baily and Barry P. Bosworth, "US manufacturing: Understanding its past and its potential future," *Journal of Economic Perspectives*, winter 2014, Volume 28, Number 1.

US manufacturing has lost some of its competitive edge, with negative consequences for small suppliers, workers, and supply chain resilience

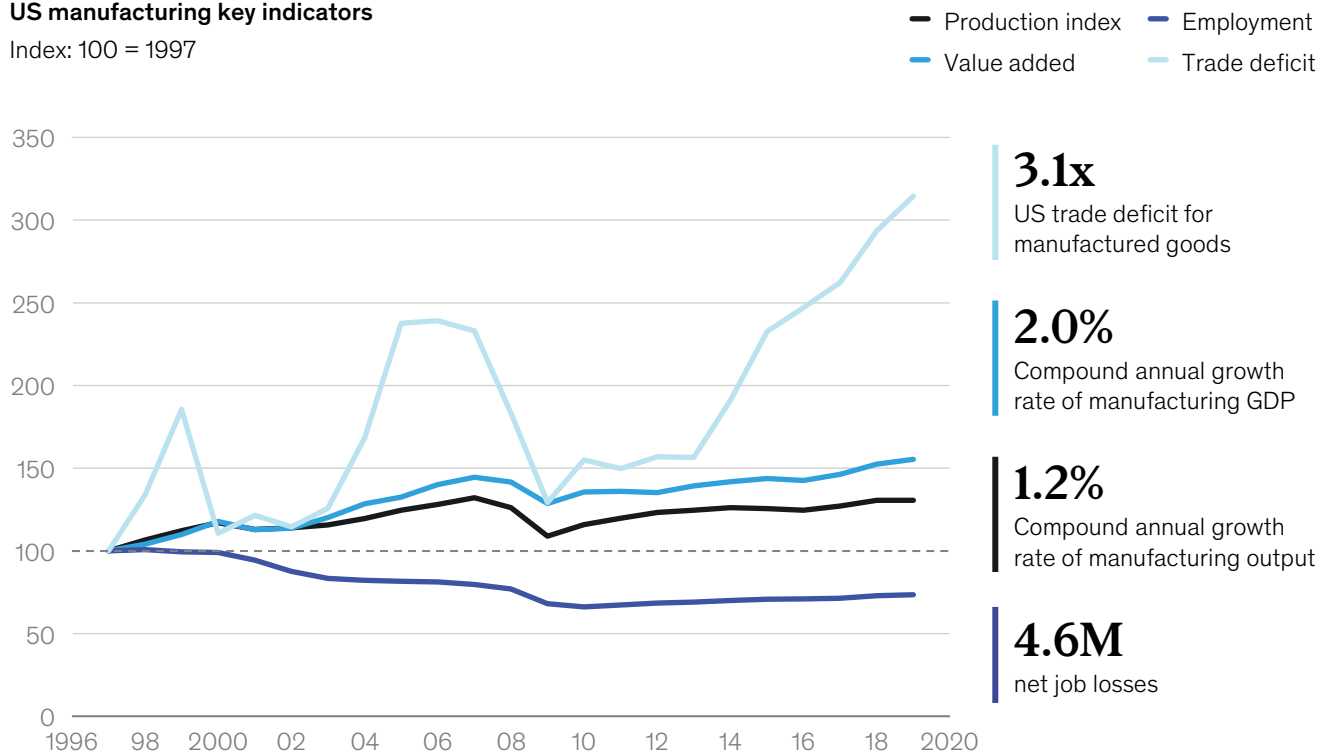
Although US manufacturing has continued to grow modestly in absolute output, the nation's share of global manufacturing fell from 25 percent in 1997 to 17 percent in 2019. Over the same period, US production grew by just 1.2 percent per year, as measured by the Federal Reserve's production index (Exhibit 2). Growth in real value added has slowed dramatically over the past three business cycles, from 4.9 percent in the 1990s to 1.4 percent in each of the last two decades—and much of that growth has been driven by design, services, and software activities rather than actual production.

Exhibit 2

US manufacturing output and value added have grown slowly since the late 1990s, while the trade deficit expanded and employment declined.

US manufacturing key indicators

Index: 100 = 1997



Source: IHS Markit (March 2021 forecast); US Bureau of Labor Statistics; US Federal Reserve; McKinsey Global Institute analysis

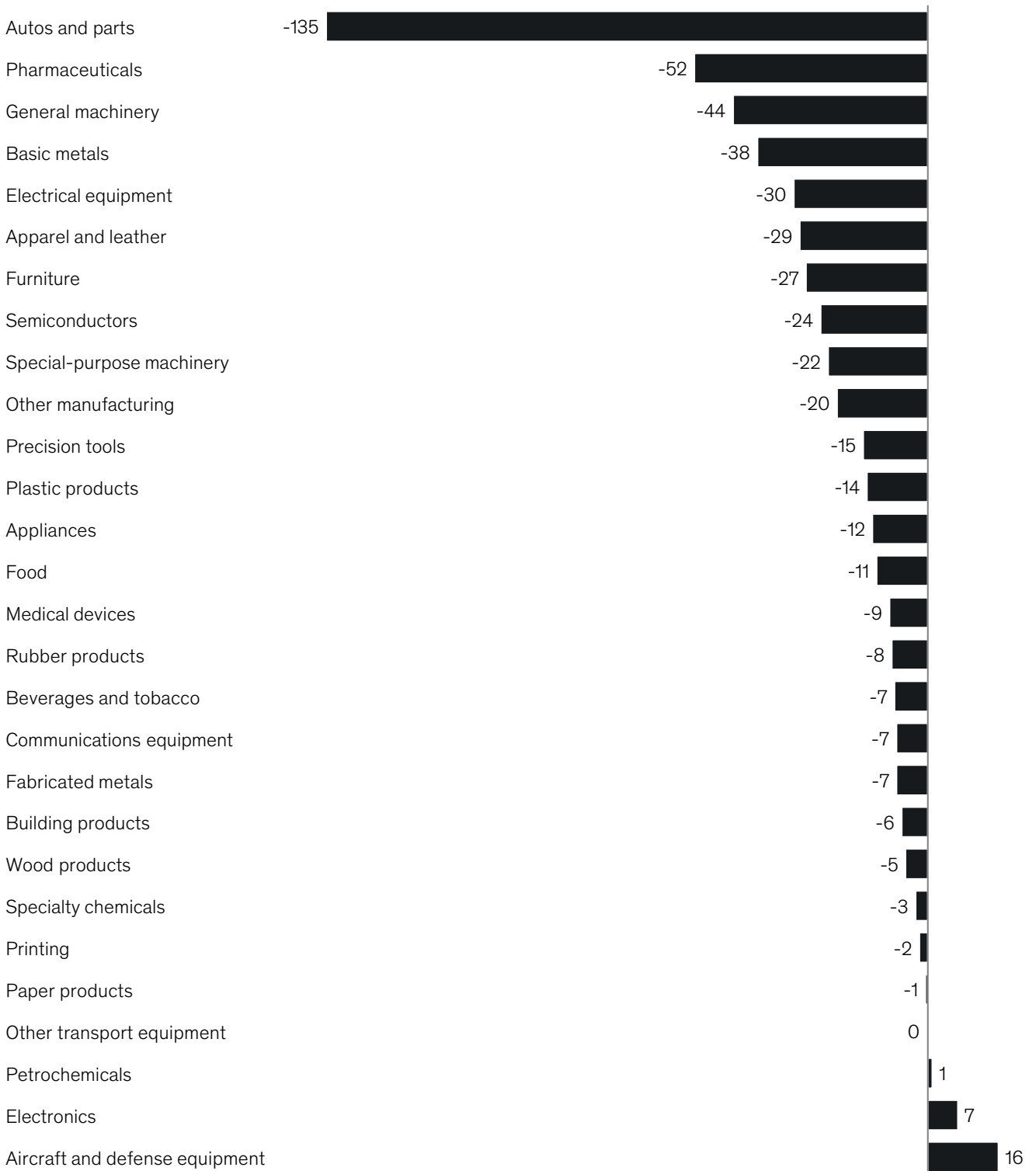
Although US shares of global manufacturing GDP, output, and exports all stabilized during the most recent decade, the trade deficit in manufactured goods has soared (Exhibit 3). From 2009 to 2019, it more than doubled, reaching \$833 billion. This represents an increase from 5 to 13 percent of total US consumption. One takeaway from these trends is that GDP growth is still attainable even as trade deficits grow. There is ongoing debate about how much emphasis to place on the deficit.¹² We highlight it here to show the relative position of the United States with regard to imports—and to highlight the nation's increased dependence on imports and its exposure to global supply-chain risks (see below for more on this issue).

¹² See, for example, Martin Feldstein, "Inconvenient truths about the US trade deficit," Project Syndicate, April 25, 2017; and James McBride and Andrew Chatzky, "The US trade deficit: How much does it matter?," Council on Foreign Relations, March 8, 2019.

Over the past decade, the US trade deficit in manufactured goods more than doubled.

Change in gross trade balance by industry, 2019 vs 2009

2019 \$ billion



\$505 billion

real deficit growth

Source: IHS Markit (March 2021 forecast); McKinsey Global Institute analysis

Multiple factors have contributed to the decline

It is important to take stock of why the US position eroded.¹³ Over the past three decades, the balance of global manufacturing has shifted in fundamental ways as a huge number of low-cost factories came online around the world, trade and investment flows grew, and capital became cheaper and more widely available. In industries such as metals, building materials, and machinery, the presence of giant emerging-market players has created overcapacity and commoditized production. These pressures are not unique to the United States (Exhibit 4). Incumbents in advanced economies have been forced to consider whether they want to maintain a presence in markets where revenue and margin growth are declining—and some have found that they cannot compete.¹⁴

Exhibit 4

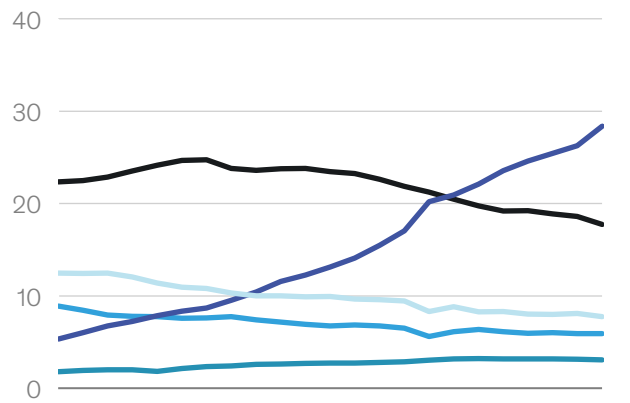
The US share of manufacturing GDP has declined gradually since the early 2000s, with varying timelines across industries.

Country shares of manufacturing GDP

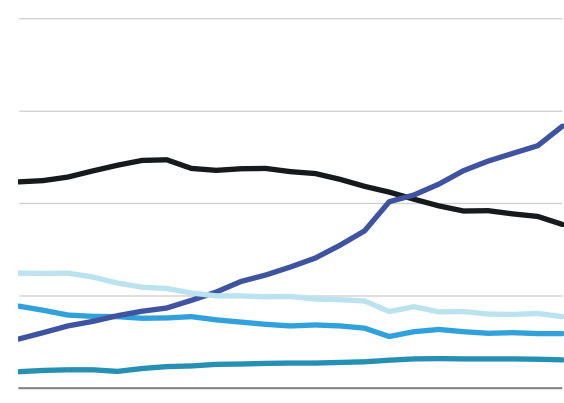
% of world GDP

— United States — Mainland China — South Korea
— Germany — Japan

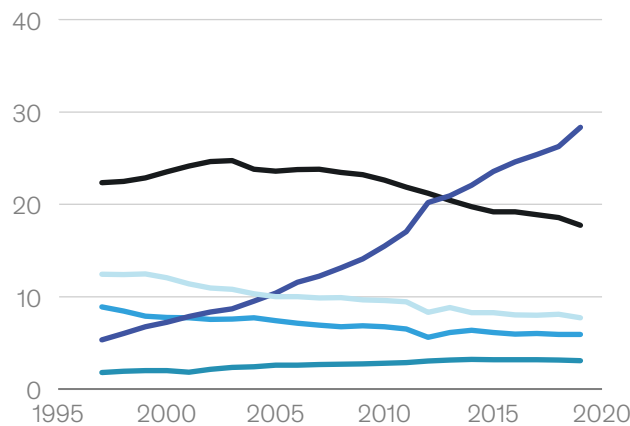
All manufacturing



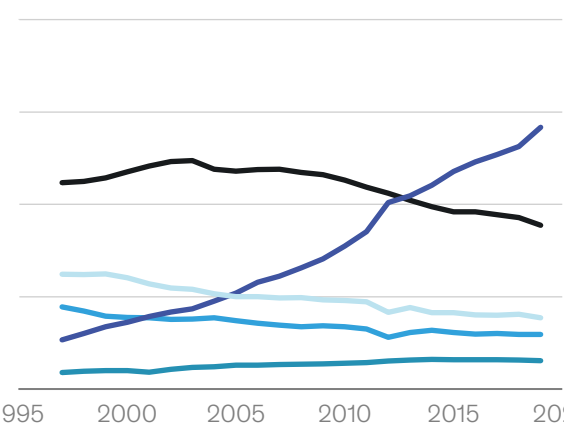
Semiconductors



Iron and steel



Motor vehicles



Source: IHS Markit (March 2021 forecast); McKinsey Global Institute analysis

¹³ The decline is part of an even longer structural shift in which manufacturing employment has been declining as a share of total nonfarm employment for more than 50 years. Furthermore, total nonfarm employment has been growing more slowly in the past 20 years than in previous periods.

¹⁴ See, for example, David H. Autor, David Dorn, and Gordon H. Hanson, *The China shock: Learning from labor market adjustment to large changes in trade*, NBER working paper number 21906, January 2016.

Intensifying global competition did not occur in a vacuum. In basic consumer goods, for instance, consolidation in the retail industry gave distributors and retailers stronger bargaining power over the supply chain. With consumers insisting on low prices, many retailers began sourcing from low-cost contract manufacturers in locations such as Mexico, China, Vietnam, and Bangladesh. In automotive, US consumers have developed a preference for imported cars. Persistently weak public and private capital investment dampened demand for machinery and equipment—a trend that in turn affected domestic suppliers of fabricated metal, rubber, and plastic products.

In this more competitive world, changes in relative costs or demand can have an amplified effect that causes permanent layoffs and plant shutdowns. The United States has been through a sequence of those events in recent decades. They include a sharp appreciation of the dollar in 1997–98, a spike in oil and metal prices in 2003–04, and the credit crunch that accompanied the 2008 financial crisis, depressing consumer and business demand for manufactured goods.

In some cases, the change in relative costs and its aftereffects can linger for years, as a look at currency trends confirms. Between 2003 and 2016, the US dollar remained 20 to 25 percent higher on average than its 1995 level in real terms versus the currencies of Germany, South Korea, and Sweden. It also averaged 30 percent higher than its 1995 level against Southeast Asian currencies, and 45 to 55 percent higher against the Taiwanese dollar and Japanese yen.¹⁵ These are all countries with persistent long-term trade surpluses versus the United States. A strong dollar does help US importers and consumers, and it can also help US manufacturers acquire assets and raw materials overseas. But an overvalued dollar can take a toll on domestic manufacturers' market share and profit share at home and abroad.¹⁶

American workers and small suppliers have been hit hardest

The United States lost some 5.8 million manufacturing jobs from 1999 to 2009.¹⁷ The next decade saw a return to modest employment growth with the addition of 1.3 million jobs, although the pandemic delivered a setback in 2020, erasing roughly 500,000 jobs.

Since the late 1990s, wages have stagnated, or even declined in real terms, in some struggling industries. More broadly, the erosion of US manufacturing has diminished prospects for the middle class, contributing two-thirds of the fall in labor's share of national income.¹⁸ One study found that a third of the country's manufacturing workers rely on food stamps or other government assistance.¹⁹

While large US-based multinationals have faced global competition, tighter margins, and shareholder pressures, most had the ability to respond by cutting costs in their supply chains, often by turning to cheaper imported components. From 1997 to 2016, foreign sourcing of the intermediate parts used in domestic car manufacturing rose from 10 to 15 percent.

These trends, which were mirrored in other industries (and other advanced economies), either squeezed smaller suppliers out altogether or forced them into relentless price competition. Our 2017 research analyzed firm-level financial results and found that since 1990, manufacturers with more than \$1 billion in assets had seen revenues grow by more than 2 percent annually, while small and medium-size manufacturers posted negative growth.²⁰ Smaller companies have also had negative growth in their investment in production plants and equipment, and are carrying a larger share of inventory risk.

¹⁵ US Department of Agriculture Economic Research Service data on real exchange rate. Note that the euro is estimated to be 10 to 20 percent too low to reflect Germany's fundamentals; see, for example, *2017 External sector report*, International Monetary Fund, July 2017.

¹⁶ Zeresh Mall et al., "Exchange rate exposure on the automotive industry: Evidence from USA and Japan," *Forman Journal of Economic Studies*, 2011, Volume 7; Simon Burru, Jessica Ghansiam, and Ceren Altincekic, *The effects of exchange rate fluctuations on Canada's automotive industry*, Automotive Policy Research Centre, March 2017.

¹⁷ There is ongoing debate about the extent to which these losses can be attributed to foreign competition and offshoring versus automation. See Daron Acemoglu and Pascual Restrepo, *Robots and jobs: Evidence from US labor markets*, NBER working paper number 23285, March 2017; and David H. Autor, David Dorn, and Gordon H. Hanson, *Untangling trade and technology: Evidence from local labor markets*, NBER working paper number 18938, April 2013.

¹⁸ *Making it in America: Revitalizing US manufacturing*, McKinsey Global Institute, November 2017.

¹⁹ Ken Jacobs et al., *Producing poverty: The public cost of low-wage production jobs in manufacturing*, UC Berkeley Center for Labor Research and Education, May 2016.

²⁰ *Making it in America: Revitalizing US manufacturing*, McKinsey Global Institute, November 2017.

Domestic manufacturing gaps have created vulnerabilities

Lengthy global supply chains are exposed to a wide range of disruptions, as we have analyzed in previous research (see Box 1, “Risk exposure across manufacturing value chains”).

The gaps created by the loss of domestic manufacturing have caused growing US concern in recent years.

A federal interagency task force led by the Department of Defense examined the erosion of domestic production capabilities in the subtiers of the defense supply chain in 2018.²¹ It specifically called out risks related to reliance on foreign suppliers from non-allied nations and sole-source suppliers; capacity-constrained markets; material shortages; potential gaps in US infrastructure; and product security. In basic metals manufacturing, for example, more than 1,100 establishments closed between 1999 and 2009—and today, the supply of some key products made by this industry is constrained. The report found only a single qualified source for upper, intermediate, and sump housing needed to provide heavy lift support to field expeditionary forces. It also flagged the fact that suppliers of cold-rolled aluminum plates face highly variable demand that affects their ability to make capital investments; this puts the supply of a key component needed in all modes of military transportation at risk.

Disruptions in the flow of goods can affect both public welfare and the operations of private-sector manufacturers that rely on global suppliers for key inputs. This manifested during the early months of the COVID-19 pandemic, when shortages of medical PPE, testing supplies, and ventilators worsened the crisis in the United States. Throughout 2020, disruptions snarled shipments of all manner of imported goods, and in 2021, a shortage of semiconductor chips caused shutdowns in the US auto industry when postpandemic demand was beginning to pick up.²²

These events drove home a clear message: the ability to make things domestically matters. Industry leaders, policy makers, and the public alike gained fresh resolve to make the United States better prepared and more self-sufficient. In February 2021, the Biden administration ordered an immediate review of vulnerabilities in the nation’s supply chains.²³

²¹ *Assessing and strengthening the manufacturing and defense industrial base and supply chain resiliency of the United States*, US Department of Defense, September 2018.

²² Jamie L. LaReau, “As chip shortage cripples auto production, Biden prepares to step in,” *Detroit Free Press*, February 24, 2021; and Bob Tita and Austen Hufford, “Consumer demand snaps back. Factories can’t keep up,” *Wall Street Journal*, February 22, 2021.

²³ “Securing America’s critical supply chains,” White House fact sheet, February 21, 2021.

Risk exposure across manufacturing value chains

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.

However, these choices sometimes led to unintended consequences. Intricate production networks were designed for efficiency, cost, and proximity to markets but not necessarily 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.

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, more 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.

Value chain risk can be thought of as what happens when these types of external shocks find vulnerabilities. In 2020, MGI research analyzed 23 industry value chains to assess their exposure to specific types of shocks. The resulting index (Exhibit 5) 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.

In addition to noting 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. Some have developed far more sophisticated and effective supply-chain management capabilities and preparedness plans than others. However, averaging across industries, MGI’s analysis found that large companies can expect disruptions to erase more than 40 percent of a year’s profits every decade, based on current probabilities. However, a single severe shock causing a 100-day disruption could wipe out an entire year’s earnings in some industries—and events of this magnitude can and do occur.


¹ *Eye of the storm*, “Earth’s 40 billion-dollar weather disasters of 2019: 4th most billion-dollar events on record,” *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.

Exhibit 5

Manufacturing industries, including those producing critical goods, are exposed to the risk of supply chain shocks.

Less exposed  More exposed

Rank of exposure (1 = most exposed)

| | | Rank of exposure (1 = most exposed) | | | | | | |
|--|---------------------------------------|-------------------------------------|------------------------|---------------------------------------|---------------------------------|--------------------------|-----------------------|----------------------------|
| | | Overall shock exposure | Pan-demic ¹ | Large-scale cyber-attack ² | Geo-physical event ³ | Heat stress ⁴ | Flooding ⁵ | Trade dispute ⁶ |
| Manufacturing (national resilience focus) | Communication equipment | 1 | 13 | 3 | 2 | 16 | 7 | 2 |
| | Other transportation equipment | 4 | 5 | 12 | 7 | 13 | 5 | 15 |
| | Computers and electronics | 6 | 15 | 5 | 4 | 14 | 14 | 9 |
| | Aerospace and defense equipment | 8 | 2 | 1 | 18 | 20 | 21 | 5 |
| | Semiconductors | 9 | 19 | 6 | 1 | 18 | 23 | 1 |
| | Specialty and petrochemicals | 11 | 16 | 4 | 6 | 19 | 16 | 8 |
| | Basic metals | 12 | 18 | 13 | 8 | 11 | 8 | 12 |
| | Autos and parts | 14 | 6 | 9 | 12 | 21 | 18 | 6 |
| | Electrical equipment | 16 | 17 | 11 | 9 | 15 | 15 | 10 |
| | General and special purpose machinery | 18 | 9 | 10 | 20 | 17 | 20 | 7 |
| | Pharmaceuticals | 19 | 23 | 2 | 17 | 23 | 19 | 4 |
| | Fabricated metal products | 21 | 14 | 18 | 19 | 6 | 17 | 15 |
| Medical devices | 23 | 22 | 8 | 22 | 22 | 22 | 3 | |
| Manufacturing (non-national resilience focus) | Apparel | 2 | 1 | 20 | 15 | 2 | 1 | 11 |
| | Textile | 7 | 7 | 22 | 11 | 3 | 2 | 21 |
| | Building products | 10 | 11 | 16 | 5 | 5 | 11 | 20 |
| | Furniture | 13 | 3 | 21 | 14 | 4 | 12 | 17 |
| | Rubber and plastic | 15 | 8 | 17 | 16 | 8 | 13 | 13 |
| | Food and beverage | 19 | 21 | 14 | 13 | 12 | 6 | 22 |
| Resource industries | Petroleum products | 3 | 4 | 7 | 10 | 7 | 10 | 18 |
| | Mining | 5 | 10 | 15 | 3 | 10 | 3 | 19 |
| | Agriculture | 17 | 20 | 19 | 23 | 1 | 4 | 14 |
| | 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

A more competitive manufacturing sector can make the United States more resilient and bolster the economy

Manufacturing will be a key determinant of whether the United States can meet the following “core four” goals well into the future.

- **Boosting productivity and economic growth:** Manufacturing has historically made outsized contributions to productivity and overall economic growth, and it can continue to do so in the future, supporting broader prosperity. As economies grow over time both at home and abroad, US manufacturers have an opportunity to meet the resulting demand—and potentially claim a bigger share of the global market than they do today. They also need to stake out positions in the next big product categories, from electric drivetrains to breakthrough medical devices.
- **Supporting jobs and incomes for workers and communities:** While manufacturing may not provide the kind of mass employment it once did, no other sector plays the same role in supporting middle-income jobs across the country, especially outside of the largest cities, both directly and indirectly in adjacent sectors. However, to be competitive, US factories will need to be more digitized, which has implications for the future of work.²⁴ Although there may be fewer workers on assembly lines, the manufacturing jobs of the future could be more technical in nature, with higher wages than the typical service-industry jobs that the US economy has been adding in great numbers. Modernizing existing plants and building new ones would also draw much-needed investment into local communities, creating geographically broad ripple effects in other industries such as construction, logistics, and sales.
- **Enhancing innovation and competitiveness:** Innovation and dynamism are critical to manufacturing success. Creating differentiated and compelling products enables companies to compete for revenue growth both domestically and around the world, given the tradable nature of manufacturing output. The United States excels in R&D and product design, but it cannot take that position for granted. Emerging economies are rapidly developing their own expertise and capabilities, which will enable them to compete in the most lucrative parts of industry value chains.
- **Ensuring national security and resilience:** As described earlier in this chapter, supply-chain disruptions have become more frequent and more severe in recent years. The risks are only growing more pronounced in light of climate change, cyberattacks, pandemics, geopolitical uncertainty, and trade disputes.²⁵ Resilience enables an economy to withstand various types of supply-chain shocks with minimal impact on public welfare and the operations of related industries that depend on key inputs. In general, supply chains that are heavily traded relative to their output are more exposed than those with lower trade intensity—and this applies to some industries that countries value for their economic value and strategic importance, such as communications equipment, computers and electronics, and semiconductors and components. Shifting to domestic production is one strategy (although not the only strategy) for securing adequate supplies of sensitive manufactured goods.

²⁴ See the McKinsey Global Institute’s ongoing body of research on this topic, including *The future of work after COVID-19*, February 2020; *The future of work in America: People and places, today and tomorrow*, July 2019; *Jobs lost, jobs gained: What the future of work will mean for jobs, skills, and wages*, November 2017; *Digital America: A tale of the haves and have-mores*, December 2015; and *Solving the productivity puzzle: The role of demand and the promise of digitization*, February 2018.

²⁵ For a more in-depth discussion of this topic, see *Risk, resilience, and rebalancing in global value chains*, McKinsey Global Institute, August 2020; and Thomas Y. Choi, Benjamin B. M. Shao, and Zhan Michael Shi, “Hidden suppliers can make or break your operations,” *Harvard Business Review*, May 2015.

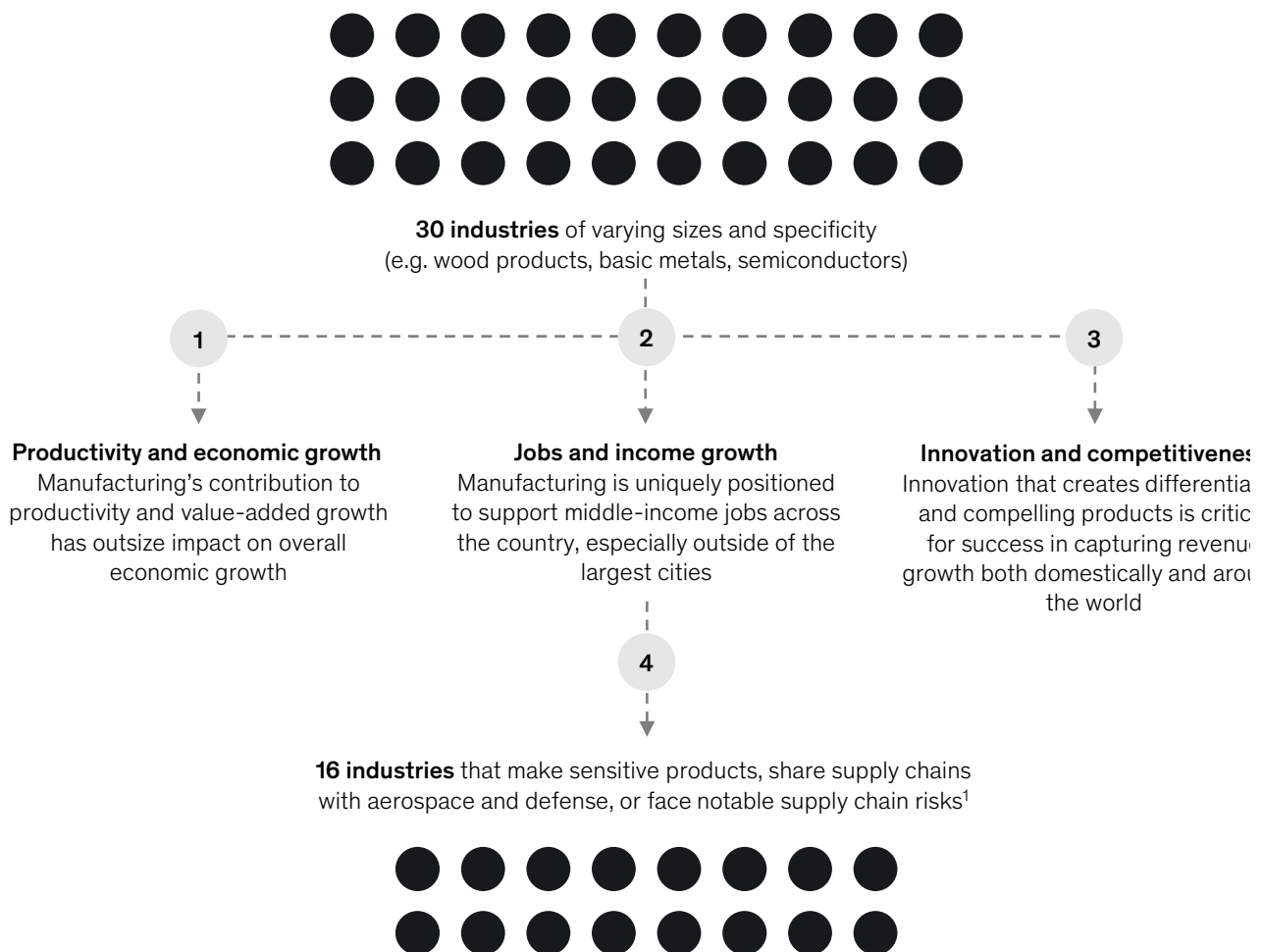
Sixteen manufacturing industries make significant contributions to these four goals

Manufacturing is uniquely positioned to help the United States meet the economic and resilience goals outlined above. But the sector is not homogenous. It encompasses a wide range of industries with varying inputs, costs, operational requirements, and technological sophistication.²⁶ Pharmaceutical manufacturing, for instance, looks nothing like the production of auto parts. Each industry has its own supply-chain structure and employment profile, and each has a unique economic impact.

After examining 30 manufacturing industries, we identify 16 that are critical to at least one (and, in most cases, more than one) of the four goals outlined above (Exhibit 6).²⁷ See the technical appendix for more details on these metrics and the selection process.

Exhibit 6

We filtered manufacturing industries to identify those with certain types of economic impact and strategic importance.



1. Defined based on the 2018 list of pilot program industries compiled by the US interagency Committee on Foreign Investment in the United States (CFIUS) and the 2020 list of critical technologies compiled by the US Commerce Department’s Bureau of Industry and Security (BIS). We mapped those technologies back to our industry definitions, which are largely based on NAICS codes. The criteria regarding supply chain risks stems from MGI’s research in *Risk, resilience, and rebalancing global value chains*.

Source: McKinsey Global Institute analysis

²⁶ We define industries using three- and four-digit NAICS codes. As noted at the beginning of this report, we use an expansive definition of manufacturing that includes computer systems design and services as well as scientific R&D services since these industries are important contributors to the sector and represent areas of US strength.

²⁷ We do not include food processing on the list of 16 priority industries despite its obvious importance to public well-being and its large employment base. Aside from some temporary shortages of specific products, the United States experienced no serious disruptions in food supply during the COVID-19 pandemic, indicating that the nation is already relatively resilient on this front. In addition, food processing is inherently regional in nature; it tends to be located close to both local supply and demand. We focus instead on industries in which US competitiveness has affected the location of production in the past or could do so in the future.

To identify industries that can support economic growth, we filter for those that have grown rapidly in recent years and have strong forecasts in the decade ahead. Semiconductors, medical devices, communications equipment, and electronics, for example, have experienced rapid global GDP growth of 6 to 11 percent annually, with further growth expected in the next decade. In addition, communications equipment, autos and parts, and precision tools stand out as having notable recent track records for productivity growth. These US industries could also benefit from trends in technology and industry structures.

Next, we screen for industries that are important generators of jobs and economic activity across a broad geographic footprint. In addition to looking for high labor intensity, we examine county-level GDP data to determine how many counties combine to generate three-quarters of the industry's US GDP. The results show that the top industries for job creation and community impact are autos and parts, metals, and machinery—all industries with extensive supply chains. Together, they directly employ 3.4 million workers and involve 75,000 small and medium-size suppliers across hundreds of counties. In fact, more than 70 percent of workers in the fabricated metals industry are employed by SMEs.

Next, we look for industries with the greatest potential to drive innovation and competitiveness. Those with the high intensities of R&D spending are pharmaceuticals, communications equipment, electronics, semiconductors, and medical devices. Manufacturers in pharmaceuticals and medical devices, for example, spend an average of 80 percent of their revenues on R&D and intangibles, more than double the share in machinery and equipment (Exhibit 7). These are industries with high value-added contributions and global product reach.

Finally, we look for industries with relevance to national security, emergency preparedness, or resilience, especially in light of the supply-chain vulnerabilities explored in our earlier research (see Box 1). All 16 industries on the final list fit these criteria.²⁸ Some produce goods that are directly related to defense, critical infrastructure systems, or public health. Others, like autos and parts as well as other transportation equipment, share more than 80 percent of their supply chains with sensitive industries.

²⁸ We consulted the lists of critical technologies compiled by the US government's interagency Committee on Foreign Investment in the United States and the US Commerce Department's Bureau of Industry and Security. We then mapped those technologies to our industry definitions, which are largely based on NAICS codes.

While all 16 manufacturing industries are relevant to national security and resilience, they contribute to the economy in different ways.

| Industry | GDP growth | | Jobs and economic health | | | | Future competitiveness | |
|--------------------------------|-------------------------------------|--|--------------------------|--------------|------------------------------------|-----------------------------|------------------------|----------------------------|
| | Historical GDP growth | Forecast GDP growth ¹ | Employment | Wages | Geographic GDP spread ² | SME employment ³ | R&D intensity | Productivity growth |
| | Global CAGR, ⁴ 1995–2019 | Expected global CAGR, ⁴ 2019–29 | Employees per \$M GDP | Share of GDP | Index to whole economy | Share of total employment | Share of GDP | CAGR, ⁴ 2009–19 |
| | | | | | | | | |
| Basic metals | 2.6% | 3.4% | 3.83 | 25.1% | 108.5% | 35.1% | 0.3% | 4.1% |
| Autos and parts | 3.8% | 1.0% | 5.15 | 30.4% | 80.2% | 22.4% | 3.6% | 8.4% |
| Fabricated metals | 1.7% | 1.6% | 6.85 | 37.7% | 159.4% | 70.6% | 0.6% | 1.1% |
| Specialty chemicals | 2.1% | 2.5% | 2.64 | 16.8% | 68.9% | 46.2% | 1.7% | -1.6% |
| Petrochemicals | 3.0% | 2.8% | 1.64 | 14.5% | 70.3% | 32.1% | 1.7% | -2.0% |
| General machinery | 3.3% | 2.6% | 5.15 | 33.9% | 121.2% | 45.2% | 3.5% | 0.5% |
| Special-purpose machinery | 2.6% | 2.4% | 5.46 | 34.1% | 137.5% | 51.8% | 3.5% | -0.3% |
| Electrical equipment | 4.0% | 3.6% | 5.84 | 35.2% | 111.6% | 47.0% | 3.3% | 1.1% |
| Medical devices | 6.9% | 3.1% | 4.25 | 29.7% | 62.5% | 38.1% | 17.3% | 0.4% |
| Semiconductors | 11.1% | 4.3% | 3.53 | 38.2% | 18.4% | 18.2% | 22.0% | 4.4% |
| Communication equipment | 6.3% | 4.2% | 4.51 | 39.6% | 27.6% | 31.1% | 22.0% | 14.3% |
| Precision tools | 5.0% | 2.7% | 4.12 | 35.6% | 35.5% | 26.2% | 10.5% | 5.8% |
| Electronics | 6.2% | 5.5% | 4.42 | 32.0% | 7.8% | 53.0% | 22.0% | 4.2% |
| Pharmaceuticals | 3.6% | 4.2% | 1.50 | 13.0% | 32.8% | 24.0% | 22.7% | -4.0% |
| Other transport equipment | 3.6% | 2.7% | 5.35 | 33.1% | 63.1% | 36.7% | 9.2% | 0.9% |
| Aircraft and defense equipment | 3.0% | 1.1% | 3.26 | 27.0% | 37.5% | 15.8% | 9.2% | 1.2% |

1. IHS Markit forecast, July 2020.

2. A measure of geographic dispersal of GDP; number greater than 100% indicates that the industry is more dispersed than the US economy on average, based on the number of countries required to comprise 75 percent of GDP.

3. Small and medium-size enterprises, defined as having fewer than 500 employees.

4. Compound annual growth rate.

Note: Data in these columns come from sources that use different industry classification systems. We have mapped these designations back to the industries listed here, as well as others that did not make our list of 16 focus manufacturing industries. The darkest shades in each column represent the greatest values across the full range of manufacturing industries, including those not among our 16 focus industries.

Source: US Department of Commerce Bureau of Industry and Security; CFIVS; IHS Markit (July 2020 forecast); US Bureau of Labor Statistics; US Census Bureau; McKinsey Global Institute analysis

Improving US manufacturing competitiveness is not a new goal. Will this time be different?

The 16 industries listed above could offer the United States a critical boost. But is there reason to believe they can ramp up growth and economic contributions?

A fresh sense of urgency could provide needed momentum. Policy makers are increasingly focused on the security and emergency preparedness dimensions of manufacturing. The same sorts of concerns are also percolating through the private sector. With a growing segment of the customer base looking for customized goods that can be delivered on a dime, US companies are realizing that localized production could serve those customers better while simultaneously reducing supply-chain risk.

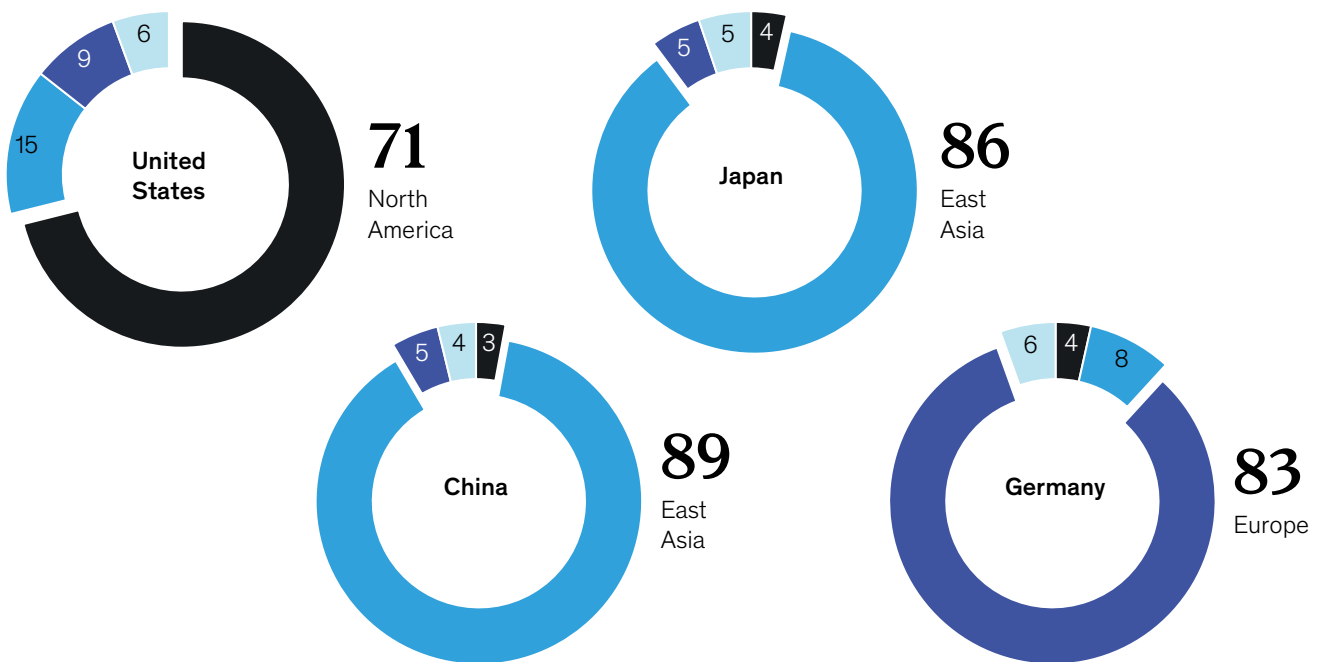
US manufacturing has room to make gains if the current focus on domestic sourcing is followed up with action. The United States meets just 71 percent of its final demand with domestic goods, a smaller share than in Germany, Japan, or China (Exhibit 8). Achieving parity on this front alone could add \$400 billion to US GDP, even before considering market opportunities in next-generation products such as electric drivetrains or cell and gene biologics.

Exhibit 8

Market proximity matters: 70 to 85 percent of manufacturing value added is created in the same region as final demand.

Origin of manufacturing value added in final demand

% of value added by major regions in country's final demand



Source: OECD; McKinsey Global Institute analysis

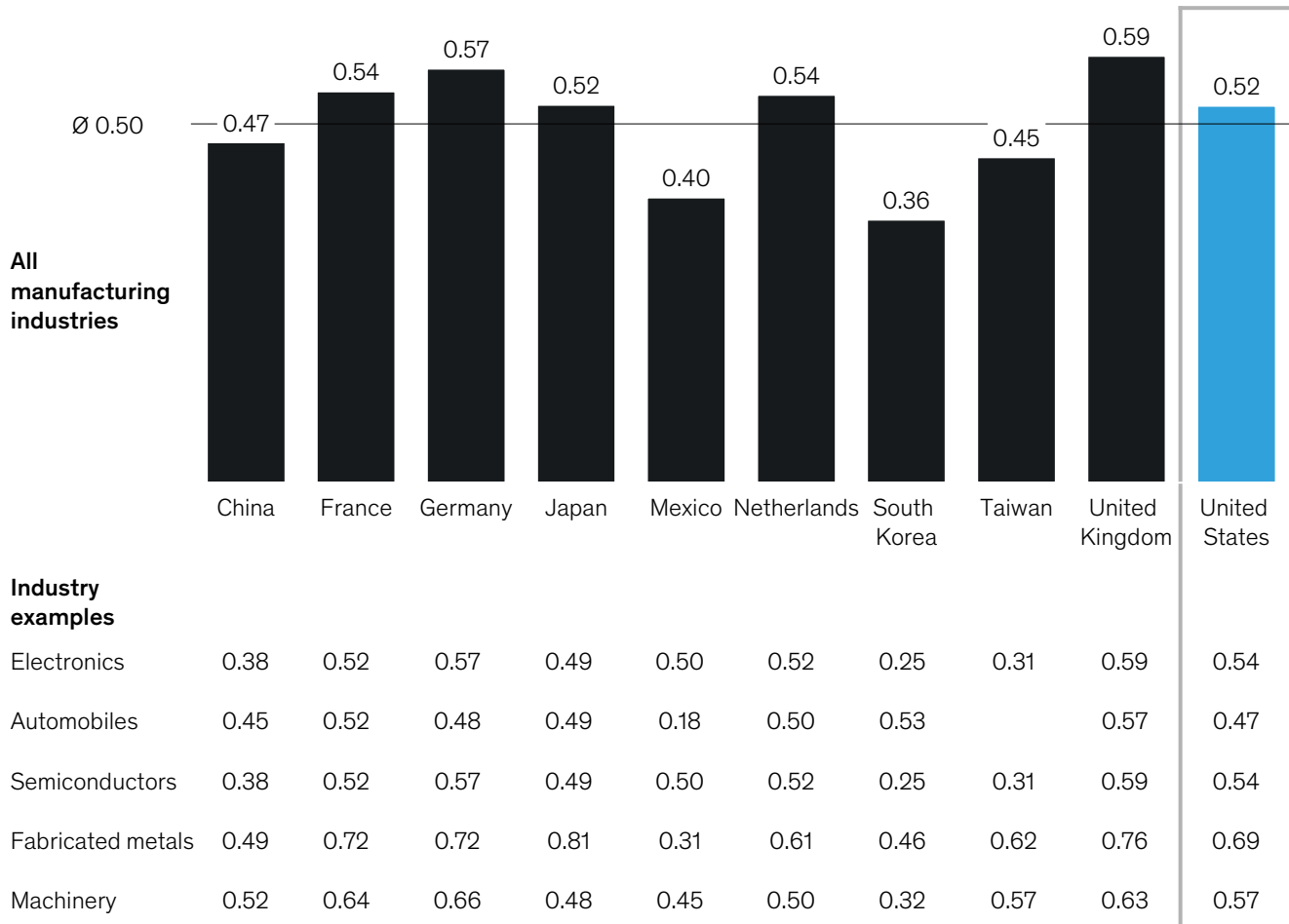
Changing cost structures make this a propitious time to act. Global labor costs have equalized over time. In major industries like autos and machinery, US productivity-adjusted labor costs are comparable to those of other manufacturing leaders in the OECD, such as Germany, Japan, and South Korea (Exhibit 9).

Exhibit 9

The United States is competitive with many of its OECD peers, including Japan and Germany, in productivity-adjusted labor costs.

Unit labor cost¹

Labor compensation as share of industry value added



1. Unit labor cost is defined as labor compensation as a share of industry value added. It is essentially a measure of wage-weighted labor productivity.
Source: The Conference Board; OECD; WIOD; McKinsey Global Institute analysis

The United States can capitalize on trends in the nature of globalization and market structures. A growing emphasis on knowledge and intangibles in global trade favors countries with highly skilled labor forces, strong innovation and R&D capabilities, and robust intellectual property protections.²⁹

US manufacturing can similarly harness technology to its advantage. An entire suite of digital innovations applied to industrial settings, collectively known as Industry 4.0, can boost productivity in a way that could change cost structures, improve product quality, deliver goods to market faster, and reduce the use of resources in production. Smart factories powered by real-time data, AI, and advanced robotics can run at maximum efficiency, optimizing and adjusting processes in real time; features such as computer vision–enhanced quality control can greatly boost efficiency and quality.³⁰ Yet the United States has catching up to do on this front.

The World Economic Forum has designated 69 global factories as “lighthouses” for demonstrating the full potential of Industry 4.0. It highlights a remarkably wide range of use cases already being deployed: AI-enabled process control, optical inspection, and material handling systems; digital workforce and scheduling tools; sensor analysis for energy optimization; and digital platforms enabling real-time end-to-end supply-chain visibility, to name just a few. For example, an Infinion factory in Singapore improved personnel efficiency by 50 percent by implementing an IoT-enabled manufacturing system and automated material-handling processes.

However, only seven of the 69 lighthouse factories are located in the United States.³¹ As these technologies move out of the experimental stage and into the mainstream, the United States still has an opportunity to ride this wave and achieve a step change in productivity—and an imperative to do so as competitors in other nations also adopt a more digital form of manufacturing.

Many types of Industry 4.0 functions, such as automated guided vehicles and computer-vision-enhanced bin picking and quality control, require advanced connectivity with high speeds and ultra-low latency. Connectivity has been a barrier, but the introduction of high-band 5G networks will provide the kind of reliability needed for critical communications, such as the wireless control of machines and robots, particularly where operations are dispersed over a large area or feature many moving assets. Private 5G networks are emerging as option for industrial companies to process data without touching public networks, which can protect proprietary applications, as we found in our earlier work looking at the impact of connectivity.³²

This is an era marked by breakthroughs in other areas as well. Cutting-edge biological capabilities and processes are beginning to be applied to the production of physical materials, potentially giving them improved performance and sustainability. Biology can be used to create novel materials that biodegrade, self-repair, flex, or resist scratches. Advances in this field could also reduce the emissions profile of manufacturing and processing. Plastics, for example, can be made with yeast instead of petrochemicals.³³

²⁹ *Globalization in transition: The future of trade and value chains*, McKinsey Global Institute, January 2019.

³⁰ Industry 4.0 technologies (sometimes referred to as Fourth Industrial Revolution technologies) involve several sets of foundational technologies: connectivity, data, and computational power; analytics and artificial intelligence; human-machine interaction; and advanced engineering. For a useful overview of relevant technologies and how they can transform industrial operations, see *The great re-make: Manufacturing for modern times*, June 2017, McKinsey.com; and Mayank Agrawal, Karel Eloot, Matteo Mancini, and Alpesh Patel, “Industry 4.0: Reimagining manufacturing operations after COVID-19,” July 2020, McKinsey.com.

³¹ *Global lighthouse network: Reimagining operations for growth*, World Economic Forum and McKinsey & Company, March 2021.

³² *Connected world: An evolution in connectivity beyond the 5G revolution*, McKinsey Global Institute, February 2020.

³³ *The Bio Revolution: Innovations transforming economies, societies, and our lives*, McKinsey Global Institute, May 2020.

While these factors together could add up to a window of opportunity, a dose of realism is in order. Concerns over supply-chain vulnerabilities have surfaced before, most notably when the double whammy of the Fukushima earthquake and catastrophic flooding in Thailand disrupted industries worldwide in 2011. Previous events, including rising wages in competitor nations, revisions to trade agreements, tax reform, and the imposition of tariffs, have raised expectations before.

For many years, revitalizing US manufacturing has been a bipartisan goal—but an elusive one. As revenue has shrunk, investment has also fallen 1 to 2 percent a year. Domestic manufacturers have entered a period of revolutionary technological change in a defensive posture, hesitant to invest in upgrades and make big bets on the future. Meanwhile, the pandemic has put surviving US companies in an even more precarious state.³⁴

However, the pandemic has been so disruptive that it offers the chance to tear up old rulebooks and try new policy approaches and business models. The United States is facing something of a now-or-never moment to regain capabilities and market share. There is also a growing sense that its frayed social fabric will not be repaired without more middle-class jobs and attention to the places that have been left behind.

There are no shortcuts or magic bullets. Solutions need to be comprehensive, strategic, and targeted to the right places. Above all, they need to be grounded in industry dynamics and the business imperatives facing companies. With those concerns in mind, the following chapter offers a different view that can provide a framework.

³⁴ See André Dua, Deepa Mahajan, Lucienne Oyer, and Sree Ramaswamy, "US small-business recovery after the COVID-19 crisis," July 2020, McKinsey.com.

2. A new lens on the dynamics and challenges in manufacturing

As described in chapter 1, we identify 16 manufacturing industries with the greatest potential to bolster the nation's resilience and its economic health. This is a useful starting point—but a very broad list. Furthermore, each of the individual industries encompasses a wide variety of companies operating at different points along their respective value chains. A high-level industry view, or even a subindustry view, does not provide sufficient insight into issues such as factor inputs, competitive pressures, and market structures. Nor is it nuanced enough to effectively target solutions.

The manufacturing sector is only as healthy as the companies that operate within it, and solutions can be effective only if they account for the forces that shape their decisions. With this in mind, we offer four activity-based archetypes based on where companies are located along the value chain and how they compete.

This analysis is grounded in a micro-level view of company behavior and competitive dynamics, but it can be aggregated to macro-level outcomes across industries, the broader manufacturing sector, and the US economy. Examining these patterns shows where US manufacturing sector is performing well and where it is under pressure.

Manufacturing contains four distinct types of activity, each driven by different microeconomic factors

US strength in manufacturing is ultimately a reflection of how individual companies perform. Four activity-based archetypes highlight differences in how and where they compete. Each has a distinct operational emphasis, investment profile, and occupational mix (Exhibit 10). The companies and industries within each of these categories also contribute to the broader economy in varying ways as they produce value through productivity, profits, and wages.

The manufacturing sector is only as healthy as the companies that operate within it.

Examining four activity-based archetypes highlights differences in where and how manufacturing firms compete.

Defining metrics of US companies within representative subindustries, 2017

| | | Type of activity | | | |
|--|--|------------------------------|---|------------------------|-------------------------------|
| | | Scale-based and standardized | Learning curve | R&D- and design-driven | Flexible and customizable |
| | | Representative subindustry | | | |
| | | Metal foundries | Production of semiconductors and memory chips | Scientific R&D | Production of aerospace parts |
| Major occupations as share of total employment | Production workers | 69% | 37% | 2% | 32% |
| | Material movers | 4% | 2% | 1% | 2% |
| | Engineers | 3% | 16% | 13% | 19% |
| | Technicians | 2% | 7% | 3% | 3% |
| | Scientists and software developers | 1% | 6% | 31% | 6% |
| Use of investment | R&D, % of sales | 3% | 19% | 16% | 9% |
| | Capex, % of sales ¹ | 4% | 8% | 8% | 2% |
| Use of physical capital | Machinery, % of capex | 85% | 73% | 0% | 72% |
| | ICT hardware and software, % of capex | 2% | 3% | 0% | 8% |
| Operational metrics | Ratio of work-in-progress to finished inventory | 77% | 106% | 0% | 1,065% |
| | Quality-adjusted price change, 20-year CAGR ^{2,3} | 2% | -4% | 2% | 2% |
| | Overall equipment effectiveness ³ | 70-95% | 75-85% | n/a | 75-85% |
| | Capacity utilization (3-year change) | 85-95% (+10-15%) | 70-80% (+10-30%) | n/a | 75-85% (+15-25%) |
| | First pass yield (3-year change) | 85-90% (+5-10%) | 90-95% (+10-20%) | n/a | 95-100% (+10-15%) |

1. We use the US Census Bureau definition of capital expenditures, which is total capital expenditure on buildings, structures, machinery, and equipment.

2. Removes any price differential based on a change in quality.

3. Compound annual growth rate.

4. The ratio of fully productive time in a manufacturing operation compared to its full potential.

Note: We considered most industries at the four-digit NAICS level in order to assign activity archetypes. The industries shown here appear most representative of their given archetypes, as shown through the highlighted metrics.

Source: US Bureau of Labor Statistics; US Census; US Bureau of Economic Analysis; McKinsey Global Institute analysis

Scale-based standardized activities

This is the classic model of manufacturing, exemplified by auto plants and metal foundries. Production and material-moving workers make up some 70 percent of the workforce in this domain. Scale-based activity demands physical assets—in fact, plants and equipment account for up to 85 percent of total capital expenditure in this domain.

Competition in this domain revolves around the cost and quality of products. Pricing pressures are intense, particularly in industries where lower-cost foreign competitors have been adding capacity and driving down the price of goods globally.

Repeatable processes and standardized components are important for achieving economies of scale and reliable quality. To make this feasible and keep costs low, plants need to operate at maximum efficiency. Metal foundries, for example, post 85 to 95 percent utilization rates on average.

Long supply chains are involved in some of the more complex scale-based activities such as auto assembly and machinery manufacturing. This model correlates with a concentration of small and medium-size suppliers. GM, for example, spends some \$80 billion annually across roughly 15,000 global suppliers.³⁵

In these industries and subindustries, an additional basis of competition is excellence in supply-chain management. Inefficient relationships between OEMs and suppliers can add to development, tooling, and product costs in a significant way; by contrast, relationships built on trust, transparency, and collaboration tend to be more productive.³⁶ But most OEMs 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.³⁷

Scale-based industries and OEMs with long, specialized supply chains contribute disproportionately to employment, with jobs spread over a wide geographic area. Out of the 16 priority manufacturing industries identified in chapter 1, those dominated by scale-based activity directly employ more than three million workers, with more than 830,000 in SMEs. Although these industries generate substantial economic value, it is spread so widely that each participating company and each worker gets a small share of the pie. Fierce price competition and tight margins affect many companies, constraining worker pay and the ability to invest for the future.

Learning-curve activities

Learning-curve activity invests time, capital, and engineering to achieve large steps forward in productivity and innovation with each successive generation of a product. The learning curve effect is a long-standing principle in industry dating to the 1930s, when Wright's Law showed that doubling aircraft production reduced the required labor for each new aircraft by 20 percent. In other words, the effort invested in the production process itself pays off in efficiency, with costs falling by a fixed proportion as scale increases, as was further articulated by Arrow in his concept of "learning by doing."³⁸

Designing and refining equipment and processes to achieve optimal production at scale can be a major endeavor when each product generation requires new technologies or skills. Competition in this type of activity is based on technical know-how and process innovation in this domain, where new products often represent major quality advances and price declines.

Production workers are 35 to 40 percent of the workforce, a much smaller share than in scale-based activity. Engineers and technicians make up roughly 25 percent of US jobs in

³⁵ 2019 sustainability report: *Driving sustainable value*, General Motors, 2020.

³⁶ See, for example, *Managing the OEM-supplier interface: Challenges and opportunities for the passenger car industry*, McKinsey & Company Automotive & Assembly Sector, 2007.

³⁷ *Risk, resilience, and rebalancing in global value chains*, McKinsey Global Institute, August 2020; 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*, 2018, Volume 114.

³⁸ Theodore Paul Wright, "Factors affecting the costs of airplanes," *Journal of the Aeronautical Sciences*, 1936. See also Kenneth J. Arrow, "The economic implications of learning by doing," *The Review of Economic Studies*, June 1962, Volume 29, Number 3.

this domain (compared to 6.6 percent in all of US manufacturing). Competing at the leading edge of these curves requires disproportionate spending on both R&D (15 to 20 percent of revenues) and capital expenditures (7 to 10 percent of revenues).³⁹

Mastering the manufacturing learning curve and capturing the ultimate benefit requires significant resources, patience, and continual process and technological innovations that build on prior progress. Investment can take an unusually long time to pay off. Although these activities are eventually profitable, mastering the processes needed to keep up with exponential technology improvements may take two to three years. During this period, operations can have sharply lower utilization rates than those in other manufacturing industries (about 70 to 80 percent), but each plant can expect double-digit growth per year in utilization and production yield. This learning-curve effect is most apparent in areas such as semiconductor fabrication, in which manufacturers are challenged to keep pace with Moore's law.⁴⁰ Learning-curve effects also benefit from strong demand to sustain ongoing process and technology innovation. Other examples of activities with strong learning-curve effects include machine tooling and the production of lithium-ion batteries and new biologics (Exhibit 11).

Learning-curve activities have high labor intensity, and wages account for more than 35 percent of their GDP. They also produce rapid productivity growth that has ranged from 4 to 14 percent per year since 2009.

Because engineers, technicians, and production workers need to collaborate and experiment, these industries can benefit when multiple companies cluster in geographic proximity to one another. The clearest example of this is Taiwan's Hsinchu Science Park. This industrial campus, founded 40 years ago, is home to TSMC, the world's largest chipmaker, and hundreds of other chip developers and high-tech firms, making it a nexus for collaboration and spillover effects that have transformed Taiwan's economy.⁴¹ A smaller ecosystem growing in Arizona is receiving a major boost from TSMC's plans to build a major US fab there.⁴²

R&D- and design-driven activities

We take an expansive view of manufacturing to include the research, design, and development of new products. The United States leads the world in these activities, which explains why US manufacturing GDP has continued to grow despite flat industrial production.

Products such as next-generation digital and medical devices demand particular expertise. Developing these products presents challenges that are fully distinct from their production, which is often outsourced.

The basis of competition is more intangible than in the other archetypes. Science, software, design, intellectual property, knowledge, and other intangibles—rather than capital-intensive physical plants—go into these activities. R&D spending equals about 15 percent of revenues. Scientists and software developers make up more than 30 percent of total occupations in this domain, with very few production workers.

These highly profitable undertakings make disproportionate contributions to economic growth and innovation. They have averaged 4 percent annual GDP growth globally since 1995, a trend that is forecast to continue for at least another decade. Maintaining US leadership in this area depends not only on continued innovation but also on protecting the underlying intellectual property.

These activities create high-wage jobs but have a more geographically concentrated footprint than other manufacturing domains. They tend to thrive within vibrant ecosystems of universities, research institutions, startups, anchor companies, high-skill professionals, and large pools of risk capital.

³⁹ Capital expenditures, as used here and throughout this section, uses the US Census Bureau's Annual Survey of Manufacturing's definition, which is total capital expenditures for buildings, structures, machinery, and equipment.

⁴⁰ Moore's law is an observable trend in which transistor density on semiconductor chips doubles roughly every 18 to 24 months.

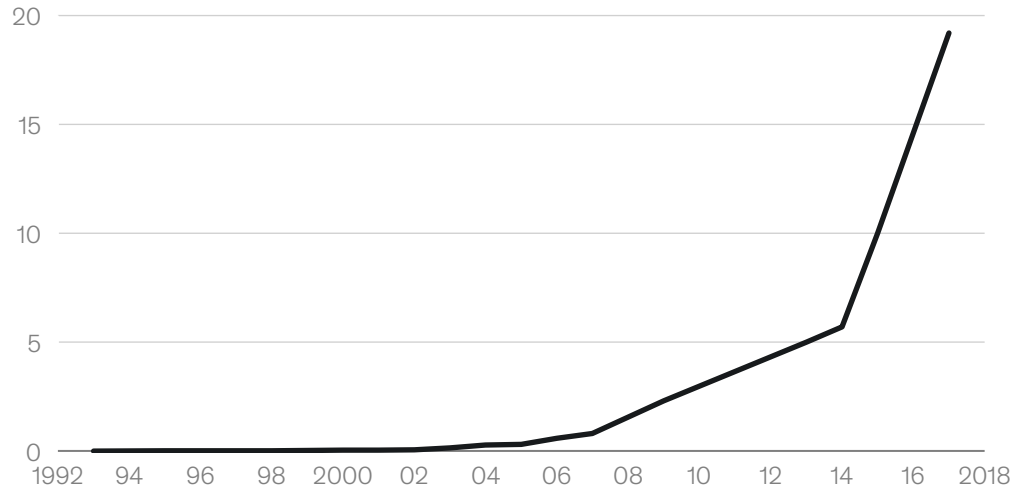
⁴¹ Cheng Ting-Fang, "How a small Taiwanese city transformed the global chip industry," *Nikkei Asia*, December 15, 2020.

⁴² Corina Vank, "Taiwan Semiconductor begins hiring for Phoenix plant," *Phoenix Business Journal*, February 26, 2021.

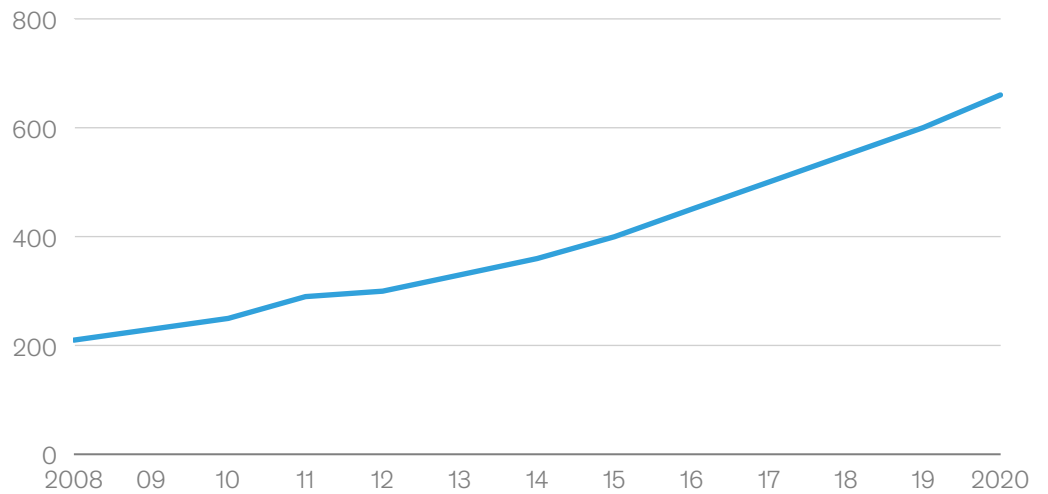
Industries with rapid innovation cycles are defined by exponential technological and process advances.

Exponential advances in semiconductors, batteries, and biotech

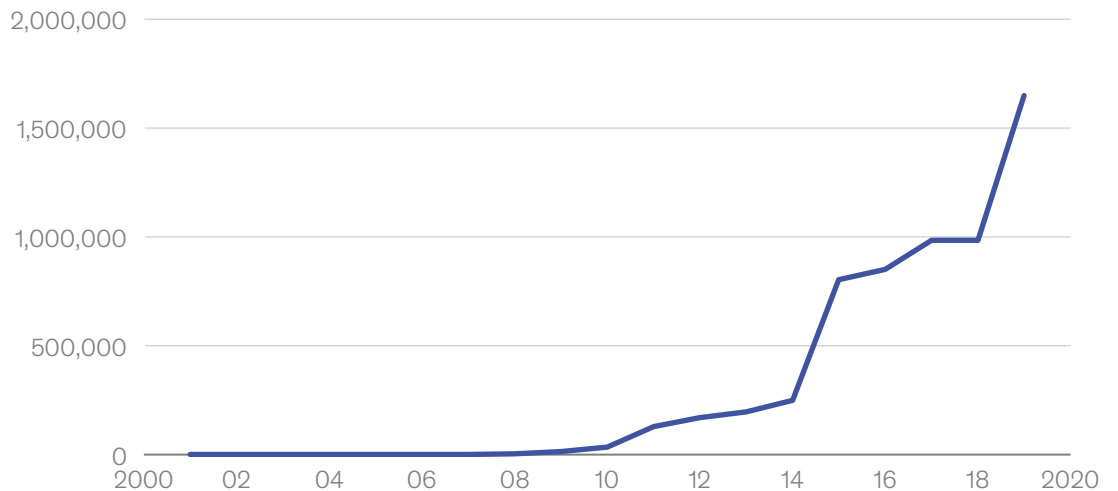
Semiconductors transistor density
Billion transistors per microprocessor



Battery energy density
Watt-hours per liter



DNA processing costs
Genomes processed per \$1 billion



Source: Our World in Data; The Economist, Cairn, US Department of Energy; US National Institutes of Health; McKinsey Global Institute analysis

Flexible and customizable activities

Digital technologies such as 3-D printers, adaptive robots, and networked CNC machines have paved the way for a new model of high-complexity, low-volume, flexible manufacturing. Enabling smaller lot sizes and reduced inventory changes the economics of production, reducing the minimum scale needed to be profitable. Molds, dies, machine tools, and even entire production lines can be reconfigured or swapped out quickly to respond to changes in demand. This domain involves high expenditures on technology, which can run to 10 percent of total capital expenditures.

The basis of competition is twofold. First, flexibility can improve the customer experience, with new business models built around customization, rapid order fulfillment, and after-sales services. Second, it can harness technology to reduce costs. Models premised on small batch sizes and direct customer fulfillment free manufacturers to carry less inventory. We see high ratios of work-in-process to finished inventory (over 200 percent) in this domain. Adoption of flexible practices can also reduce cycle times by up to 60 percent.⁴³

Flexible manufacturing is often used with high-value, low-volume aircraft components and special-purpose machinery. It is also uniquely suited to making medical devices that need personalized features and fits. Invisalign, for example, produces millions of unique dental molds to straighten teeth. The company improved its process engineering to quadruple output and cut unit costs and production time by half over a four-year period.⁴⁴

The economic benefits of flexible activity come primarily in the form of productivity growth, higher-value jobs, and new service-based models. The occupational mix includes a heavy concentration of engineers, who make up 19 percent of all employees in aerospace parts manufacturing, for example. Flexible manufacturing is less labor-intensive than scale-based manufacturing but pays higher average wages, ranging from \$65,000 to \$85,000.

Flexible manufacturing is an important frontier for future competitiveness, with the potential to unlock immense value to consumers. Parts of many industries are beginning to adopt this model, a trend that could dramatically change the landscape of manufacturing (making it more distributed at the point of sale or use) and raise consumer expectations for customization. Many countries are making large investments in digital manufacturing ecosystems with a new emphasis on flexible activity, but since this model involves proximity and speed, production is less amenable to offshoring—and the United States has the advantage of a large domestic market.

Most manufacturing industries (and many companies) include multiple activity archetypes

It is important to note that industries typically engage in a mix of the four activities described above. Even individual companies may include more than one of the four activity types, with varying mixes, depending on the product-market arenas they compete in. The mix of activities can also evolve over time. Indeed, the point of mastering learning-curve activities is to eventually graduate to standardization and repeatability at scale.

One of the classic examples of scale-based manufacturing, for example, is the auto industry. But every OEM devotes significant resources to research- and design-based activities—and this emphasis has been growing as automakers are racing to develop electric and autonomous vehicles. In autos, for example, software accounts for 10 percent of the value of a car, and McKinsey expects that share to rise to 30 percent by 2030.⁴⁵ Auto manufacturers are also incorporating some flexible activity, with innovations such as production lines that can switch between making traditional combustion engines and hybrid or electric engines. Increasingly, they are also inviting customers to choose the trims and features that go into

⁴³ *Global lighthouse network: Four durable shifts for a great reset in manufacturing*, World Economic Forum and McKinsey & Company, September 2020.

⁴⁴ Kevin O'Marah, "Mass customization and the factor of the future," *IndustryWeek*, January 14, 2015.

⁴⁵ Ondrej Burkacky, Johannes Deichmann, Georg Doll, and Christian Knochenhauer, "Rethinking car software and electronics architecture," February 2018, McKinsey.com..

a vehicle. For other examples, see Box 2, “The mix of activities in the semiconductor and pharmaceutical industries.”

Despite the mixing of activities, it is possible to map activity types to individual industries based on the relative intensity of each activity in each industry. Exhibit 12 shows the relative intensity of activity types across specific industries in the United States, based on analyzing company metrics. Note that this chart should be read by column rather than by row—that is, it compares industries to one another rather than illustrating the precise mix of activities within a given industry. For example, semiconductor manufacturing has more learning-curve activity than basic metals, but we cannot conclude it has more learning-curve activity than R&D- and design-based activity. Scale-based activity shows up more clearly in basic metals and auto parts than in other industries, for example, while semiconductors and communications equipment place greater emphasis on learning-curve activity than many other industries. See the technical appendix for a detailed view of the metrics used to make these determinations.

Box 2

The mix of activities in the pharmaceutical and semiconductor industries

As pharmaceuticals illustrate, different segments within a single manufacturing industry can bear little resemblance to one another.

The most profitable part of pharmaceuticals is focused on research- and design-based activity to develop new and improved drugs, including the full gamut of scientific collaboration, clinical testing, trials, and regulatory approval. R&D expenditures are ten to 20 percentage points higher here than in other pharmaceutical segments, while the cost of supplies is 15 to 40 percentage points lower.

Moving a new biologic into actual production, by contrast, is a learning-curve activity that involves setting up production environments according to strict regulatory guidelines, producing the actual drug substances, and fine-tuning processes to maximize yields while guaranteeing safety and efficacy. Once the learning-curve effect hurdles are met, drug production becomes a scale-based activity, particularly for treatments with wide applicability to large patient populations. For the industry to fulfill the promise of personalized medicine with new cell and gene treatments, however, it will need to add flexible manufacturing capabilities. Companies are exploring ways to deploy highly customized products in low batch sizes, a process that marries emerging manufacturing technologies with advanced scientific research.

The semiconductor value chain also encompasses varying mixes of activities. So-called fabless semiconductor companies focus on chip design but fully outsource production. The challenges they face are largely scientific and mathematic, resulting in R&D expenditures that are 10 to 16 percentage points higher than for other semiconductor segments but much lower plant, property, and equipment costs.

Leading-edge semiconductor fabrication is a perfect example of learning-curve activity. The production challenges are immense in an industry governed by Moore’s law; for 50 years, it has held true that transistor density on advanced chips doubles roughly every two years. Keeping up with this trend requires ongoing investment in new production technologies. Plant, property, and equipment expenditures are much greater in this segment than in design or equipment.

Once a generation of chips has been in production for at least three to five years, the challenges become more typical of scale-based manufacturing. Producers typically face greater price competition at this point and must achieve higher utilization and efficiency in production to stay competitive. Some semiconductor equipment manufacturers focus on flexible activity, working hand in hand with their customers to deliver machinery capable of incredible precision.

Each type of activity shows up in varying degrees of intensity from industry to industry.



| Industry | Activity | | | |
|------------------------------------|---|-----------------------------|-------------------------------------|--|
| | Scale-based and standardized ¹ | Learning-curve ² | R&D- and design-driven ³ | Flexible and customizable ⁴ |
| Basic metals | Black | Lightest grey | Lightest grey | Lightest grey |
| Iron and steel milling | Black | Lightest grey | Lightest grey | Lightest grey |
| Aluminum | Black | Lightest grey | Lightest grey | Lightest grey |
| Other metals | Black | Lightest grey | Lightest grey | Lightest grey |
| Autos and parts | Black | Lightest grey | Lightest grey | Light blue |
| Auto OEMs | Black | Lightest grey | Lightest grey | Lightest grey |
| Auto bodies and trailers | Dark blue | Lightest grey | Lightest grey | Light blue |
| Auto parts and equipment | Black | Light blue | Lightest grey | Light blue |
| Fabricated metals | Black | Light blue | Light blue | Lightest grey |
| Specialty chemicals | Black | Lightest grey | Light blue | Lightest grey |
| Petrochemicals | Black | Light blue | Light blue | Lightest grey |
| General machinery | Dark blue | Medium blue | Lightest grey | Light blue |
| Special purpose machinery | Dark blue | Light blue | Lightest grey | Light blue |
| Ag, mining, construction machinery | Dark blue | Light blue | Lightest grey | Light blue |
| Commercial / service machinery | Medium blue | Medium blue | Light blue | Lightest grey |
| Electrical equipment | Dark blue | Medium blue | Lightest grey | Light blue |
| Medical devices | Dark blue | Dark blue | Light blue | Medium blue |
| Semiconductors | Medium blue | Black | Dark blue | Lightest grey |
| Communications equipment | Light blue | Black | Dark blue | Medium blue |
| Precision tools | Light blue | Black | Dark blue | Medium blue |
| Computers and electronics | Lightest grey | Medium blue | Dark blue | Light blue |
| Computer system design | Lightest grey | Lightest grey | Dark blue | Lightest grey |
| Scientific R&D | Lightest grey | Light blue | Black | Lightest grey |
| Pharmaceuticals | Medium blue | Light blue | Black | Lightest grey |
| Other transport equipment | Dark blue | Light blue | Light blue | Dark blue |
| Railroad rolling stock | Black | Light blue | Light blue | Dark blue |
| Ship and boat building | Medium blue | Light blue | Light blue | Dark blue |
| Aerospace products and parts | Light blue | Dark blue | Light blue | Black |

1. High intensity of scale-based and standardized activity indicated by large shares of production workers and capital expenditures that favor physical machinery.
 2. High intensity of learning-curve activity indicated by large shares of engineers and technicians, and prices that fall over time.
 3. High intensity of R&D- and design-driven activity indicated by large shares of math, science, and software employees; few production workers; and high R&D expenditure.
 4. High intensity of flexible and customizable activity indicated by high ratios of work-in-progress to finished good inventories as well as adoption of additive manufacturing for parts and finished goods.

Note: This chart should be read by column rather than by row. The colors indicate which industries have the strongest intensity in each type of activity relative to one another.

Source: US Bureau of Labor Statistics; US Census; US Bureau of Economic Analysis; McKinsey Global Institute analysis

The United States is competitive in some of these activities but not in others

Across the 16 focus industries covered in this paper, the trade picture has been deteriorating. But within them, we can see that US manufacturing has an uneven presence and performance in the activity areas described above.

From 1995 to 2019, the US share of global manufacturing GDP dropped by an average of 6.0 percentage points across these 16 industries, and the gross trade deficit grew by 7.5 percentage points. But this is only part of the story. Adjusted for value added in exports and imports, the US trade balance is slightly more positive due to its greater focus on higher-value activities. Across all computer and electronic products, for example, the US value-adjusted trade balance improved by five percentage points from 2005 to 2015, a period in which gross trade balance dropped by six percentage points.⁴⁶ This is driven partly by factory-less goods producers such as Apple, which locates product design entirely within the United States but largely outsources production and assembly to contract manufacturers in other countries. This exemplifies US strength in research- and design-based activities as well as its difficulties in competing in scale-based manufacturing.

This pattern shows up even more prominently in another set of US trade statistics covering our 16 focus industries. The US trade deficit as measured by weight (kg) is an average of 44 percentage points worse than its gross trade balance as measured by dollars. In other words, the gross trade balance actually underestimates the fragility of the US supplier base and the nation's dependence on imports of lower-value intermediate goods. While there is an economic logic to focusing on high-dollar goods, some goods with low dollar values are nevertheless strategically important.

In aircraft and defense equipment manufacturing, for example, the US has a gross trade surplus of 56 percent but a trade weight deficit of 81 percent. In pharmaceuticals, the United States is a world leader in biotechnology but has lost volume production of generic active pharmaceutical ingredients (APIs). In 2019, the US trade balance by weight was a 95 percent deficit for aspirin and a 90 percent deficit for penicillin. In power transformers, the US trade deficit is 27 percent by value but 71 percent by weight. The nation's strengths in the highest-value areas clearly benefits economic growth and innovation, but its large gaps in trade by volume in certain products raise valid concerns about resilience and security.

Looking at US manufacturing by activity types, these trends are clear (Exhibit 13). The United States has lost six percentage points of its global share in scale-based activity over the past quarter century. Activities that are purely scale-based, such as final assembly of personal electronics, have all but disappeared from the United States. Labor productivity has grown rapidly over the past decade in industries in which scale-based activities are dominant (by 4.1 percent annually in basic metals and 8.4 percent in autos and parts). Yet US shares of global GDP remain below pre-recession levels. Technology has not yet made enough of an impact to restore lost global share. Scale-based manufacturing was the hallmark of China's economic development, although the economy is now moving into higher-value industries and producing more intricate, innovative goods. Other scale-based competitors include Mexico, which has attracted electronics and auto assembly, and India, which produces a substantial share of the world's generic pharmaceuticals.

The ensuing losses have been both direct and indirect. In metal foundries alone, 115,000 jobs and more than 1,100 establishments disappeared from 1998 to 2017. The downstream impacts have created some vulnerabilities. As of 2019, the United States had a 79 percent trade deficit in steel, leaving customer industries largely dependent on imports. When protective tariffs drove demand back to the United States, the domestic producers that remained were unable to keep up with the surge. Unfilled orders reached five-year highs in the fourth quarter of 2020. Buyers of fabricated metals, aircraft and defense equipment, and auto parts reported shortages affecting their own production.⁴⁷

⁴⁶ Including semiconductors, communications equipment, electronics, and some precision tools and medical devices.

⁴⁷ Rajesh Kumar Singh, "US manufacturers grapple with steel shortages and soaring prices," Reuters, February 23, 2021.

The United States is most competitive in R&D- and design-based activities but losing ground in scale-based and learning-curve activities.

| Archetype | Industries included | Change in US share of global industry GDP, 1995–2020, percentage points | Change in US employment, 1998–2017, % | Change in number of US establishments, 1998–2017, % |
|-------------------------------------|---|---|---------------------------------------|---|
| Scale-based and standardized | <ul style="list-style-type: none"> • Basic metals • Autos and parts • Fabricated metals • Petrochemicals • Specialty chemicals | -6 | -25 | -13 |
| Learning curve | <ul style="list-style-type: none"> • Precision tools • Semiconductors • Communication equipment | -11 | -37 | -20 |
| R&D- and design-driven | <ul style="list-style-type: none"> • Computer systems design and services • Scientific R&D | +4 | +118 | +66 |
| Flexible and customizable | <ul style="list-style-type: none"> • Special purpose machinery • Maritime, railroad equipment • Aircraft and defense equipment | -4 | -28 | -18 |

Note: The figures in this table are calculated as weighted averages across the industries included for each archetype.
 Source: IHS Markit (February 2021 forecast); US Census Bureau Statistics of US Businesses; McKinsey Global Institute analysis

The United States has similarly lost its edge in learning-curve activities. Its share of global GDP in this segment has fallen by 11 percentage points over the past quarter century, with a spike in job losses and factory closures in the late 1990s and early 2000s. Like the decline in scale-based activities, losses in learning-curve industries have knock-on effects, as the examples below show.

Two products characterized by these curves—semiconductors and lithium-ion batteries—are fundamental to many current and upcoming innovations. Advanced semiconductor chips power everything from personal devices to advanced military aircraft, while the growing electric vehicle market has caused demand for batteries to surge beyond current global capacity to make them. Access to these goods at competitive prices is vital to the United States from both economic and security perspectives. But the challenges of domestic production are formidable. Both leading-edge semiconductor fabs and state-of-the-art battery factories cost more than \$5 billion to build; they require two to three years to ramp up

production and longer to break even; and they draw from similar pools of specialized talent. Tesla's ability to establish battery production shows that patient capital can still ultimately pay off. However, the United States has catching up to do in this fast-growing and pivotal market. A recent report found that China has 93 "gigafactories" producing lithium-ion batteries, but the United States has only four.⁴⁸

The US share of global GDP in flexible and customizable activity has declined by a more modest four percentage points since 1995. This is driven partially by increased competition in aerospace but also by relatively slow adoption of the Industry 4.0 technologies needed to reduce cycle times and minimum lot sizes. One German manufacturer, for instance, used digital solutions and reimagined line design to produce nine different tractor models on a single line, with a minimum batch size of one and cycle time reduced by 60 percent.⁴⁹ The United States is quite competitive in tractor manufacturing, with a value surplus of 19 percent, but it can take cues from this type of process innovation. The special-purpose machinery industry as a whole has a unique opportunity to capitalize on a strong base of US software talent to lead in fully integrated solutions that invite customers to co-create. Flexible manufacturing is a new frontier, where Western Europe and Japan stand out as front-runners. But the United States also has an opportunity to establish itself as a leader.

R&D- and design-based activities are the bright spot for the United States. Over the past 25 years, the nation's share of global manufacturing GDP is up by four percentage points in this domain. US employment in these activities has more than doubled in the past two decades. However, the United States cannot afford to be complacent. US R&D productivity is declining at a time when China and other emerging economies are developing more sophisticated capabilities—and their presence will intensify global price competition. Separating design and production activities has been lucrative for individual companies; nearly 1.4 million new high-wage jobs were added from 1998 to 2017. But the resulting weakness in the domestic industrial base means that these companies are increasingly exposed to supply-chain resilience concerns.

Some US manufacturers are trapped between high investor expectations and competitors that can sustain low profits

A company measures its profitability as the return that it can generate above its cost of capital—in other words, what it can earn over and above the return it must generate for its equity and debt investors.

In a global capital market, this cost of capital, a weighted average of a company's debt and equity cost, is estimated at roughly 8 percent, with some variances by country, industry, and specific company. Despite the rapid decline in borrowing cost, investors' cost of equity and companies' own internal hurdle rates for investment decisions have not significantly changed.⁵⁰

⁴⁸ Jeanne Whalen, "Biden wants to create millions of clean-energy jobs. China and Europe are way ahead of him," *Washington Post*, February 11, 2021.

⁴⁹ *Global lighthouse network: Four durable shifts for a great reset in manufacturing*, World Economic Forum and McKinsey & Company, September 2020.

⁵⁰ *Diminishing returns: Why investors may need to lower their expectations*, McKinsey Global Institute, May 2016. One reason that the hurdle rate remains high is that companies cannot lock in a low cost of equity the way they can lock in a low long-term borrowing rate. Companies are reluctant to lower their hurdle rate if they believe that equity costs will return to higher levels within the 10- to 30-year lifespan of a large capital investment. Furthermore, as corporate debt has grown in the past decade, the equity risk premium has also risen to levels not seen since the 1970s. See Fernando Duarte and Carlo Rosa, "The equity risk premium: A review of models," Federal Reserve Bank of New York, *Economic Policy Review*, Volume 21, Number 2, December 2015.

Despite the seemingly uniform cost of capital for manufacturers worldwide, US companies are under pressure to produce higher returns on capital than their competitors in the OECD and China. In scale-based activities, large US manufacturers average returns of 12 to 14 percent, while the comparable figure is 7 to 9 percent for European peers and 5 to 7 percent for Asian counterparts (Exhibit 14). The challenge for US-based manufacturers is often framed as low-cost competition, but a more apt label is low-return competition. A significant share of Asian manufacturers are able to continue operating while generating returns below the estimated cost of capital.⁵¹

Exhibit 14

Large US firms tend to post higher returns than those in peer countries, but the cost of doing so is apparent in other metrics.

Revenue and factor input growth of large firms, %¹

| | | United States | Germany | Japan | South Korea | China |
|--|--------------------------------|---------------|---------|-------|-------------|-------|
| Electrical equipment | 1995 ROIC ³ | 13.2 | 10.9 | 4.9 | 5.1 | 6.9 |
| | 2018 ROIC ³ | 18.6 | 13.1 | 8.5 | 3.7 | 9.1 |
| Growth (real CAGR), ² 1995–2018 | Revenue | 1.3 | 3.3 | -0.2 | 10.4 | 31.0 |
| | Cost of goods sold | 0.8 | 6.1 | -0.2 | 10.7 | 32.1 |
| | Property, plant, and equipment | -0.3 | 2.6 | -1.7 | 9.8 | 28.2 |
| | Salary | -3.0 | 1.6 | -1.8 | 12.6 | 27.5 |
| Auto components | 1995 ROIC ³ | 8.7 | 3.9 | 5.3 | 3.7 | 8.6 |
| | 2018 ROIC ³ | 13.0 | 8.7 | 8.4 | 6.2 | 8.7 |
| Growth (real CAGR), ² 1995–2018 | Revenue | 0.8 | 7.9 | 3.2 | 11.1 | 24.4 |
| | Cost of goods sold | 1.0 | 8.9 | 3.1 | 11.2 | 24.2 |
| | Property, plant, and equipment | -0.1 | 5.7 | 2.0 | 11.5 | 25.0 |
| | Salary | -9.7 | -7.9 | 2.1 | 11.9 | 21.1 |

1. Defined by headquarter country; all with more than \$1 billion in revenue.

2. Compound annual growth rate.

3. Return on invested capital.

Note: The figures above are calculated based on headquarter country using a set of firms with greater than \$1 billion in revenue. The definition of ROIC used is calculated as NOPLAT divided by invested capital (including goodwill). The salary figure shown on the chart is only inclusive of direct wages, not additional benefits

Source: McKinsey and Company Corporate Performance Analytics Tool; McKinsey Global Institute analysis

⁵¹ *The future of Asia: Decoding the value and performance of corporate Asia*, McKinsey Global Institute, June 2020. See also *China's economy in transition: From external to internal rebalancing*, International Monetary Fund, November 2013 (in particular, chapter 4, "Determinants of corporate investment in China: Evidence from cross-country firm-level data").

The contrast in financial returns versus other indicators of underlying health are striking, particularly when placed in a broader global context. In auto parts, for instance, US companies have produced returns that are 1.7 to 2.0 times higher than the global average for the past 25 years (13 percent for US companies in 2018, compared to roughly 8.5 percent in Japan and Germany and 6 percent in South Korea, for example). But revenue growth has stalled for US producers since 1995 (0.8 percent annual growth, compared to almost 8 percent for German peers and more than 11 percent for South Korean peers). Investment growth has similarly ground to a halt for US producers, while rising sharply for German and especially South Korean peers. Employee wages in the auto parts industry have grown modestly over this period in Germany and Japan, and strongly in South Korea, while declining in the United States.

The focus on financial performance in the United States has led manufacturers to gravitate to the highest-value activities and drop out of the lowest. Activities that are less profitable, have long investment horizons, or involve lower capital productivity tend to be ceded to foreign companies. This pattern is most apparent in industries where concept and design can be separated from production. In the semiconductor industry, the United States is a world leader in chip design but has fallen behind on producing the next generation of seven- and five-nanometer chips. While other countries have backed their semiconductor industries with substantial subsidies, the US share of global production capacity has fallen from 37 percent in 1990 to 10 percent today (Exhibit 15). With lower-value activities largely situated outside the United States, the overall semiconductor supply chain is more exposed to global shocks and disruptions, as highlighted in chapter 1.

Exhibit 15

The semiconductor industry shows how the United States has migrated toward the highest-value activities and abandoned lower-value activities, although the latter still matter for resilience.

Share of 2018 sales based on company headquarters

High  Low

%

| Regions | Scale-based | Learning-curve | R&D- and design-based | | Mixed archetypes |
|---|-------------------|---------------------|------------------------------|-----------------------|---------------------------------|
| | Materials (wafer) | Foundry (pure play) | Electronic design automation | Chip design (fabless) | Integrated device manufacturers |
| United States | 0 | 11 | 63 | 58 | 47 |
| Taiwan | 20 | 71 | 1 | 18 | 2 |
| Europe | 14 | 3 | 19 | 4 | 10 |
| Mainland China | 1 | 11 | 0 | 16 | 1 |
| Rest of world | 65 | 4 | 17 | 4 | 40 |
| Average return on invested capital, 2019 | 20 | 22 | 146 | 123 | 31 |

Note: The shares of global sales are taken based on aggregate level sales by headquarters country. The average return on invested capital (not inclusive of goodwill) is calculated based on the 50 largest global semiconductor firms.

Source: IHS Markit; Strategy Analytics; McKinsey Corporate Performance Analytics Tool; McKinsey Global Institute analysis

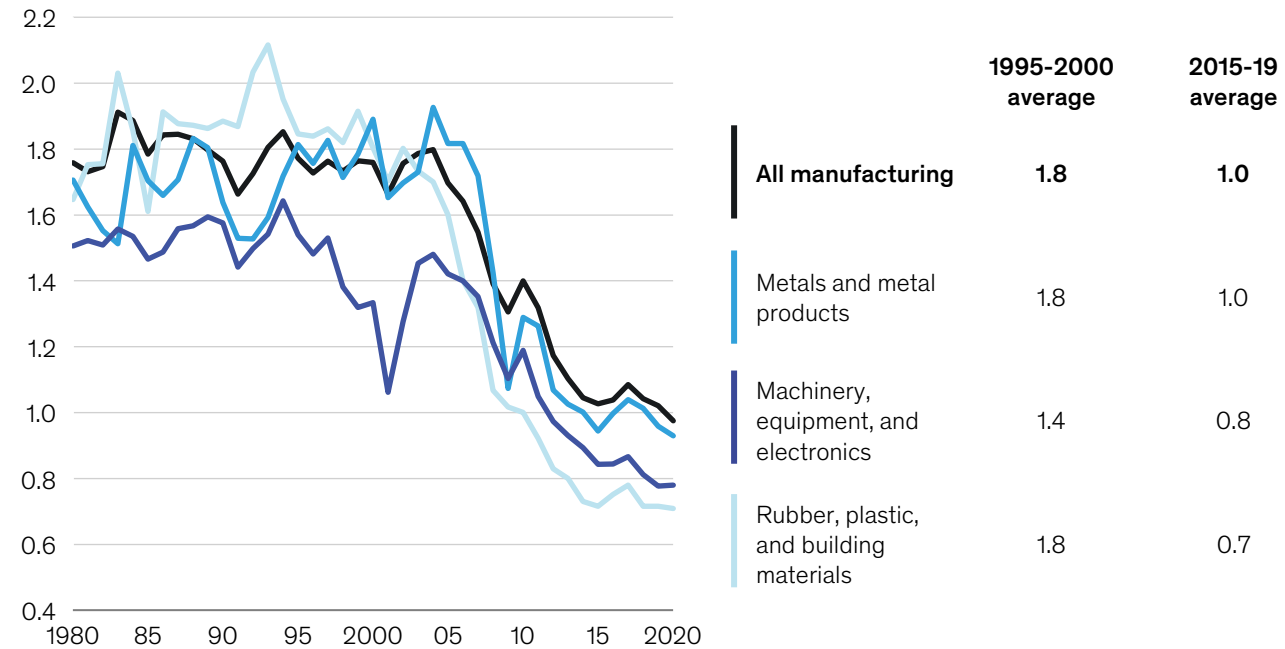
It is getting harder to meet investor expectations over time. Manufacturing has become less profitable everywhere as low-return producers have expanded capacity. Globally, the average profit for a dollar of capital investment has fallen by 80 percent over the past two decades (Exhibit 16). These falling returns make manufacturing investment look even less attractive for US investors and companies.

Exhibit 16

Profitability in certain scale-driven industries has fallen to the extent that additional capex spending generates negative profit.

Operating profits per dollar of capital expenditure, world average

Ratio of nominal profits to nominal capex



Source: IHS Markit (January 2021 forecast); McKinsey Global Institute analysis

In this low-return environment, even small differences in currency valuations, compliance costs, and input costs can have a magnified effect. An overvalued US dollar can mean an effective price discount of 10 to 15 percent for low-margin import competition, enough to reduce net income margins from 5 percent to near zero for US equipment manufacturers, metal fabricators, and machine tooling shops. A 10 percent increase in commodity prices or other production costs can have a similar effect.

The high returns noted above for US manufacturers are driven by the largest companies only. Some of them have achieved this level of performance by withdrawing from foreign markets (such as GM's exit from India, one of the world's fastest-growing car markets) or cutting costs at home to protect profit margins.⁵² Large OEMs have transferred more inventory risk to suppliers.⁵³ They now rely more heavily on cheaper imported content and components, which has forced domestic suppliers into relentless price competition.

⁵² Nick Bunkley, "GM quits, but India remains a battleground," *Automotive News*, June 5, 2017; and Stephanie Strom, "Big companies pay later, squeezing their suppliers," *New York Times*, April 6, 2015.

⁵³ *Making It in America: Revitalizing US manufacturing*, McKinsey Global Institute, November 2017.

As a result, many small and medium-size US manufacturers are in distress. The drive to cut costs has led to wage stagnation and fissured workplaces (that is, a growing reliance on low-wage temporary workers). The inability to invest in equipment and technologies has made US manufacturing SMEs 40 percent less productive than large manufacturers.⁵⁴ According to US Bureau of Economic Analysis data, the average major piece of equipment in the metals industry is 13.5 years old; in the machinery industry, it is 11 years old.

Some types of scale-based manufacturing activities are simply no longer economically viable in the United States. This includes production of some critical goods, including medical PPE, rare earth metals, electrical grid equipment, and consumer electronics. In these industries, a dollar of capital investment in the United States may return only 70 to 80 cents. In pharmaceuticals, for example, products such as ibuprofen, ACE inhibitors, over-the-counter cold remedies, and antibiotics have become commoditized, and their production has shifted to lower-cost hubs where it is cheaper to build and operate new plants. China and India export a relatively small share (3 percent each) of overall pharmaceutical products by value, but they are the world's key producers of APIs and small-molecule drugs.⁵⁵

The gap in capital costs and expected returns between US manufacturers and foreign companies has been a concern since at least the 1980s.⁵⁶ But the situation has worsened since the late 1990s amid greater trade competition and a global savings glut that the Federal Reserve flagged as a risk for US competitiveness as early as 2005.⁵⁷

Now the outcomes affect US national security and, as the pandemic has highlighted, emergency preparedness. Lengthy global supply chains have more “surface area” that exposes them to all types of shocks, including financial crises, terrorism, extreme weather, and pandemics. In a McKinsey survey of global executives, respondents reported that their industries have experienced disruptions lasting a month or longer every 3.7 years on average. Shorter disruptions have occurred even more frequently.⁵⁸

The lack of a healthy domestic supplier base has caught up to large US companies, hindering their ability to scale up production at home to meet demand growth or bring innovations to market—a situation that was unfolding as of this writing when a shortage of semiconductor chips caused shutdowns in the US auto industry just when post-pandemic demand was beginning to pick up.⁵⁹ Large US manufacturers are looking to regionalize supply chains to reduce risk exposure and shorten cycle times, and now some report that there are no more suitable domestic suppliers to work with.⁶⁰

Large US manufacturers have delivered strong returns for shareholders and debt holders but often at the expense of their own long-term prospects, the health of US industries, and the broader economy. As new technologies appear and companies reassess the risk exposure in lengthy global supply chains, this may be a moment to address the imbalance. In industries like autos, the accelerating electrification of drivetrains makes it urgent to act now before the United States misses out on a fundamental market shift.

⁵⁴ *Supply chain innovation: Strengthening America's small manufacturers*, Executive Office of the President and US Commerce Department, March 2015.

⁵⁵ *Risk, resilience, and rebalancing in global value chains*, McKinsey Global Institute, August 2020.

⁵⁶ See the Young Commission's report *Global competition: The new reality: Report of the President's Commission on Industrial Competitiveness*, January 1985; also see Robert N. McCauley and Steven A. Zimmer, “Explaining international differences in the cost of capital,” *Quarterly Review*, Federal Reserve Bank of New York, summer 1989.

⁵⁷ Ben S. Bernanke, *The global saving glut and the US current account deficit*, Sandridge Lecture, Virginia Association of Economists, Richmond, VA, March 10, 2005.

⁵⁸ *Risk, resilience, and rebalancing in global value chains*, McKinsey Global Institute, August 2020.

⁵⁹ Jamie L. LaReau, “As chip shortage cripples auto production, Biden prepares to step in,” *Detroit Free Press*, February 24, 2021.

⁶⁰ Jack Nicas, “A tiny screw shows why iPhones won't be ‘assembled in U.S.A.’,” *New York Times*, January 28, 2019; and *Risk, resilience, and rebalancing in global value chains*, McKinsey Global Institute, August 2020.

3. The opportunity, the key issues to address, and a way forward

On top of the imperative to drive economic and job growth, supply-chain resilience has taken on new urgency as a matter of public health and national security. The stage could be set for industry leaders, investors, and policy makers to coalesce around a pragmatic and comprehensive agenda to revitalize US manufacturing.

The importance of manufacturing is clear. Its decline has undermined America's middle class; countless communities have yet to recover from the loss of their anchor industries. A nation with a growing chasm of income inequality needs to address this dislocation and offer real hope for a turnaround. Manufacturing is uniquely positioned to help the United States achieve the four goals outlined earlier in this paper: productivity and economic growth; jobs and income growth for workers and communities; innovation and competitiveness; and national resilience.

The United States needs to retain and expand its technical know-how, its innovation edge, and its ability to build competitive products and grow new companies. All of these are tied to the ability to physically make things. Large manufacturers have come to recognize the importance of having a healthy domestic supplier base close at hand to support innovation, speed, and resilience in the face of growing global risks.⁶¹ Even some venture capitalists have highlighted the need to rebuild US manufacturing capabilities.⁶² In addition, meeting bolder sustainability goals requires confronting the environmental costs of importing goods from halfway around the world, particularly if they are made in places with looser standards for industrial pollution and emissions than the United States.

Fragmented initiatives have not worked in the past, and they are unlikely to achieve a broad manufacturing renaissance now. Nor will pure market forces solve the issue. This moment seems to call for an ambitious, comprehensive plan grounded in the competitive realities facing companies in different parts of the value chain. Since multiple interconnected issues affect manufacturing, they would all need to be addressed in tandem. This chapter examines the organizing considerations and five specific pillars that need to be addressed. It begins by estimating the potential payoff if such an effort is successful and concludes by posing some of the key questions that would need to be debated as this agenda takes shape.

Revitalizing the 16 focus industries could boost the sector's GDP by more than 15 percent and add up to 1.5 million direct and indirect jobs

Turning around a two-decade-plus trend of decline is no easy task. But the United States is looking for drivers that can fuel a recovery, and in an ultra-low-interest-rate environment, it has an opportunity to think bigger about how to build a more inclusive post-pandemic economy. Given the rate of change in both technologies and the capabilities of competitors, the nation is facing what may be a now-or-never moment to inject new life into its industrial base.

⁶¹ For more discussion on this point, see Susan Helper, *Supply chains and equitable growth*, Washington Center for Equitable Growth, October 2016.

⁶² See Andreessen Horowitz, "It's time to build," blog entry by Marc Andreessen, April 18, 2020, a16z.com.

The payoff for this effort could be substantial. We analyze the economic potential through two methods. First, we consider each industry in turn, applying estimates for either reducing the trade deficit or building on current momentum, based on the revealed comparative advantage of US exports. Second, we take a different approach based on assumed productivity growth that could reduce the price of US-made goods to an extent that can make domestic production attractive relative to some imports. (See the technical appendix for full details.) We then combine the approaches to range the outcomes.

The results show that renewed growth and competitiveness in the 16 priority manufacturing industries alone could boost the sector’s annual GDP by \$275 billion to \$460 billion, or 10 to 16 percent, over baseline growth forecasts by 2030 (Exhibit 17).⁶³ The growth could translate into up to 1.5 million jobs; this figure includes both direct employment in these industries as well as indirect effects in related industries. Spillover effects and investment could revitalize communities across the country.

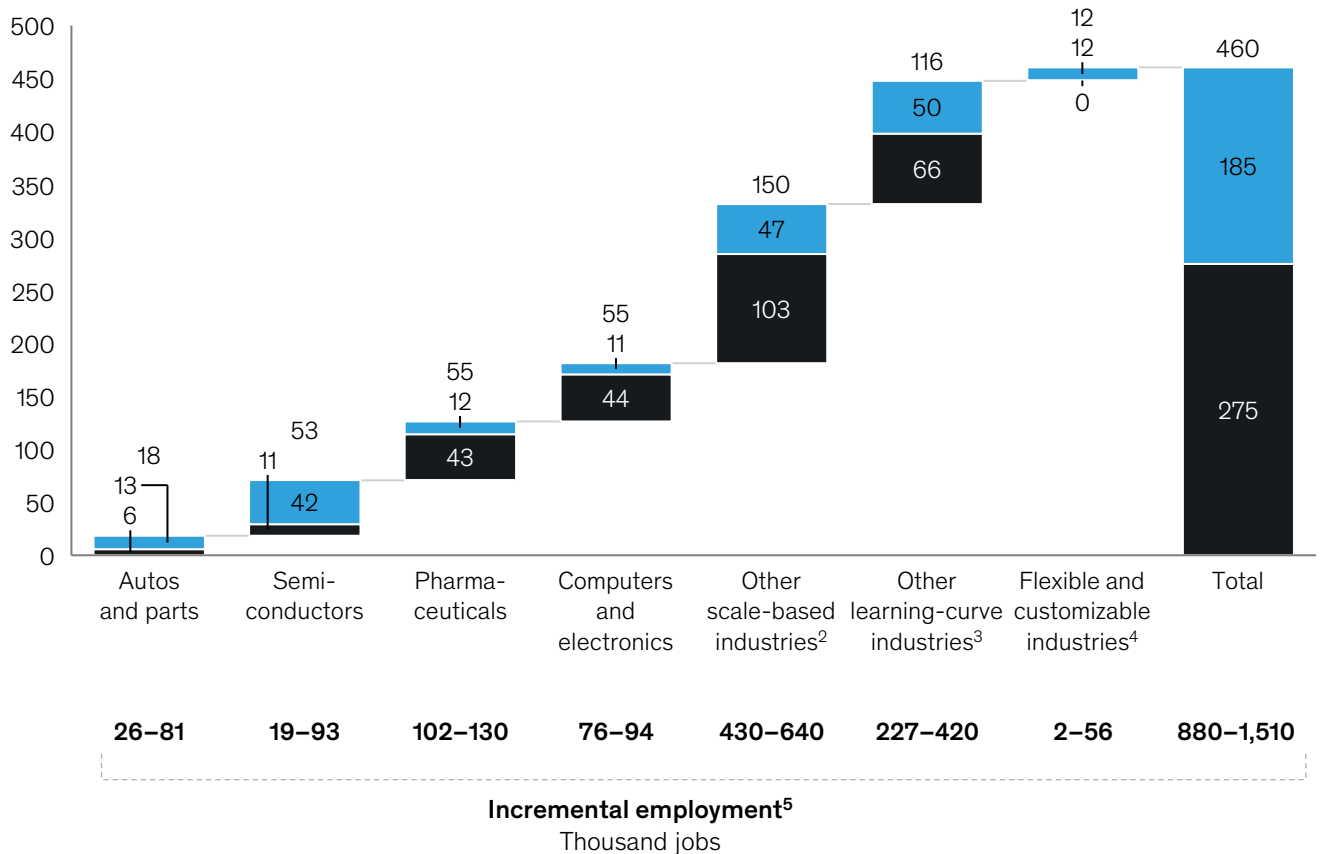
Exhibit 17

An effective transformation of the US manufacturing sector could boost GDP by \$275 billion to \$460 billion while adding up to 1.5 million jobs.

Incremental 2030 GDP opportunity¹

\$ billion (index = 2020)

■ Additional optimistic opportunity ■ Low-end opportunity



1. Above 2030 IHS forecast.
 2. Basic metals, electrical equipment, fabricated metals, general machinery, petrochemicals, specialty chemicals.
 3. Communications equipment, medical devices, precision tools, special purpose machinery.
 4. Aerospace and defense equipment, railroad and maritime equipment.
 5. Includes direct jobs within each industry and indirect jobs in other sectors.
- Note: Figures may not sum to 100% because of rounding.

Source: IHS Markit (January 2021 forecast); OECD; McKinsey Global Institute analysis

⁶³ Note that this estimate falls below the \$500 billion in annual GDP gains described in our 2017 research. Our prior work focused on the entirety of the manufacturing sector, while this estimate is based on a subset of 16 industries. Growth is also expected in some of the omitted industries, such as food and beverage, which is not accounted for here.

A large-scale, well-coordinated national strategy could put US manufacturing on a more competitive footing

Past efforts to revitalize US manufacturing, while well intentioned, have not added up to a cohesive strategy. In the past decade, federal agencies and state and local governments have poured more than \$85 billion into some 15,000 initiatives such as business enticements, employment subsidies, and R&D incentives.⁶⁴ Many have focused on encouraging companies to move across state lines, creating a “race to the bottom” that does not help the sector grow nationally. Executive actions have included trade enforcement, workforce training and apprenticeship programs, export and foreign direct investment promotion, and investment in technology institutes. Recent bipartisan legislative proposals include industry-specific grants, investment tax credits, public investment in emerging technologies, and currency alignment.⁶⁵

The sheer range of these past efforts underscores the multifaceted nature of the challenge. Indeed, making US manufacturing more competitive would involve adding new capacity, upgrading existing plants and equipment, deploying new technologies, upgrading workforce skills, and setting off a virtuous cycle of import substitution.

Spurring change on all of these fronts may take a variety of public and private initiatives, but a piecemeal approach can render them ineffective. Achieving large-scale change in a fragmented sector will require organizing principles and coordination.

This starts with clearly articulating goals and a road map for achieving them. Without this kind of touchstone, businesses could find themselves navigating a maze of individual initiatives that struggle to gain traction. An integrated plan with a long-term outlook can provide the kind of certainty businesses need to invest. To be effective, it would need to be informed by a global view of where US manufacturers are operating at a competitive disadvantage and would need to be quickly followed by tangible evidence of commitment and momentum.

A national strategy should focus on five major pillars to address some of the gaps identified across key manufacturing activities

The five pillars described below are important inputs in a national manufacturing strategy—and they are interdependent. Investing in digital factories, for example, requires relevant workforce skills. But training programs will not yield jobs without investment. Manufacturing cannot attract talent without wage growth, and wage growth requires the kind of productivity improvement that new technologies can deliver. It is not enough to pull just one lever; all five need to move in concert. Moreover, the approaches must be tailored to match the needs of the four activity types described earlier in this paper.

The US manufacturing sector needs a major infusion of investment

Deferred investment needs have been piling up across the US manufacturing landscape, and the issue is coming to a head now because the global sector is going through a period of technology transformation.

A paradox surrounds investment in the US manufacturing sector. As noted in chapter 2, US-based companies produce higher returns on average than their foreign competitors—and yet the sector as a whole is struggling, with large unmet investment needs. This points to the fact that private US investors expect higher returns than many industries and subindustries can deliver in the United States. Traditional market investors are not delivering the full infusion of capital that is needed, especially to small suppliers, nor are they amenable to long time horizons for returns.

⁶⁴ WavTeq Incentives Monitor database.

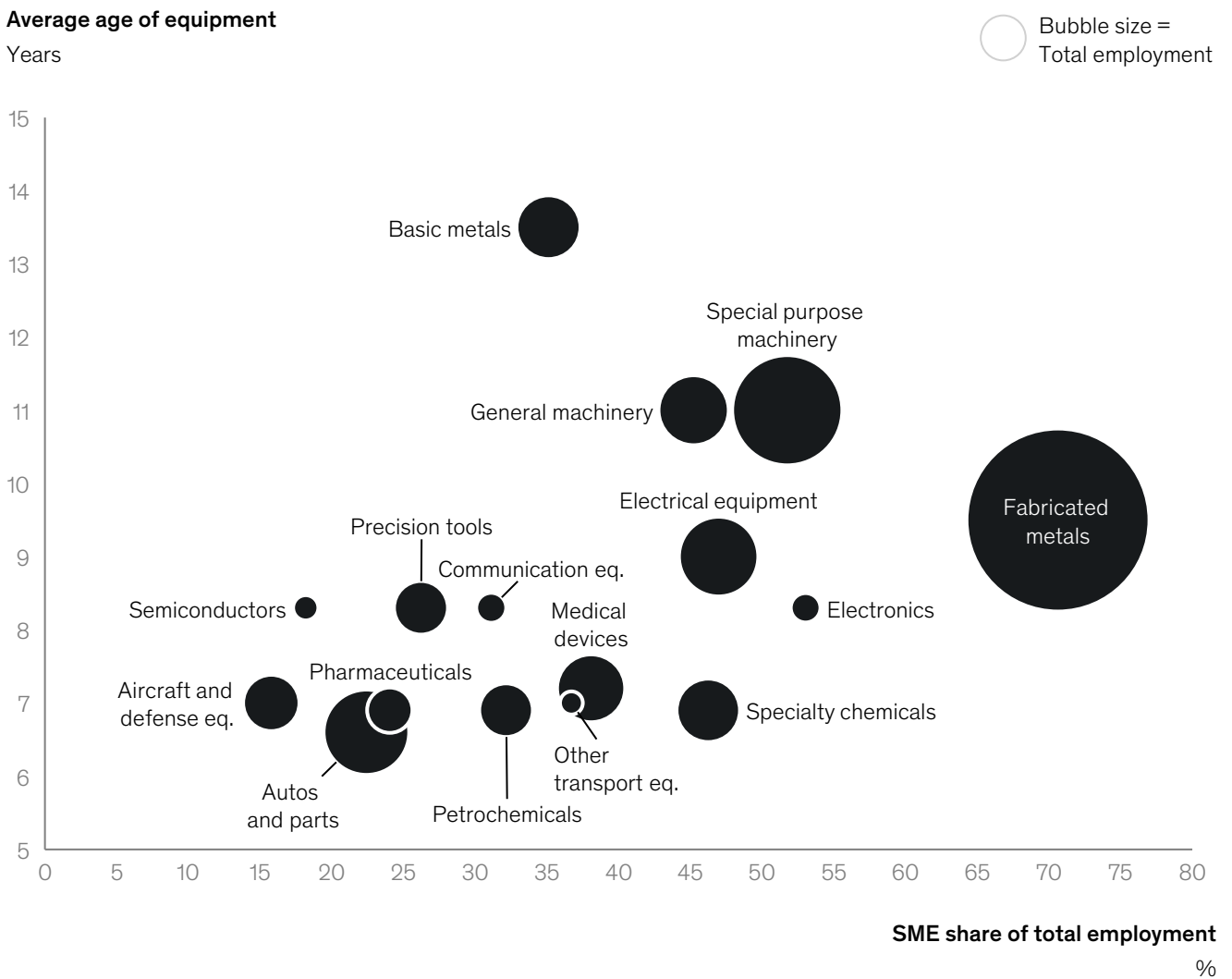
⁶⁵ Sample legislative proposals include the CHIPS for America Act, the Industries of the Future Act, and the Competitive Dollar for Jobs and Prosperity Act.

In three scale-based industries alone—auto parts, metals, and machinery—financing needs to flow to some 75,000 small and medium-size manufacturers (Exhibit 18). These small suppliers tend to be 40 percent less productive than their larger counterparts, due in part to their inability to invest in upgrading equipment and plants.⁶⁶ We estimate that \$15 billion to \$25 billion is needed annually over the next decade for a full Industry 4.0 upgrade in these industries. Some of this will involve replacing aging assets. But in some cases, companies can retrofit their legacy equipment, and interfaces are becoming simpler and cheaper over time, lowering the barriers to getting started.⁶⁷

Exhibit 18

Industries with many small suppliers tend to have older equipment and hence greater capital requirements for modernization.

SME share of employment vs. average age of equipment, 2019



Source: US Bureau of Economic Analysis; US Census Bureau Statistics of US Businesses; McKinsey Global Institute analysis

In learning-curve activities, the investment issue plays out differently, with extremely high capital requirements up front. It can take \$20 billion to build a new fab that produces next-generation five-nanometer chips—and the cost can double every two to four years in succeeding product generations. It can take three years of low utilization and yield to ramp up

⁶⁶ Supply chain innovation: Strengthening America's small manufacturers, Executive Office of the President and US Commerce Department, March 2015.
⁶⁷ Mads Lauritzen, Denise Lee, Martin Lehnich, and Kelly Liang, "Industrial IoT generates real value—if businesses overcome six myths," June 2020, McKinsey.com.

to full-scale production, and then another four to six years to break even. But few US investors will accept such a long horizon. Companies could simply build smaller fabs with lower up-front costs, but they risk losing economies of scale. TSMC's most recent five-nanometer fab in Taiwan, for example, has about four times more capacity than its planned Arizona facility for a cost estimated to be only 48 percent greater.⁶⁸

The US semiconductor industry faces another competitive hurdle when it comes to investment. In addition to the fact that foreign competitors have already achieved economies of scale with large and well-established ecosystems, some are also backed by substantial public subsidies. An industry report estimated that this can account for up to 70 percent of the cost differential between a US leading-edge fab and one based in mainland China, Taiwan, or South Korea.⁶⁹ Construction costs, too, can be higher in the United States—but this is an area where state and local governments can improve the equation by comparing their review and permitting requirements against global benchmarks. Streamlining approval processes can shave valuable months off construction timelines, improving capital productivity.⁷⁰

To revitalize manufacturing, the United States may need to consider hybrid funding approaches. Public spending could fill the gaps where returns are not attractive enough for private investors, but the scale of what is needed will take ample private investment. In other words, government funding could seed the ground to “crowd in” private capital.⁷¹ Other avenues to consider include engaging pension funds and other institutional investors, designing new types of “American made” public bond offerings, guaranteeing demand through government procurement, and attracting more foreign direct investment from international sources willing to accept lower returns than US investors.

One potential long-term solution could be a national industrial finance corporation that can raise manufacturing bonds on the private capital market, channel funding via long-term vehicles to thousands of SMEs, and package the lending with technical assistance to improve productivity and reduce investment risk.⁷² Models exist in other countries: European and Asian manufacturers can access long-term capital through institutions like the European Investment Bank, the European Investment Fund, Germany's KfW, and the Japan Finance Corporation.

As noted in chapter 2, some types of scale-based manufacturing have largely disappeared from the United States because they cannot produce returns there. Even in highly automated form, it is no longer economically viable to manufacture products such as medical PPE, generic pharmaceuticals, rare earth metals, and electrical grid equipment in the United States—and without returns, these activities cannot attract private capital. Establishing a minimum level of domestic production to ensure national resilience would require subsidies (although doing so could support jobs even if it does not turn a profit).

US manufacturing needs to add and develop specialized talent—and confront the wage stagnation underlying its inability to fill job openings

Any discussion of revitalizing US manufacturing in recent years has included the skills gap. Indeed, companies report difficulty filling open positions, with too few applicants or applicants who lack the necessary technical abilities. But the tenor of this debate has tended to blame the workers themselves or the US educational system. In fact, American workers are highly competitive in productivity. Most companies should be able to shoulder their own workforce training, and they will be in a better position to do so once their underlying

⁶⁸ Bob Davis, Kate O'Keeffe, and Asa Fitch, “Taiwan firm to build chip factory in U.S.,” *Wall Street Journal*, May 14, 2020; “TSMC breaks ground on Fab 18 in Southern Taiwan Science Park,” TSMC, January 2018.

⁶⁹ *Government incentives and US competitiveness in semiconductor manufacturing*, Boston Consulting Group and Semiconductor Industry Association, September 2020.

⁷⁰ *Reinventing construction: A route to higher productivity*, McKinsey Global Institute, February 2017.

⁷¹ Enrico Moretti, Claudia Steinwender, and John van Reenen, *The intellectual spoils of war? Defense R&D, productivity, and international spillovers*, NBER working paper number 26483, November 2019, revised August 2020.

⁷² See “Working together for jobs and growth: The role of National Promotional Banks (NPBs) in supporting the Investment Plan for Europe,” European Commission, 2015; “National Development Banks as active financiers: The case of KfW,” in Stephany Griffith-Jones and Jose Antonio Ocampo, *The future of national banks*, Oxford University Press, 2018; and Jordan Eizenga and James Hairston, “Manufacturing bonds,” Center for American Progress, February 2012.

economic health improves (although some targeted incentives could help). Some are already tackling this issue in concert with industry groups and community colleges to create a pipeline for higher-level specialized skills.

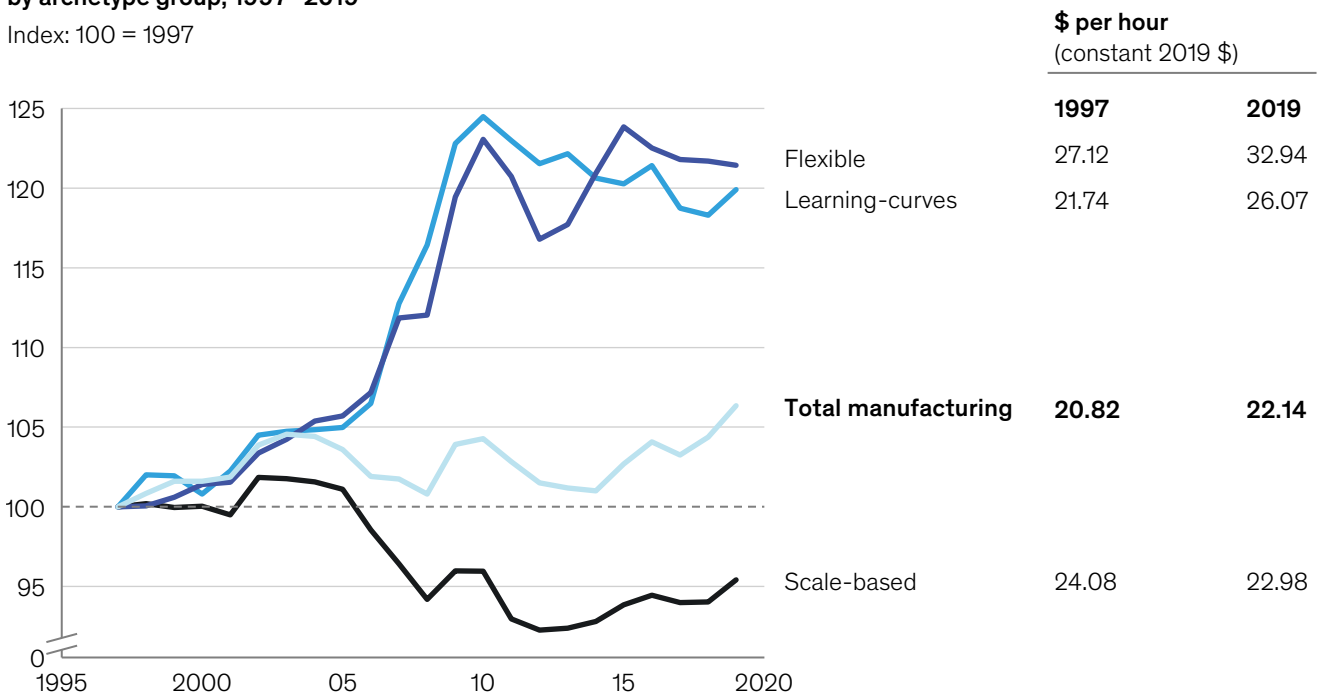
The broader inability to fill production openings has to be considered in the context of the wages being offered (Exhibit 19). The manufacturing workforce is aging, but attracting a new generation is more difficult when the jobs are deteriorating in quality. In real terms, production wages have stagnated since 1995, and they have actually declined in the most distressed industries (by 20 percent in auto parts, for example). The worst of this pain is concentrated in scale-based manufacturing. One study found that one-third of all manufacturing production workers rely on food stamps or other federal assistance programs to make ends meet.⁷³

Exhibit 19

Average US manufacturing wages have stagnated since the late 1990s, driven by a real decline in scale-based industries.

Average real hourly wages for production workers, by archetype group, 1997–2019¹

Index: 100 = 1997



1. Production (non-supervisory) workers constitute 70–88% of the total workforce. Examples include retail salespeople, construction laborers, and truck drivers. Source: US Bureau of Labor Statistics; McKinsey Global Institute analysis

Training subsidies do not always address the core of the issue. Reskilling programs at local community colleges often do not benefit SMEs that are hoping for job-ready skills on Day 1 but hire too few graduates to be able to influence the curriculum. On-the-job training is often a better option, but companies need to be in stronger financial and strategic condition to offer desirable apprenticeship programs.⁷⁴

Manufacturing must be able to support jobs that pay a living wage. But companies that are struggling to compete have been forced into cost-cutting mode. Breaking this cycle can start with solving the capital investment problem described above. Over the longer term, however, only productivity can sustain income growth—and here it is possible to move the needle if

⁷³ Ken Jacobs et al., *Producing poverty: The public cost of low-wage production jobs in manufacturing*, UC Berkeley Center for Labor Research and Education, May 2016.

⁷⁴ Based on interviews with technical and community college directors, SME owners, and National Institute of Standards and Technology Manufacturing Extension Partnership officials

entire industries can adopt next-generation technologies (see below). Because scale-based activity needs to become more digitized and automated, OEMs, industry groups, and public-private initiatives will need to work with SMEs on technical assistance and training.

We do see some niches with clear talent gaps. The R&D- and design-based activities that can boost future output growth and competitiveness require more scientists, product designers, and software developers. Learning-curve activities need highly specialized engineers and technicians to develop equipment, tooling, and processes. Entry-level training time is four to six years for engineers, and two to four for technicians. Some experienced supervisors and managers have left the manufacturing workforce, and those that remain are getting older on average. US industries will need strong successors to keep up with their global peers in process innovation. One survey of 400 manufacturers in tech-driven industries found this technical skills gap to be the challenge “most likely to derail future plans in the next two to three years.”⁷⁵

This gap is exacerbated by challenges in retaining foreign students after they graduate. In 2017, international students accounted for 56 percent of graduate STEM enrollments, but foreign-born workers accounted for only 18.5 percent of the skilled technical workforce.⁷⁶ The National Science Board notes that “stay rates” are declining for graduates from China and India, the two nations with the greatest shares of international students receiving US doctorates. In short, the United States is educating engineers, scientists, technicians, and innovators from all over the world, but not always putting their training to use.

Like investment initiatives, worker training needs coordination and scale. Skill certifications that vary by state can be confusing for large manufacturers with supply chains that cross state boundaries. Harmonizing these requirements and scaling up successful state-level programs that already exist would be a solid place to start.

Boosting productivity across the entire sector requires embracing process improvements and bolstering technical know-how

Much of the challenge in US manufacturing comes down to the need to boost productivity. This can lower the price of goods, enabling more import substitution (Exhibit 20).

Investing in new equipment and Industry 4.0 technologies is a critical part of this effort. Design and simulation tools, for example, can create “digital twins” of physical products and production processes, validating product designs and using virtual simulations to iron out the production process before it goes live. Sensors can feed real-time data into analytics systems, which can adjust machinery automatically to reduce downtime and waste. Computer vision tools powered by AI can spot defects on a production line that the human eye could miss. Particularly in scale-based manufacturing, where competition often comes down to excellence in supply-chain management, control tower systems can integrate real-time data, from inventory levels to road delays, across plants, suppliers, and distributors.⁷⁷

Beyond technology adoption, large US companies and their suppliers need to catch up with global leaders in process improvements. In scale-based industries, the core principle of Japanese industries has always been kaizen, or continuous improvement. Ongoing experimentation and refinement is a core value that has led to the development of lean manufacturing systems, modular platforms, and deep supplier collaboration. Toyota’s adoption of automation technologies and analytics has come with an emphasis on how human judgment can inform interactions with machines.⁷⁸ In other countries, cross shareholdings

⁷⁵ Irene Petrick and Faith McCreary, *Creating lasting value in the age of AI + IoT—futureproofing your business*, Intel, December 2019.

⁷⁶ Amy Burke, “The skilled technical workforce,” in *Science & engineering indicators 2020: Science and engineering labor force*, National Science Board, 2019, nces.nsf.gov.

⁷⁷ See, for example, Mayank Agrawal, Karel Eloit, Matteo Mancini, and Alpesh Patel, “Industry 4.0: Reimagining manufacturing operations after COVID-19,” July 2020, [McKinsey.com](https://www.mckinsey.com); and Andreas Behrendt, Enno de Boer, Tarek Kasah, Bodo Koerber, Niko Mohr, and Gérard Richter, *Leveraging Industrial IoT and advanced technologies for digital transformation*, February 2021, [McKinsey.com](https://www.mckinsey.com).

⁷⁸ Jeffrey Liker, “When the Toyota Way meets Industry 4.0,” *IndustryWeek*, August 27, 2020. For more on international differences in process improvements, see Dean M. Schroeder and Alan G. Robinson, “America’s most successful export to Japan: Continuous improvement programs,” *MIT Sloan Management Review*, April 1991.

between industrial firms, OEMs, and large suppliers tend to promote technology sharing and long-term relationships that help raise productivity in the supply chain. In the United States, where OEM-supplier relationships remain more arms-length and transactional, this might require both cultural and structural changes.⁷⁹

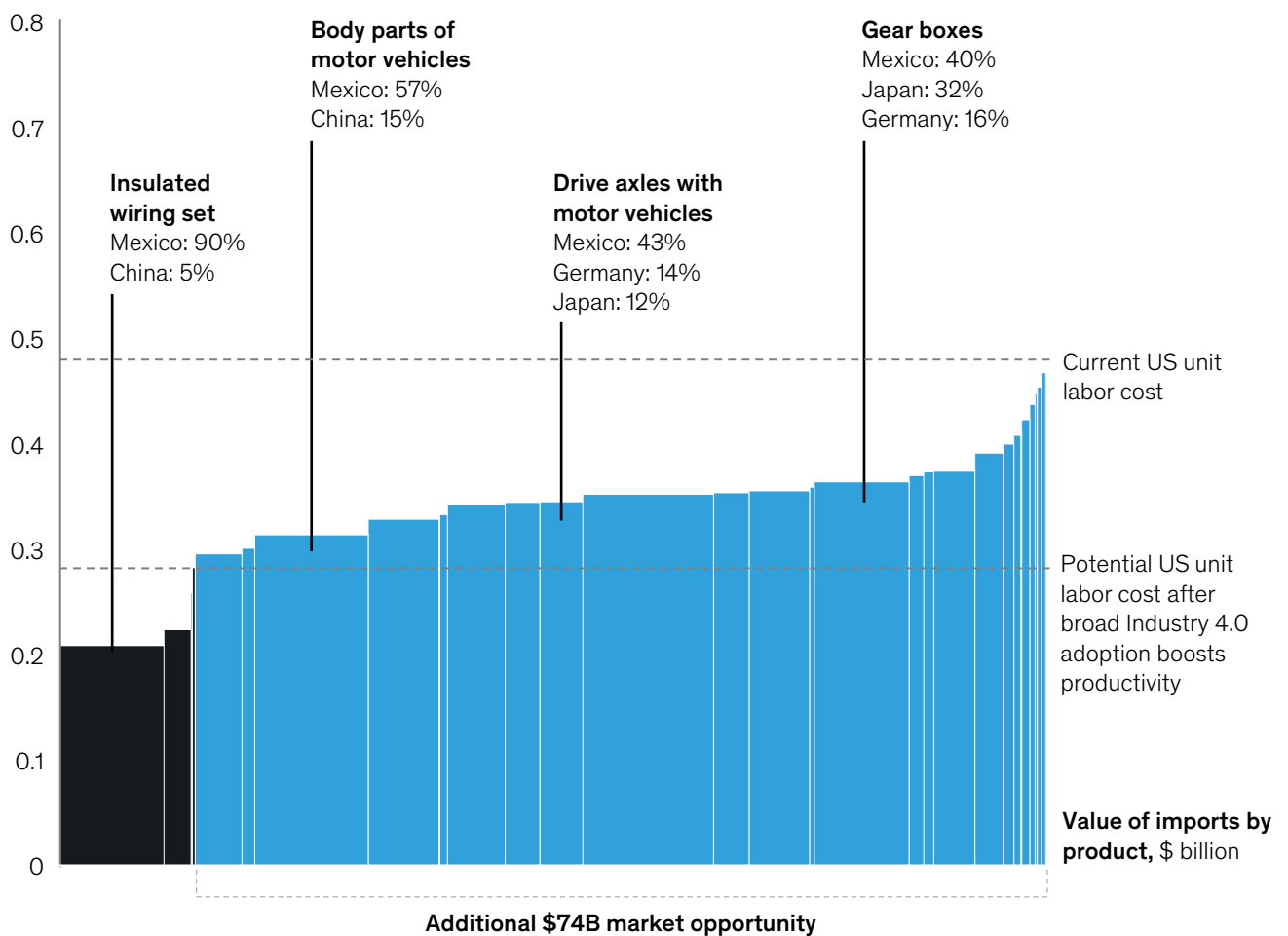
Part of the strategy for revitalizing some scale-based manufacturing could be an evolution of the classic model, with bolder moves toward innovation and sustainability or perhaps incorporating more flexible activity.

Exhibit 20

Improved productivity in auto manufacturing could lower unit costs and enable domestic production of a range of currently imported auto parts.

US weighted average unit labor cost of imported products based on country of origin

Intermediate inputs, automotive, 2019



Note: Unit labor costs for India and China are assumed to be identical to Mexico for each sector. Countries where unit labor cost data are available are used for the analysis. Source: USA Trade Online; OECD; The Conference Board; World Economic Forum; McKinsey Global Institute analysis

In learning-curve activities, the trend of ever-increasing complexity may mean that specialized companies are better positioned to achieve production breakthroughs and faster yield improvements than integrated players. In semiconductors, for example, some companies have self-selected into fabless design or pure-play foundry. Something similar could unfold in the electric vehicle market, where OEMs are approaching a decision point about whether to produce or procure their batteries. Likewise, biotechnology companies

⁷⁹ Susan Helper and Timothy Krueger, "Supply chains and equitable growth," Washington Center for Equitable Growth, September 2016.

must determine whether to license out emerging technologies or fight through the challenges of production curves.

Focusing on productivity is not only about improvements on the factory floor, however. The public sector can also make the big long-term investments in infrastructure that support productivity in industry, such as transportation infrastructure, education and vocational training, digital networks, and energy. Although it was focused on developing countries, recent MGI research identified some commonalities among consistently fast-growing economies—and the results could hold some lessons for the United States. Governments in the “outperformer” countries have tended to invest in building competence, are agile and open to regulatory experimentation, and are willing to adapt global best practices. They also institute competition policies that create incentives for productivity growth and increased investment.⁸⁰

Manufacturing needs a healthy domestic supplier base and more resilient supply chains to thrive

US industries need a holistic approach to address the health and comprehensiveness of many small and medium-size suppliers—an effort that would have positive implications for spurring new economic activity in small towns across the country.

Scale-based industries, by definition, are at the epicenter of this issue. The practice of large manufacturers seeking out ever lower bids from suppliers has driven the operating margins of SMEs down by 20 percent since 1997. Since then, roughly 15 percent of plants supplying scale-based industries have shut down, including 25 percent of establishments in electrical equipment and 22 percent in metals.⁸¹ All of these closures represent lost jobs and hits to local economies.

One way for large manufacturers to turn this around would be changing incentive structures for their own purchasing teams. Instead of just monitoring key suppliers, OEMs could mentor them, solicit their ideas, invest in their capabilities, and build trust to create a preferred relationship. They could even design contracts with incentives for finding efficiencies or partner with suppliers to go after new opportunities, sharing both risk and reward.⁸² Investing in new technologies is especially risky for small suppliers with tight margins, but larger partners can offer some type of assurance that these investments will pay off.⁸³ McKinsey's procurement research shows that companies that collaborate effectively with their suppliers show distinct growth in margin relative to others in the same industry.

Small and medium-size US manufacturers need more of the networking and interaction available to their counterparts in many other advanced economies to learn about growth opportunities and share best practices.⁸⁴ The prime example of this model is the institutional support enjoyed by Germany's Mittelstand (medium-size firms). While the German approach may not translate to the US context, it does offer some lessons about how coordination and scale can produce economic sustainability. The United States could build on state organizations such as the Colorado Advanced Manufacturing Association, the Pennsylvania Governor's Manufacturing Advisory Council, and the Massachusetts Advanced Manufacturing Collaborative. It could also scale up its Manufacturing USA regional technology institutes.

Policy can help SMEs modernize through capital access programs, business accelerators, or tax incentives. Canada funds technology access centers at colleges and universities. Following the model of successful programs in Europe, Connecticut introduced an “innovation

⁸⁰ *Outperformers: High-growth emerging economies and the companies that propel them*, McKinsey Global Institute, September 2018.

⁸¹ *Statistics of US Businesses*, US Census Bureau, 1997–2018.

⁸² For further discussion of varying international approaches to OEM-supplier relationships, see Susan Helper and Janet Kiehl, “Developing supplier capabilities: Market and non-market approaches,” *Industry and Innovation*, March–June 2004, Volume 11, Numbers 1–2.

⁸³ *Supply chain innovation: Strengthening America's small manufacturers*, Executive Office of the President and US Commerce Department, March 2015.

⁸⁴ Nancy J. Miller, Terry Besser, and Avinash Malshe, “Strategic networking among small businesses in small US communities,” *International Small Business Journal*, 2007, Volume 25, Number 6.

voucher” program that offers smaller manufacturers relatively modest grants for purchasing specialized equipment or consulting with business and technical experts.⁸⁵ Like other US initiatives aimed at bolstering the sector, these programs would need to be scaled up for maximum impact.

Companies can also make their own supply chains more resilient. In a McKinsey survey of supply-chain executives conducted in May 2020, an overwhelming 93 percent reported that they plan to take steps such as building in redundancies across suppliers, nearshoring, reducing the number of unique parts they use, and regionalizing production networks. For large companies, creating a comprehensive view of the supply chain through detailed sub-tier mapping is a critical step to identifying hidden relationships that invite vulnerability. Connecting the entire supply chain with a seamless flow of real-time data can deliver major benefits to efficiency and transparency that few companies have fully realized.⁸⁶

The United States needs to evaluate and address competitive disadvantages

For years, domestic manufacturers have been caught between investors who expect high returns and competitors that can sustain low returns because they are subsidized. They have also been hampered by a strong US dollar, which further distorts the competitive landscape. The overvalued dollar adds 15 percent to the relative price of US-made products versus foreign imports—a major headwind in low-margin, price-competitive markets.

At the very least, the United States needs to assess the full range of assistance programs and supportive policies provided by other major manufacturing nations, with an eye toward potentially adopting global best practices.

Germany’s Fraunhofer Institutes, which provide technical and business support to manufacturing SMEs, has eight times the budget and 15 times the staffing that the US Manufacturing Extension Partnership does.⁸⁷ European and Asian manufacturers can access long-term capital through institutions like the European Investment Fund, Germany’s KfW, and the Japan Finance Corporation, but nothing similar is available to US manufacturers. Singapore’s Productivity and Innovation Credit Scheme provides 400 percent tax allowances for investments in automation, workforce development, or intellectual property—and additional benefits when companies demonstrate their use of these investments. At the same time, the United States has its own particular mix of manufacturing industries and players; it can adapt the examples of other countries and also develop its own approaches.

To restore the competitiveness of US manufacturing, business leaders and policy makers will need to wrestle with key questions

Translating these complex issues into a concrete agenda—and, more importantly, into action—will not be easy. Multiple approaches are possible, and it will be crucial to incorporate a range of ideas into a coherent whole. Private-sector leaders and policy makers will need to work hand in hand on both design and execution.

The topics below can provide a framework for leaders as they develop actionable plans and policies.

- **Unlocking capital investment.** What mechanisms and vehicles can marshal sufficient capital and ensure that it flows to the activities and companies that need it most? How should public spending figure into this agenda? Can the US adapt best practices from examples such as Germany’s KfW, the Japan Finance Corporation, the European Investment Fund, and even its own federal farm credit system?
- **Ensuring that investment leads to better outcomes.** Could demand guarantees and public procurement accelerate scale and learning-curve effects? Could procurement

⁸⁵ Connecticut Department of Economic and Community Development; “*Making” our future: What states are doing to encourage growth in manufacturing through innovation, entrepreneurship, and investment*, National Governors Association, January 2013.

⁸⁶ For more on this topic, see *Risk, resilience, and rebalancing in global value chains*, McKinsey Global Institute, August 2020.

⁸⁷ *The Manufacturing Extension Partnership Program*, US Congressional Research Service, September 2019.

practices require product improvements, supplier investment, and productivity growth over time? What role does corporate governance play?

- **Addressing areas where private investment at sufficient scale cannot be expected.** Should the public sector take a different approach when it comes to goods with strategic importance to defense, key sectors, infrastructure, or emergency preparedness? Is the United States prepared to subsidize production of some critical goods if they do not produce returns for private investors?
- **Strengthening the manufacturing workforce.** How can the United States quickly address the need for more specialized high-skill talent in roles that require years of training? How can industries prepare for the looming retirement of the current generation of senior technical experts? What changes to education and immigration policy might be needed? Can US manufacturers raise wages and improve the quality of jobs to attract the workers they need?
- **Shoring up supply chains.** What tangible steps could accelerate the rebuilding of the domestic supplier ecosystem? How much of this can large US manufacturers achieve on their own? Could restructured business relationships and industry norms spur technology adoption and co-creation? Can flexible manufacturing play a role in resilience? What kinds of technologies can make supply chains more transparent and cohesive? How can the United States secure supplies of critical products in cases where it does not return to domestic production?
- **Partnering abroad.** Can international alliances and partnerships play a role in expanding market access and improving competitiveness? What role could they play in making supply chains more flexible and robust?

Making US manufacturing more competitive would involve adding new capacity, upgrading existing plants and equipment, deploying new technologies, upgrading workforce skills, and setting off a virtuous cycle of import substitution.

Technical appendix

This technical appendix includes the following.

- Methodology for determining GDP and jobs opportunity
- Methodology for industry-level economic contributions
- Methodology for determining Industry 4.0 labor productivity opportunity
- Methodology for the relative intensity of each activity archetype across industries

Methodology for determining GDP and jobs opportunity

Our estimates of the total potential GDP boost and the total jobs that could be added are aggregated from industry-level ranges for each of the 16 priority industries identified. For each industry, the ranges stem from two different methods of estimating improvements to US gross trade balance, then translating that gross opportunity into GDP and jobs.

Gross trade opportunity: Method 1, deficit recapture/surplus momentum

For industries in which the US trade balance shifted toward deficit from 2000 to 2020, we assume that a variable percentage x of the added deficit since 2000 can be recaptured by 2030. For industries in which the real US trade balance has shifted toward surplus in that time, we assume that half of the same variable percentage x of the added surplus can be replicated by 2030.

To determine the x percentage for each industry, we leverage product-level trade data from UN Comtrade to calculate the percentage of US exports in each industry for which the US revealed comparative advantage is greater than 1. We then rescale these percentages to range from 50 to 100 percent and use those values for the recapture and momentum rates. The resulting gross trade balances are capped at 25 percentage points above baseline IHS forecasts. Last, since this opportunity is calculated in real terms indexed to 2015, we account for net inflation of 9.9 percent from 2015 to 2020.

Gross trade opportunity: Method 2, import substitution

We calculate the weighted average unit labor cost of US imports and that of US production using data from the OECD and The Conference Board. We determine the opportunity for US labor productivity improvement as a result of Industry 4.0 adoption by industry (see “Methodology for determining Industry 4.0 labor productivity opportunity,” below). Then we leverage product-level trade data from UN Comtrade to approximate the total share of imports for which this productivity improvement would make domestic production more economical than importing. We assume that this amount can be translated into incremental gross output opportunity. For certain industries, including autos and parts and electronics, we assume that intraregional imports from North America will not be converted.

Translating gross trade opportunity to GDP opportunity (for both methods)

To determine an appropriate ratio of value added to gross output for each industry in 2030, we must account for both productivity gains and the benefits of a more proximal supply chain. We begin with IHS Markit forecasts of GDP and value added, which include assumptions on productivity growth but may not account for the supply-chain impact of the solutions detailed here. To account for those effects, we take the highest ratio for each industry of GDP to gross output forecast for any given country, and assume that the United States will be able to achieve that ratio. In the case of some outliers, we instead use the second-highest ratio. In all but four of the industries included in the analysis, the United States already has the highest forecast ratio, while Japan and Germany have slight advantages in the others.

Next, we account for indirect effects. An added unit of output in a given industry has spillover effects to other manufacturing industries as well as other economic sectors entirely, such as retail and wholesale. For this, we use the US Bureau of Economic Analysis 2019 input-output tables to calculate output to indirect GDP multipliers. We use a standard methodology, setting up an incidence matrix of sales between each pair of industries, subtracting it from an identity matrix, then inverting the result, which produces an output-to-output multiplier matrix. Finally, we multiply each row of that matrix by BEA reported ratios of value added to gross output and add the rows, subtracting out the direct effect. This yields a single value for each manufacturing industry that can be multiplied by the gross output opportunity to determine spillover effects.

The two methods yield differing results; the presented ranges for each industry are determined by the two separate results, and the total opportunity range is determined by taking the sum of each of the lower estimates versus the sum of each of the higher estimates.

The GDP estimate breaks down into approximately \$180 billion to \$310 billion in direct impact and approximately \$95 billion to \$155 billion in indirect impact.

Translating gross trade opportunity to potential jobs

Translating the gross trade opportunity to jobs requires a similar set of steps. For this, we also draw on the BEA's input-output tables to generate a set of multipliers. This begins with the same output-to-output matrix as calculated in the previous step. Translating this to jobs, however, requires additional steps. We first bring in the BEA's estimate of full-time-equivalent employees for each industry from 2019. We then account for productivity improvements over the next decade, this time assuming each manufacturing industry will see 15 percent productivity growth from 2019 baselines. Finally, we multiply each row of the output-to-output multiplier matrix by the estimated number of employees per million dollars in output, resulting in an output-to-jobs multiplier matrix. For each of our industries, we take the sum of the appropriate column, yielding the output-to-jobs multiplier for that industry.

The provided range of jobs created for each industry is simply the product of the two gross output estimates and the appropriate multiplier.

The employment estimate breaks down into 500,000 to 800,000 direct jobs, plus 400,000 to 700,000 indirect jobs. Some of the latter are also manufacturing jobs created in upstream and downstream industries; others are in adjacent sectors such as logistics, wholesale trade, retail, and services.

Methodology for industry-level economic contributions

Across the four types of economic contribution, we use various data sources to quantify industry-level metrics that could help us better understand why each industry matters.

National security and resilience

We use two methods for determining which industries have national security and resilience implications. First, we consider two distinct lists published by federal departments and include all industries that appear on at least one of the lists.

The first comes from the Committee on Foreign Investment in the United States, an interagency body with representatives from the departments of State, Defense, Commerce, and Homeland Security. In 2018, the committee chose 27 priority industries as defined by six-digit NAICS codes for a pilot program requiring review of new investments by foreign entities in US enterprises. We designate any parent industry with at least one six-digit NAICS code included as a priority.

The second government list is the Bureau of Industry and Security's emerging technologies list. The bureau, a Commerce Department agency, published a list in 2020 of 14 emerging technologies seen as critical to US national security. We consider any industry that conducts core R&D into these technologies a focus industry.

Our second measure of national security and resilience impact is based on the correlation of supply chains with the aerospace and defense industry. For this, we leverage Bureau of Economic Analysis input-output tables to determine how much each manufacturing industry purchases from each of the others. We translate these sales into percentages and then take the correlation of each industry's supplier base against that of aerospace and defense. We consider any industry with greater than 75 percent correlation to be significant for national security.

In addition to the two methods above, our considerations of resilience for the manufacturing sectors is also informed by our prior research on global supply-chain shocks, including pandemics, cyberattacks, geophysical events, heat stress, flooding, and trade disputes. For more on this, see Box 2, "The mix of activities in the semiconductor and pharmaceutical industries," and MGI's 2020 report Risk, resilience, and rebalancing in global value chains.

Productivity and economic growth

The two metrics used to evaluate GDP growth are fairly straightforward. We leverage industry-level data from IHS Markit to determine the global historical compound annual growth rate of GDP in each industry for 1995–2019, as well as the forecast global compound annual growth rate for 2019–29.

The measure of productivity growth is more straightforward; we take US employment and GDP as provided by the Bureau of Labor Statistics and BEA to calculate real labor productivity over time. The metric chosen is the compound annual growth rate of labor productivity for 2009–19.

Jobs and incomes for workers and communities

Employees per million dollars of GDP and wages as a share of GDP are both taken from the 2018 US Census Bureau Annual Survey of Manufacturers using six-digit NAICS code mappings.

Regional GDP spread is an index comparing the number of US counties required to make up 75 percent of each industry's GDP against the comparable number for the US economy at large. The county-level data come from the BEA and include industries at the six-digit NAICS level.

Last, the SME share of total employment comes from the US Census Bureau's 2017 Statistics of US Businesses data set. We define an SME as any company with fewer than 500 employees.

Innovation and competitiveness

The calculation of R&D intensity (R&D as a percentage of revenue) comes from OECD data on both total US R&D and total US GDP by industry. The industry groups the OECD uses in these data sets are, for some industries, less granular than the base level we consider. For example, the data set does not have separate entries for semiconductors, communications equipment, and computers, but rather groups them as "computers, electronic and optical products." For these industries, we take the ratio of the higher-level group used by OECD and assume it is consistent across the subindustries.

Methodology for determining Industry 4.0 labor productivity opportunity

The purpose of this analysis is to determine the average productivity growth opportunity for each industry stemming from adoption of Industry 4.0 processes and technologies. Our analysis begins with a review of World Economic Forum lighthouses.⁸⁸ Across all of the lighthouse factories analyzed (some including single establishments and others in multiple locations), individual use cases resulted in productivity improvements ranging from 5 to 160 percent. Recognizing that individual use cases may not be representative of industry average opportunities, we remove the top quartile and bottom quartile of productivity improvements, reducing the range to approximately 10 to 40 percent.

Next, to determine where industries fell within this range, we rely on a combination of quantitative analysis and expert opinion. We begin by identifying each industry across the following three metrics:

- **Ratio of information and communications capital and intellectual property to total equipment costs.** A lower ratio indicates lower baseline digital maturity and, in turn, higher growth potential.
- **Labor productivity (GDP per employee).** Again, a lower ratio indicates lower baseline operational maturity and higher growth potential.
- **Operational concentration (GDP per establishment).** We assume that a higher ratio indicates greater benefits of scale and hence greater productivity opportunity.

Using these metrics, we establish relative rankings of each industry, which allow us to distribute the productivity opportunities across the range of 10 to 40 percent. We use information drawn from interviews with experts on technology adoption within each industry to make adjustments where necessary.

The last step in our analysis is to consider the effect of small suppliers on the ability of an industry to capture the full opportunity. Believing that SMEs will have more difficulty acquiring the necessary capital to update their factories, we reduce the opportunity in each industry proportionally to its SME share of employment, as determined from the US Census Bureau's Statistics of US Businesses data set. This makes the final industry average opportunity range 10 to 30 percent.

⁸⁸ *Global lighthouse network: Four durable shifts for a great reset in manufacturing*, World Economic Forum and McKinsey & Company, September 2020.

Methodology for the relative intensity of each activity archetype across industries

We set out to assign relative scores to illuminate the relative intensity of each activity type across the priority industries. Note that this analysis compares intensity across industries but does not attempt to pin down the proportional mix of activities within any single industry.

We use industry-level data for US companies from the following sources:

- **Occupational mix data from the Bureau of Labor Statistics (2019)**
- **Capital allocation, inventory mix, and sales data from the US Census Bureau Annual Survey of Manufacturers (2017, 2018)**
- **Pricing trends from IHS Markit (2000–20)**
- **Trends in additive manufacturing derived from the 2020 Wohler Associates report**
- **Operational metrics, including overall equipment efficiency, plant capacity utilization, and first-pass yield, come from a range of sources.** We first use the MPI Group's 2018 manufacturing survey, which included each of these data items but lacked sufficient sample size for several key industries. We supplement this with additional data available through proprietary McKinsey & Company data sources. Data for metals manufacturing, for example, come from McKinsey's SteelLens solution; data for pharmaceuticals and medical devices from McKinsey's POBOS solution; and data for food and beverages from McKinsey's COBI solution. Given the lack of a single data source, we use these operational metrics to provide supplemental insights rather than conclusions.

From these sources, we identify the following specific metrics that are disproportionately high or low when associated with different types of activities:

- **Scale-based and standardized activities.** Associated with a high share of production workers as well as transportation and material moving occupations in the total workforce. Machinery accounts for a high share of capital expenditures.
- **Learning-curve activities.** Associated with a high concentration of engineers and technicians in the total workforce, a high value added share of revenue, and declines in the real price index.
- **R&D- and design-based activities.** Associated with a high percentage of software developers, programmers, and science-based occupations as well as a low share of production occupations in the total workforce. These activities are also characterized by a high ratio of R&D expenditure to revenue.
- **Flexible and customizable activities.** Associated with a high ratio of work-in-process and raw material inventory relative to finished goods inventory; high adoption of additive manufacturing for parts and finished goods.

We first calculate each of these ratios at the four-digit NAICS level for all four-digit codes that map back to one of our focus industries. We then translate those ratios, assuming that they exist in a normal distribution, and rescore each industry based on the cumulative distribution function (CDF) of that normal curve. For example, if the ratio for a given NAICS is equal to the average of that ratio across all NAICS codes, we score it 0.5.

This produces a CDF score for each of the two to four metrics used to define each archetype. For example, for scale-based activities, we have a CDF score for share of production workers, share of transportation and material moving occupations, and machinery share of capital expenditures. For each NAICS code, we take an average of the appropriate CDF scores to assign a single score for relative intensity of each activity archetype. We then rescale these scores linearly to range from zero to one.

The last step is to aggregate these four-digit code scores to the main industry level. To do this, we take weighted averages of all applicable four-digit code scores, weighted by gross sales.

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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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