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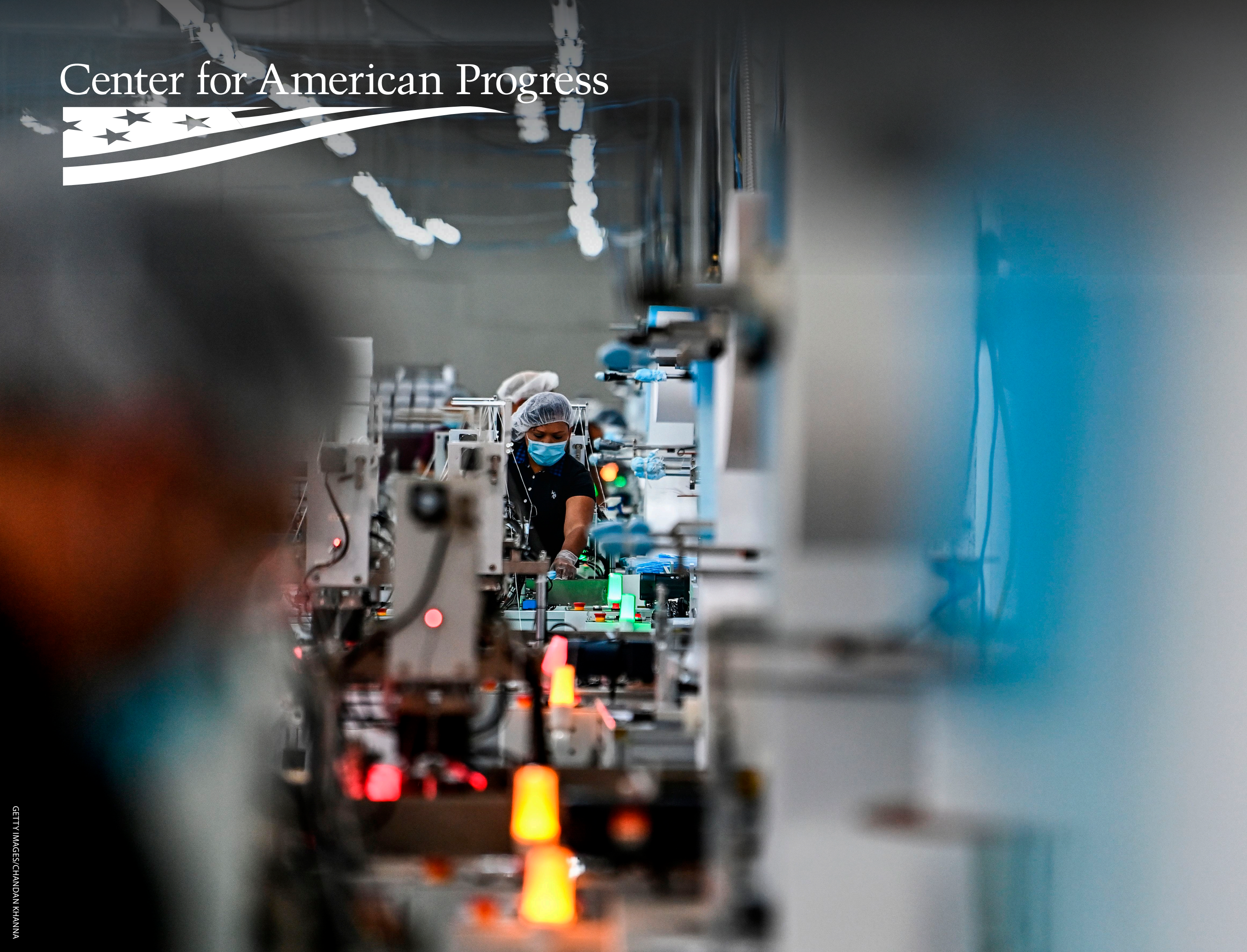

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Building U.S. Manufacturing Competitiveness and Capacity

By Marc Jarsulic March 2021

Contents

Introduction and summary

There are two major challenges facing U.S. manufacturing. The first is building competitiveness with global manufacturers, especially for U.S. small- and medium-sized enterprises (SMEs), and the second is overcoming strategic risks to health care, national defense, and other areas of the global supply chain.

As to the first challenge, the long-run competitiveness of U.S. manufacturing, along with the higher-wage employment that it has traditionally offered, is at risk. Productivity growth, which depends in significant measure on technical innovation, is the basis for long-run competitive success. Greater output per unit of input means longer-term success in the marketplace. Unfortunately, however, in most U.S. manufacturing sectors, productivity growth is substantially below the best-in-class standard set by Germany. In addition, many U.S. SMEs are not productive enough to compete with the cost advantages of Chinese and other low-wage competitors.

These failures present a puzzle. The United States is the world leader in scientific research, and scientific discovery is the basis of manufacturing innovation. So why has competition from firms in countries such as Germany and China, with scientific establishments inferior to those of the United States, not caused U.S. manufacturers to translate an absolute advantage in basic science into a similar advantage in manufacturing innovation and productivity growth? Why has this country been less successful than Germany at diffusing technology across the U.S. manufacturing sector, especially to SMEs? Why can't U.S. small firms overcome low-wage competition through innovation that delivers higher quality and greater efficiency, as do many German firms?

The source of these failures lies in public good and collective action problems that have not been addressed. Individual profit-maximizing firms underinvest in applied proof-of-concept research, measurement technology and standards, and workforce development, because they cannot capture all the benefits of those investments. This slows productivity growth, since these kinds of investments are needed to translate basic scientific discoveries into manufacturing processes and allow workers to adapt to continual technical change. These problems can be solved, but policy intervention is required to overcome the market failures that produce them.

This report recommends policy measures, analogous to those successfully adopted by Germany, that can address these problems. These actions include:

- Reconfigure and expand the existing Manufacturing Extension Partnership program (MEP) to help SMEs translate cutting-edge scientific discoveries into new manufactured products and manufacturing processes and deliver higher wages and employment levels for manufacturing workers.
- Reconfigure and expand the Manufacturing USA program (MUSA) to ensure that early-stage scientific research suitable for use in manufacturing production is sited in the United States and to develop the production processes that are specifically geared to address climate change.
- Mandate that the U.S. Department of Labor (DOL) develop workforce training for firms participating in MEP and MUSA in order to enable workers to adapt to new production processes.
- Require the federal government to buy manufactured goods from high-performing U.S. firms, with high productivity, high wages, and good workforce training, in order to support good jobs and encourage innovation.

In addition, this report suggests how these policy measures can help the United States deal with the problems created by rapid climate change. As control of greenhouse gas emissions becomes central to America's and the world's long-term survival, the need to switch to new manufactured products and processes is urgent. These changes will require rapid translation of scientific knowledge into productive technique. The policies proposed in this report will make these goals much easier to achieve.

The second challenge to U.S. manufacturing, as noted above, is overcoming strategic risks presented by global supply chains, particularly with respect to health care, national defense, and other crucial areas. The COVID-19 pandemic, for example, has revealed weaknesses in the U.S. supply chain in areas ranging from vaccine production to personal protection equipment. Evaluations by the U.S. Department of Defense (DOD) point to several areas where secure, trusted, and technically advanced manufacturing needs to be fostered. This report also shows that fully understanding the risks posed by a lack of domestic manufacturing capacity is hampered by a lack of knowledge of how supply chains actually function. The policy recommendations offered in this report aim to address these concerns and include:

- Carefully map supply chains for strategically important manufactured products.
- Support expansion of important domestic manufacturing capacity where strategically necessary.
- Develop supply agreements with trusted partner nations where important strategic risks exist.

Taking the steps outlined above can help to expand the ability of U.S. manufacturing industries to meet the challenges of global competition, expand the population of high-road firms that provide high-wage employment and training for their workers, and reduce the risks that arise when America does not have access to manufacturing capacity that meets health, defense, and other strategic domestic needs.

Addressing faltering productivity growth and diminished competitiveness

Manufacturing has historically been a source of productivity growth and high-wage employment for noncollege-educated workers in the United States. Much of manufacturing productivity growth has derived from innovation—adoption of new technologies rather than merely adding more capital equipment per unit of labor. The ability of many U.S. manufacturers to operate at the technological frontier—that is to say, at the productivity level of the globally most productive firms—has made U.S. manufactured goods competitive internationally, and until recently, the United States was the world's largest manufacturing exporter.

While in the aggregate, much of U.S. manufacturing productivity remains at frontier levels, the competitive lead has been eroded. For example, between 1995 and 2004, U.S. manufacturing productivity growth was higher than that of Germany, a major advanced economy manufacturing competitor. But from 2004 to 2016, the labor productivity growth rates of the two countries have converged.[1]

In addition, from 2004 to 2016, German manufacturing total factor productivity (TFP) growth—the fraction of output growth that is not attributable to increased inputs to production and that is commonly used as a measure of innovation[2]—exceeded that of the United States and was more or less evenly distributed across all manufacturing sectors.[3] In contrast, TFP growth in the United States was concentrated in just a few sectors, often related to Silicon Valley technology.

Economist Martin Baily and his colleagues summarize the matter:

> *The data for Germany are very striking in that there is relatively steady [productivity] growth across the sub-industries in manufacturing over the period from 1991 to 2015, although with a broad slowdown after 2004. Food products and transportation equipment are exceptions to this pattern, with much faster growth after 2004. Both in labor productivity, and TFP … it appears that German manufacturing companies are able to improve operations year by year across a broad range of industries. There are not periods of very rapid growth (as in the United Stated in the 90s) but improvement is generally continuous. The United States and Japan had faster growth than Germany over the full period, but it came more in fits and starts and has been markedly slow since 2004, especially in the United States. United States growth has been very strong in machinery and equipment (where computers and electronics are located in this data) but has seen little consistent growth in other manufacturing industries, and very slow growth since 2004. The story for Japan has been surprisingly similar, with consistently strong productivity growth in machinery and equipment and little growth elsewhere.*[4]

The data from Baily and his colleagues for U.S. and German TFP growth are presented in Table 1.

TABLE 1

U.S. and German manufacturing industries' total factor productivity growth

	United States (2004–2016)	Germany (2004–2015)
Food products, beverages, and tobacco	–0.7	1.9
Textiles, wearing apparel, leather, and related products**	0.8	1.3
Wood and paper products and printing	0.6	2.7
Coke and refined petroleum products	–3.5	N/D *
Chemical and pharmaceutical products	–2.3	1.2
Rubber and plastics products***	–0.2	1.7
Other nonmetallic mineral products	–0.8	N/D *
Basic metals and fabricated metal products	0.1	0.9
Machinery and equipment	4.2	1.5
Transport equipment	1.9	3.8
Furniture and other manufacturing	0.7	0.6
All manufacturing	0.7	1.9

* Data are not available for this industry.
** German data do not include leather and related products.
*** German data include other nonmetallic mineral products.
Source: Martin Neil Baily, Barry P. Bosworth, and Siddhi Doshi, "Productivity comparisons: Lessons from Japan, the United States, and Germany" (Washington: Brookings Institution, 2020), Appendix 2, available at https://www.brookings.edu/research/productivity-comparisons-lessons-from-japan-the-united-states-and-germany/.

In fact, U.S. productivity growth may be even smaller than these data indicate. Work by economist Susan Houseman shows that much of the productivity growth outside computers and electronics—the major contributor to U.S. productivity growth, even though it is a tiny share of the dollar value of the country's manufacturing output—reflects the outsourcing of production to low-cost production locations such as China.[5]

The differences in productivity growth and its distribution show that Germany is very effective at diffusing technology across its manufacturing firms, including the large numbers of SMEs that are a significant part of its manufacturing sector.[6] In contrast, the United States has failed to do so. As a consequence, German manufacturing continues to be highly competitive worldwide and accounts for a greater percentage of gross domestic product and employment than in the United States, and German manufacturing workers are paid about 28 percent more in real terms than their U.S. counterparts.[7]

It is important to note that this has been accomplished despite Germany's rather pedestrian basic scientific research institutions. No German university ranks in the worldwide top tier of scientific discovery.[8]

U.S. manufacturing has also been challenged by the rise of China as a manufacturing competitor. China has overtaken the United States as the world's leader in manufacturing value added[9] and leads the United States in manufacturing exports.[10] Millions of domestic manufacturing jobs were lost to the China shock beginning in 2000, as domestic Chinese firms entered the U.S. market as competitors and as U.S. multinationals offshored an increasing share of U.S. manufacturing employment to China and elsewhere.[11]

The competitive position of Chinese manufacturers is enhanced by the relatively low costs of production on the Chinese mainland. Lower real wages in China, as well as a complex set of financial, fiscal, and direct subsidies that come from government control of many aspects of the economy, contribute to these input cost advantages.[12] Moreover, Chinese manufacturing is becoming more technically advanced and productive over time, which suggests a long-run competitive challenge even if input costs rise.[13]

In addition, in 2015, the Chinese government announced a program called Made in China 2025, which has the goal of rapidly developing capacity in 10 high-tech industries. They include artificial intelligence, advanced robotics, energy-saving vehicles, and biopharma. The stated aim of the plan is to significantly improve manufacturing quality, productivity, and innovation, as well as to have the leading global position in advanced manufacturing by 2049.[14] The tools China will use to achieve these goals include subsidies, investments in foreign companies to obtain technology, and technology acquisition via joint venture requirements for foreign firms operating in China. The success of this effort is yet to be determined, but the government commitment and scale of resources available for the effort appear formidable.

The puzzle posed by low U.S. productivity growth

The trends previously outlined make clear the importance of productivity growth both to the long-run competitiveness of U.S. domestic manufacturing and to the prospects of the country's workers. But they also point to a puzzle. The United States is the world leader in basic scientific research, and scientific discovery is the basis of the technical change that underlies improvements in manufacturing productivity. Moreover, competitive pressure should provide strong incentive to raise productivity. So why has competition from countries such as Germany and China not spurred more domestic U.S. manufacturers to translate this absolute advantage in basic science into manufacturing innovation and a larger productivity advantage?

Public good obstacles to manufacturing innovation

This puzzle—this obvious disconnect—is in part answered by understanding the prerequisites for manufacturing innovation. As economist Gregory Tassey has pointed out in his insightful work on advanced manufacturing, innovation in production is not accurately characterized as a two-step process where government supports the public good of basic science and then hands it off to industry, which then does the applied research and development to create the kinds of technologies needed to produce commercial products.[15] This schematic misses two intervening steps between basic science and the development of a commercially viable technology, described by Tassey:

> *One is "proof-of-concept research" to establish broad "technology platforms" that can then be used as a basis for developing actual products. The second is a technical infrastructure of "infratechnologies" that include the analytical tools and standards needed for measuring and classifying the components of the new technology; metrics and methods for determining the adequacy of the multiple performance attributes of the technology; and the interfaces among hardware and software components that must work together for a complex product to perform as specified.*[16]

Tassey cites Bell Labs' demonstration that semiconductors can function as switches or amplifiers as an early and clear example of proof-of-concept research.[17] The work at Bell Labs created a technology platform and showed that there was a wide variety of possible commercial applications. Bell Labs was in a position to make this investment because it was part of AT&T, a regulated monopoly with an extremely long time horizon for applied research and development investment and with monopoly profits sufficient to support proof-of-concept work.[18]

Tassey also points out that applied research of the type he describes is rarely pursued by individual corporations, because they are unable to capture all the benefits of technology platform innovations.[19] Although some proof-of-concept work can be kept secret, there are spillovers to other firms because reverse engineering is possible and because it is difficult to prevent ideas from traveling. The outcomes of expensive efforts such as this are also highly uncertain.

Research evaluating the first 10 years of SEMATECH—the nonprofit consortium that was established with an initial commitment of $100 million in annual federal funding over five years and a matching amount of private funds[20] and that engaged in proof-of-concept work surrounding semiconductor manufacturing processes—suggests that the inability of the participating firms to capture all the benefits of their individual research and development expenditures was significant.[21] This implies that private corporations on their own will shy away from making these kinds of investments—in other words, private underinvestment—even when profitability of new products seems reasonably clear.[22] For this reason, proof-of-concept research is often referred to as the valley of death, which basic scientific discoveries must cross before leading to commercial manufacturing innovation.

It is an obvious point, but one worth remembering, that the underinvestment problem becomes more acute when a new technology has the potential to produce significant positive externalities. Manufacturing methods that will reduce carbon emissions—which are significant for making cement and steel, for example—will require substantial effort to cross the valley of death. But the benefits of an improved climate will not be captured solely by cement or steel manufacturers, leading to underinvestment by individual firms.

As an example of infratechnology research, Tassey points to the efforts of semiconductor companies, industry consortia, and the National Institute of Standards and Technology (NIST) to develop novel measurement equipment, software, and systems that produced significant efficiency gains. From 1996 to 2006, collective expenditure on this effort was significantly more than $12 billion, with about one-fourth of that expenditure coming from NIST and SEMATECH.[23]

In sum, the public goods aspects of proof-of-concept research, as well as the collective action problems inherent in developing the infrastructure-like measurement and standards needed for advanced manufacturing innovation, provide significant obstacles to the commercial development of basic science.

Germany's successful Fraunhofer approach to public goods problems in manufacturing

The continuing success of German manufacturing, often in established industries such as machine tools, where SMEs play an important role, relies in significant measure on institutions that are designed to overcome these collective action and public goods problems. The Fraunhofer institutes, a set of 74 public-private applied research institutes, are central to that design. A study by the National Research Council describes their role and operation in the following way:

> *Fraunhofer institutes operate in vast, multiple overlapping human and institutional networks embracing universities, companies, research organizations, trade associations, and foundations, organized by scientific field and areas of interest. Relevant units of these networks can be brought to bear on research projects, consortia, and development alliances to address specific tasks based on their particular competencies. Any private or public entity which enters into a research relationship with Fraunhofer gains entrée to these networks.*
>
> *Fraunhofer is more than a networking organization. It possesses deep and broad organic competencies and institutional scientific memory, reflecting its permanent staff of scientists, technicians, and managers. Its institutes are extremely well-equipped and most of them operate multiple pilot manufacturing lines and other demonstration facilities. The Fraunhofer is a beneficiary of the "power and generosity of the ... German machine tool industry," which permits its labs to be equipped with state-of-the-art machines loaned on generous terms. The institute holds a massive patent portfolio which can be deployed on behalf of clients seeking to license cutting-edge technology. It is relentlessly focused on practical applications of technology.*[24]

The Fraunhofer's current range of areas is wide, including process engineering and packaging; applied optics and precision engineering; laser technology; and wind energy systems.[25] Approximately two-thirds of Fraunhofer funding comes from direct government support and government contracts, and the remainder from private sector contracts.[26] The annual research budget of the Fraunhofer institutes in 2019 was 2.8 billion euros, which implies average annual government support for each institute of about 25 million euros.[27]

The role of workforce development in manufacturing productivity growth

The National Research Council points out that the success of German manufacturing also relies on the country's dual system of vocational training, in which students engage in academic training for practical work while simultaneously receiving training in apprenticeship programs run by firms or public institutes.[28] This commitment to workforce training provides the industry with flexible, highly skilled workers who can adapt to changing production processes. It also provides workers with recognized credentials, which give them mobility and bargaining power with their employers. These credentials, together with extensive union representation, mandatory works councils, and worker representation on corporate boards, help to deliver the high real wages paid to German manufacturing workers.[29]

The United States lacks such a formal training system. Moreover, manufacturing firms have limited incentive to provide worker training that is not firm-specific. Because workers are mobile, other firms can free-ride on that training. While workers have an incentive to pay for training that is not firm-specific, a worker seeking skill-enhancing training faces real obstacles. There are limited opportunities for workers to engage in on-the-job training that allows them to earn while they learn. While unions help organize and fund apprenticeship programs with some employers in certain manufacturing industries, the decline of unions limits the reach of this kind of training. Training that is available through community colleges and other programs is the product of a complex set of federal- and state-supported programs and lacks a recognized credentialing system, which would allow employers to easily identify workers with needed skills and give workers job mobility and the ability to command higher wages.[30] Furthermore, the connection between supported training and subsequent employment is not tight.[31]

The role of demand certainty in manufacturing innovation

Demand plays a central role in sustaining manufacturing innovation. The Fraunhofer public-private partnerships persist because there is demand for some significant fraction of the products that are developed with its help. Given the frontier position of much of German manufacturing, demand for new products can be reasonably forecast and realized. However, when demand is highly uncertain, public support for manufacturing research and development alone is unlikely to deliver limited commercially viable innovation.

It is, for example, recognized that the scale of demand acts as a key limitation on manufacturing innovation in the U.S. defense sector. Although great amounts of money are spent on defense overall, manufacturers outside the defense sector have limited incentive to innovate products that might have defense applications. Relative to commercial products, the defense market can be small. To address this problem, the DOD at times works to find ways to introduce defense-important technology into commercial applications. For example, in the 1990s, the Defense Advanced Research Projects Agency (DARPA) successfully funded research and development in optoelectronics. However, in order to stimulate continued private sector development of the technology, DARPA funded two private-public partnerships that had the goal of establishing commercial fiber-optic networks. These efforts contributed to subsequent broad commercial adoption of fiber-optics.[32]

The absence of demand is especially important for the innovation of carbon-reducing manufactures, which have the potential to produce large external benefits that are not captured by the producer. A recent study by the European Commission Directorate-General for Environment is devoted to policies to initiate markets for these kinds of manufactures through "innovation procurement policy." The study identifies the most significant barrier to this kind of climate-friendly innovation as a "chicken or egg" problem, wherein "manufacturers wait until there is a demonstrated demand before they develop and commercialise technologies, but buyers wait to see the product on the market before they demonstrate they will buy it."[33] The proposed innovation procurement strategies range from public purchase of high-speed trains to public sector investment in the manufacturing process in exchange for a share of future returns.

Demand certainty, on the other hand, has facilitated important manufacturing innovation. A salient example is presented by the development of the global solar photovoltaic panel (PV) industry. Until the late 1990s, there was no mass market for PVs, there was limited production capacity for what was then a niche product, and the cost of PV power was high.

However, the decisions by the governments of Japan, Germany, and Spain to subsidize the adoption of solar power created a surge in demand for solar panels. Because the demand could not be met by existing PV companies, an opening was created for new entrants.[34]

In the early 2000s, several Chinese startup companies entered the PV market and now account for significantly more than half of all PVs produced in the world.[35] Because of continuing technical improvements and scale economies in production, the cost of solar power has decreased dramatically, and in some cases, solar power is now competitive with other sources of electricity.[36]

It should be recognized that while Chinese companies now play a huge role in the PV market, they did not have domestic institutional support for proof-of-concept or infratechnology research and development. Instead, they were able obtain these necessary supports from foreign sources. The technology platform research came from multiple locations. Company management and board members of the Chinese startups often had foreign science degrees and experience in international companies working on solar technology. In addition, several of the startups had strong support from solar research centers at the University of New South Wales (UNSW) and employed many of their graduates. UNSW provided virtual modeling tools that helped the startups establish their first production lines and gave them access to intellectual property.[37] Infratechnology came from international sources as well. The startups were able to conform their output to the quality and testing standards previously created, over time, by NASA's Jet Propulsion Laboratory, UL, TÜV Rheinland, and the International Electrotechnical Commission.[38]

Evaluating current U.S. policy efforts to support manufacturing

The United States has a diverse but not well-coordinated portfolio of policies that are intended to support domestic manufacturing.[39] Two of these programs have a family resemblance to the Fraunhofer institutes, although they are small in comparison and have significant limitations.

Manufacturing Extension Partnership

MEP is a system of government-nonprofit partnerships coordinated by NIST. The program currently comprises 51 manufacturing centers, each operated by a state government, university, or other nonprofit.[40] The centers are intended to help small- and medium-sized manufacturers improve production processes, upgrade their technological capabilities, and innovate. NIST matches funds from nonfederal sources such as state governments or user fees.

The actual level of federal support is quite low. In fiscal year 2019, the MEP budget allocation was $140 million.[41] Total center-related employment, including field staff and NIST employees, was less than 1,900 people in fiscal year 2018.[42]

There is a huge population of manufacturing SMEs in the United States: nearly 250,000 in 2017, employing about 43 percent of all manufacturing workers.[43] The other 57 percent of manufacturing workers are employed by slightly more than 3,900 large firms. One might expect that the large population of SMEs has a more difficult time competing in an increasingly competitive international environment, but this is not universally true. As economist Daniel Luria and political scientist Joel Rogers have pointed out, between 15 percent and 33 percent of manufacturing firms, depending on the subsector, have lower production costs than the median costs of competitors located in low-wage countries. And almost all of these firms have higher productivity than the firms in their industry that do not have lower costs.[44] Another fraction of the manufacturing population is close to matching the cost levels of low-wage competitors[45]—that is to say, increased productivity growth could move many higher-performing U.S. manufacturing firms to the competitive frontier.

MEP also appears to help client firms move in the right direction. Evaluations of MEP centers are generally positive, finding that their services have positive effects on performance indicators such as value added per worker or survival probabilities and that the return on the overall costs of operating the centers is high.[46]

However, although MEP appears effective, it can contribute only modestly to manufacturing productivity growth because it operates at a very small scale. The MEP program is in fact dwarfed by the highly effective Fraunhofer system. U.S. federal support for the entire MEP program is less than the average support for six Fraunhofer centers. The German system has nearly 28,000 employees, more than 14 times that of MEP.[47]

Moreover, the more lightly resourced MEP centers attempt to do far more than the Fraunhofer institutes. In addition to helping with adoption of better production technology, MEP centers help clients implement learn production methods, develop marketing plans, and provide workforce training. It is difficult to imagine how MEP, as currently configured, could effectively address all these issues.

In addition, the MEP centers do not appear to focus their resources on firms that are most likely to benefit from them, or on firms that deliver significant benefits for their workers in the form of wages and compensation. Their services are offered to any firm that wants them.

Manufacturing USA

MUSA is a network of 14 research institutes, each focused on a particular advanced manufacturing technology, intended to make early-stage scientific research suitable for use in manufacturing production. The institutes are all recently established, a result of the Revitalize American Manufacturing and Innovation Act of 2014.[48]

The research institutes are public-private consortia, located near universities or national laboratories. The institutes focus on new technologies with the potential for manufacture as identified by a Massachusetts Institute of Technology-led university and industry group. Each institute has a particular focus. For example, Advanced Functional Fabrics of America (AFFOA), located in Cambridge, Massachusetts, focuses on so-called smart fabrics that have the potential to provide communication, lighting, cooling, health monitoring, and other functions. Lightweight Innovations for Tomorrow (LIFT), located in Detroit, focuses on lightweight and high-performance metals and their associated production processes, which have potential applications in products such as wind turbines, medical devices, and pressure vessels.[49]

The federal government provides funding, with a minimum 1-to-1 cost share from the participating large manufacturing firms, SMEs, and state and local governments. The federal funding for the institutes comes from existing departmental appropriations over a five-year period, after which federal funding sunsets.[50] Ten of the 14 institutes were established with DOD funding, and other funding comes from the departments of Commerce and Energy. Total annual institute expenditure in fiscal year 2019 was $488 million, with $133 million coming from the federal government.[51] Like MEP, the MUSA effort is a tiny program relative to the size of the U.S. manufacturing sector.

Although several institutes engage in workforce training, almost all training activity has been concentrated at the LIFT center, which in 2018 accounted for 93 percent of all students engaged in institute internship and training programs.[52] In general, worker training is not an important focus for most of the institutes.

Although the MUSA institutes are recently established, there has been time for thoughtful evaluation of their operations so far. Policy advisers William Bonvillian and Peter Singer recently wrote *Advanced Manufacturing: The New American Innovation Policies*, an extensive and important account of the genesis and functioning of the institutes, and the National Academies of Sciences, Engineering, and Medicine (NAS) recently published the proceedings of a workshop to evaluate the research institutes.[53] While both evaluations are positive about the progress made thus far, they also identify areas where there are significant shortcomings. According to the evaluations, the institutes need to do more when it comes to:

- **Providing effective support for SMEs and domestic supply chains:** The NAS proceedings note that many SMEs are not sufficiently sophisticated to take advantage of the networking, collaboration, and product implementation resources provided by the institutes. The proceedings describe successes in aiding SMEs, such as the ability of the AFFOA and America Makes institutes to develop networks that allow SMEs to implement new technology along with help in developing clusters of regional manufacturers. However, low-productivity, low-wage SMEs were noted as an ongoing source of weakness that is difficult for the institutes to address on their own.[54]

Furthermore, as both the NAS and Bonvillian and Singer point out, there is a tendency for the interests of SMEs to be crowded out by those of larger manufacturers, which are better able to provide matching funds for the institutes. These bigger firms tend to have a greater interest in technology development and less in process development, feedback, and testing.[55]

- **Providing workforce training needed for the successful use of advanced manufacturing methods:** Although many advanced manufacturing jobs do not require university degrees, manufacturing workers do need to have requisite middle-level skills. SMEs have particular difficulty finding workers with requisite skills;[56] they have limited resources to develop on-the-job training, and existing community college and vocational training is often not aligned with manufacturing needs.

  This has become evident as the institutes have operated, and some such as AFFOA and LIFT have developed, training initiatives of their own. However, workforce development has not been a coordinated focus across the institutes. Asking lightly funded institutes to achieve both technology and workforce development goals seems excessive, and it is not surprising that most have not done much in this regard.

- **Providing support over a sufficient horizon:** Federal support is provided for five years. This is short of the 10 years or more required to translate basic scientific innovation into manufacturing processes.[57]

- **Providing metrics for institute performance:** To date, there are limited metrics that can be used to measure the goals of the institutes and whether they have been met, although MUSA has recognized this issue and has made steps to develop a set of metrics.[58] It is important to have detailed metrics on employment, workforce development, and intellectual property creation in the institutes.

Policy changes to effectively support manufacturing competitiveness

While existing federal policy recognizes the problem of translating science into manufacturing innovation, efforts to address the issue are insufficient. As the forgoing review of these efforts shows, the scale of that federal policy response is not adequate to complete the task. The efforts fail to provide sufficient support to high-performing firms, do not address workforce development needs systematically, and fail to direct federal demand for manufactured goods to high-performing domestic firms.

Moreover, to date, there has been no coordinated effort to respond to the manufacturing changes required by climate change. The pressing worldwide need to address greenhouse gas emissions will require innovative manufacturing processes and techniques. This presents opportunities to increase the competitiveness and scale of domestic manufacturing.

Policy changes to address these shortfalls include the following actions.

Expand and improve MEP institutes

To move the MEP program to an effective level, funding for each institute should be raised to a much higher level. Federal funding of $25 million per year for each of the MEP institutes would bring them near Fraunhofer level. Given the variety of manufacturing technologies in the United States, 100 institutes might easily be required to meet the needs of domestic industry. As is currently the case, funding should be provided for five years, renewable for 10 years on the condition of meeting defined goals.

MEP programs should be located around important industries and industrial clusters rather than allocated them equally across states. At the moment, the institutes are distributed in traditional congressional fashion, with one located in every state and Puerto Rico. This sort of geographical allocation will meet the actual needs of manufacturers only by chance. A more effective allocation would be to focus the institutes around particular manufacturing technologies and place them adjacent to the clusters of large firms and SMEs that use them.

As policy experts Daniel Luria, Joel Rogers, and Susan Helper have advocated,[59] MEP should focus on firms that have a reasonable chance of becoming competitive in the long run and that deliver good wages and working conditions for their employees. Therefore, MEP should only provide services to SMEs that have high value added per full-time equivalent employee, pay wages at the top third for their industry, and provide continuing high-standard worker training.

Renewal of funding for MEP programs should be based on measurable criteria, such as creation of important intellectual property, introduction of new manufactured products, inclusion of SMEs, and improvement in SMEs' productivity and wages.

Expand and improve MUSA institutes

The MUSA institutes should be funded at the level proposed for MEP institutes, with matching funds provided by participating firms. The current number of institutes is modest, and expansion to at least 25 institutes would bring the effort nearer to Made in China 2025 levels. The proposed MEP conditions on funding duration, metrics, workforce development, and the requirement that institutes should work with high-performing firms should also apply to the MUSA institutes.

Coordinate workforce development for MEP and MUSA through the DOL

The DOL should develop—in coordination with the institutes, worker representatives, and participating businesses—training programs that solve the problems of existing training schemes. Such an effort would subsidize not only manufacturers, but also efforts of manufacturing workers to build their human capital and achieve greater labor market mobility.

Worker representation, certainly including but not limited to trade unions with experience developing successful apprenticeship programs, is essential. Through participation in the design of training programs, workers would have some influence on how new and developing technology is implemented in firms. This can help improve on-the-job conditions and increase the desirability of manufacturing work.

Firms participating in MEP and MUSA programs should be required to have high-quality workforce development programs so that workers are prepared to participate in an expanding and more advanced manufacturing sector.

Direct government expenditure to domestic manufacturers that are more productive and pay higher real wages

To provide the economic incentive for adopting high-performing manufacturing production, federal expenditures on manufactured goods should be conditioned on the characteristics of manufacturing firms. That is, firms should have high value added per unit of labor input, real wages should be in the top third for its industry, and the firm should provide quality worker training.

To the extent that these federal purchase requirements affect foreign suppliers of manufactured goods, they may conflict with restrictions in the World Trade Organization Agreement on Government Procurement (GPA), to which the United States is a party.[60] Article VIII (b) of the GPA limits the participation criteria for firms bidding on government contracts to those "essential to ensure the firm's capability to fulfill the contract in question."[61]

It may be the case that the high-performing domestic firms that this rule is intended to support would be unharmed if foreign manufacturers were exempt from the high-performance requirements. The most efficient domestic manufacturers might be able to meet foreign bids because of their productive advantages. However, if this should not be true, it might be necessary to revise the GPA to allow government support for high-performing domestic firms.

Help domestic manufacturing adopt new technology to meet the requirements related to climate change

The expanded MEP and MUSA institutes should help domestic manufacturers adapt to changed production requirements related to climate change. As climate change forces governments around the world to limit greenhouse gas emissions, manufacturers will need to employ new technologies both to meet domestic regulatory requirements and to avoid impending carbon border adjustment taxes on exports with high embedded carbon content.[62]

Some MUSA institutes could, for example, help to develop the nascent low greenhouse gas technologies for industries such as cement, steel, and renewable hydrogen production. These technologies could put domestic producers in a stronger competitive position in world markets, and, in coordination with MEP, MUSA institutes could make sure that these technologies are disseminated widely across the manufacturing economy.

Cement production

The global cement industry releases 8 percent of global carbon dioxide emissions.[63] Half of this comes from the coal burned to generate the industrial heat used in the cement-making process, and the remainder is released as a byproduct of the chemical reaction needed to generate cement from limestone.

Innovations to reduce the emissions of the latter carbon dioxide source are referred to as "clean cement." These innovations can include cements with substitutes for clinker, the ingredient that releases carbon dioxide in a chemical reaction; clinker-reducing cement formulas; use of supplementary cement materials; alternative lower-carbon cement chemistries; and carbon-sequestering cement. These can all give domestic producers who successfully implement them a competitive edge.[64]

Steel production

The U.S. steel industry, including iron production, currently relies on natural gas and coal coke breeze for fuel and is one of the largest energy consumers in the manufacturing sector.[65] Steel manufacture contributes 6 percent to 7 percent of global greenhouse gas emissions.[66] Zero- or low-carbon steel, which will reduce greenhouse gas emissions, requires mining iron from ore through electrolysis powered by electricity or hydrogen and replacing fossil fuel-generated heat used for the steel-making process. Technical advances that can help to meet these requirements are being piloted by producers around the globe.[67] Domestic steel producers will be more competitive if they can successfully implement low-emission processes.

Renewable hydrogen from electrolysis

As domestic and world electricity production transitions to renewable sources, there is increased need for storage of energy that is produced intermittently. Manufacturing that storage technology will fill a substantial demand. Among the promising possibilities is the use of excess electricity production to create hydrogen, which can then be used as clean fuel.

Hydrogen has the potential to provide low- or no-emission medium- to high-temperature industrial heat; enable innovative processes, such as the production of low-emission steel; and replace natural gas and coal as a low-emission industrial feedstock. Hydrogen from electrolysis, which differs from hydrogen produced from natural gas, uses electricity to split water into hydrogen and oxygen.[68] This fuel can be produced through excess electricity from renewable energy resources, often called green hydrogen or renewable hydrogen, which would otherwise be curtailed or wasted—making hydrogen a long-duration energy storage technology as well.

Work has been done to develop manufacturing technology in each of these cases, but more is needed to implement these processes on a large scale. Coordinated efforts among MEP, MUSA, and domestic manufacturers have a reasonable chance of success and could produce long-term competitive advantage as greenhouse gas reduction becomes more central to government policy worldwide.

Eliminating strategic supply chain risks

A second set of manufacturing-related issues arises from the evolving structure of production. Adoption of just-in-time production methods, a focus on core competencies, and cost minimization have led manufacturers to avoid investing in reserve production capacity. At the same time, improvements in information technology and containerized shipping have allowed U.S. manufacturers intent on reducing costs and capital expenditure to outsource and offshore substantial parts of their production processes to locations around the globe.

While for some industries this supply system serves America's domestic needs reasonably well, that is not always the case. The example of the COVID-19 pandemic has shown that dispersed or insufficient domestic manufacturing capacity of crucial health care products such as vaccines, medications, and personal protective equipment can expose the U.S. population to unacceptable risks. When there is a surge in demand, there is a need to increase supply quickly, which may be impossible unless there is spare production capacity to meet America's domestic needs.

In addition, recent assessments of U.S. defense production capability suggest that a lack of domestic manufacturing capacity in a variety of areas such as microelectronics creates undesirable national security vulnerabilities.[69]

When it is clear that normal business behavior creates important supply-side risks, those risks need to be addressed directly. This requires two steps:

1. The identification of products that need to be stockpiled or manufactured domestically or by a trusted subset of nations in order to eliminate unacceptable risk

2. Where required, the expansion or creation of a U.S. manufacturing base that can be depended upon to provide the necessary goods

The required steps are explored below, using the examples of health care and national defense. However, it is clear that a thorough examination of overall supply chain risks and needed mitigation efforts is in order.

U.S. health care

Identification of crucial products

The succession of threats from the SARS and Ebola viruses, and the ongoing COVID-19 pandemic, shows that the United States needs to be able to respond quickly and effectively to viral epidemics. The immediate response to the current pandemic has been hampered by limitations in the health care manufacturing base.

As explained in a July 2020 Center for American Progress report from Topher Spiro and Zeke Emanuel, the recent development of COVID-19 vaccines is only a first step in immunizing the population.[70] Manufacturing and delivering vaccines is very likely to be hampered by gaps in capacity. The shortages are likely to be felt in vaccine manufacturing, fill-finish facilities that put the vaccine in vials, supplies of vials, rubber stoppers for vials, needles and syringes, and cold storage capacity. A coordinated effort to map and mobilize existing manufacturing capacity, and retrofit capacity for vaccine-related production and delivery, is clearly needed. Reallocation of production capacity to vaccines may affect the ability of manufacturers to supply other needed drugs. Therefore, some central coordination will be required to minimize such impacts.

Given that COVID-19 vaccines are likely to be needed for years to come, and taking into account a rising frequency of viral epidemics, a coordinated effort to calculate and establish the necessary surge capacity for producing vaccines and delivery capacity is clearly in order.

Lack of manufacturing capacity and effective stockpiling of basic supplies for essential workers have also become apparent during the pandemic. There have been widespread shortages of personal protective equipment—including masks, gowns, and face shields—and supplies such as sanitizing wipes. Stockpiles of ventilators were inadequate, and ramping up production proved to be difficult. These shortages need to be addressed immediately. The Defense Production Act provides authority and funds to redirect existing production capacity and support needed expansion to meet these shortfalls.

Shortages in prescription pharmaceuticals needed to treat COVID-19 patients also point to critical weakness in the U.S. drug supply. As a recent report from the Center for Infectious Disease Research and Policy (CIDRAP) at the University of Minnesota points out, the Food and Drug Administration (FDA) says that shortages exist among 18 of the 40 critical drugs for COVID-19 patients, while the American Society for Health-System Pharmacists puts the number substantially higher.[71] These drugs include sedatives for intubated patients, albuterol inhalers, and antibiotics such as azithromycin. These shortages affect patients with other conditions who also need these drugs. When there are shortages, doctors can be forced to ration drugs, and in some instances, patients may not receive needed treatment.

While these shortages reflect a huge surge in demand, they also signal the inability of domestic and foreign drug manufacturers to redirect capacity or mobilize unused capacity to meet the need. It is startling to note just how little is known about where the supply problems are located. CIDRAP estimates that in 2019, two-thirds of U.S. drugs and about 55 percent of biologic and specialty drugs were imported.[72] According to the FDA, 28 percent of the facilities manufacturing active pharmaceutical ingredients (APIs) are located in the United States, while India has 18 percent of API facilities and China 13 percent.[73] But beyond data such as these, limited information exists about production capacity and utilization.

This lack of information makes it difficult to know with precision the weak points in domestic supply. As the director of the FDA Center for Drug Evaluation and Research noted in a congressional testimony, "The security of the nation's drug supply rests on three main factors: freedom from dependence on foreign sources of API, the resilience of our domestic manufacturing base, and the reliability of the facilities that make products for the U.S. market."[74] But the director went on to say that the FDA lacks the information needed to measure how dependent the United States is on foreign APIs, since policymakers do not know the amount of these APIs included in domestic consumption. That lack of information extends to measuring how quickly domestic producers of APIs could increase their production to meet domestic demand if foreign supplies were cut off, since domestic production capacities are unknown as well.

A systematic effort to identify potential gaps in the health care supply is required. This was explicitly recognized in the Coronavirus Aid, Relief, and Economic Security (CARES) Act.[75] Section 4111 of the act requires the U.S. Department of Health and Human Services (HHS) to commission a National Academies of Sciences, Engineering, and Medicine report on the supply chain of critical drugs and medical devices and to recommend steps to remedy risks. This report should provide systematic information of the risks discussed above and indicate where there are gaps in domestic stockpiles and production capability that need to be filled in the near and long term.

Section 4112 of the CARES Act amends the Public Health Service Act to require the strategic national stockpile to include personal protective equipment, supplies needed for the administration of drugs, and diagnostic tests. This mandate will require HHS to determine what should be stockpiled in the future.

Capacity expansion

After the above steps are taken and health care supply risks are well-identified, needed domestic health-related manufacturing capacity and stockpiles should be secured. It may be possible to meet this goal through an agreement with trusted international partners. Where it is determined that domestic capacity needs to be established, creation of a manufacturing base is essentially a problem of subsidizing production that is currently done elsewhere, or not done at all.

A potential approach to domestic capacity expansion is to make available capacity payments for critical products to ensure sufficient supply. In some U.S. electric power markets, for example, producers get capacity payments to cover capital costs for generation facilities in exchange for a commitment to meet peak demand.[76] These payments are often determined at auction, which introduces a limited amount of competition. Similar subsidies could be used to establish domestic capacity in areas identified as critical, such as vaccine production and delivery, generic drugs, and medical equipment.

U.S. national defense

Identification of crucial products

Because of its mission, the DOD requires a supply of manufactured goods that is secure in times of conflict, that comes from trusted producers that deliver uncompromised products, and that is at a technical level sufficient to deter or defeat potential adversaries. While many defense goods are highly specialized systems delivered by large defense contractors—which make planes, ships, communications equipment, weapons, and other complex products—those contractors cannot by themselves provide all the mechanical, electronic, chemical, software, and other inputs that are required. These large contractors rely on other, commercially oriented manufacturers. And while the DOD obtains much of what it needs from large contractors, it also directly depends on a wide range of manufacturers for critical supplies.[77] Ultimately, the DOD depends on a nondefense manufacturing base to meet important security-related needs.

While the needs of the DOD are large in the aggregate, defense demand for particular products can be so small relative to the commercial demand, or so specialized, that it fails to support a reliable supplier base. The DOD fiscal year 2019 Industrial Capabilities Report identifies several gaps in the domestic manufacturing base that raise national security concerns.[78] These concerns can be most easily understood by considering examples cited in the DOD report.

For example, microelectronic integrated circuits are extremely small electronic components often made of semiconductor material. According to the DOD report, microprinted circuit boards (micro-PrCBs) are essential to all national defense electronic systems.[79] However, the report points to several risks to defense procurement. First, U.S. manufacturing production capacity is in decline. Nearly all commercial production capacity for micro-PrCBs is located in Taiwan, South Korea, Japan, and China; competition is intense and capital costs for fabrication facilities are high, discouraging new entrants; and there is limited research and development for defense-related micro-PrCBs.[80] Second, government procurement rules do not require that micro-PrCBs be purchased from trusted manufacturers, which means that faulty or malicious products could be introduced into systems purchased by the DOD. Third, difficulties in filling and replacing domestic STEM professionals in the PrCB workforce are expected to worsen. Finally, the scale of Chinese support for domestic and foreign high-tech manufacturers may make it more difficult for U.S. firms to enter and compete in this market.

In short, micro-PrCBs are important to national security, but the economics of commercial production have located it mostly outside the United States, and foreign producers are developing technical and cost advantages that force the DOD to depend on them.[81] Even if procurement rules were changed, it is not clear that DOD-related demand would be sufficient to incentivize domestic production at the most technically advanced level.

Another manufacturing area that poses security issues is the mining and refining of rare earths such as cobalt and lithium. Rare earths are used in high-tech devices such as cell phones, electronic displays, lasers, and guidance and sonar systems. While the continental United States has deposits of rare earths, domestic production of these metals has declined significantly in recent decades, and 97 percent of world production is now located in China.[82] China significantly reduced exports in 2010, causing world demand to exceed supply.[83] The DOD has funded the reopening of a California rare earth mine, although it is partially funded by a Chinese company that takes all of its product. This has engendered some skepticism.[84]

Capacity expansion

While the DOD has done a lot to stimulate frontier technological development through a variety of avenues—via projects funded through DARPA and MUSA institutes—its own industrial capabilities gap analysis recognizes that there are significant weaknesses in the manufacturing supply chain that ought to be addressed. As in the case of health care, this is likely to require subsidies of capital investment.

A recent U.S. Air Force program to end the use of Russian rocket engines for military satellite launches provides an example of using capital subsidies to build desired capacity.[85] In 2018, the Air Force sponsored a competition for the design of a new rocket engine. United Launch Alliance, Northrop Grumman, and Blue Origin were awarded contracts worth $2.3 billion to develop the new engines.[86] The companies were incentivized to participate because the winners would be eligible for military launch contracts, which would add stable revenue to their earnings from civilian satellite launches.

The Air Force chose the United Launch Alliance engine and the existing SpaceX engine as the winners. Those two companies since have been awarded contracts for military satellite launches for the next five years.[87] Whether the new rocket engines perform as reliably as the older Russian engine will only be determined over time. But subsidies for engine development clearly played a role in developing commercial launch companies whose services aligned with DOD national security concerns.

The DOD has several avenues for subsidizing capital investment, including the Defense Production Act Title III program[88] and the Industrial Base Analysis and Sustainment Program.[89] The level of funding for these and other sources of funds depends on congressional appropriations, which have declined in recent years. These funds to close manufacturing capacity gaps, in coordination with expanded MEP and MUSA efforts, could help strengthen domestic competitiveness.

Conclusion

Two key challenges face the U.S. manufacturing sector: supporting long-run productivity growth, especially for small- and medium-sized enterprises, and reducing the risks presented by extended global supply chains. Failing to address productivity challenge will allow the U.S. manufacturing sector to continue losing ground to international competitors, and ignoring supply chain vulnerabilities will leave U.S. citizens exposed to unacceptable levels of personal and economic harm.

The policy changes identified in the report will help to meet these challenges. These recommendations include expanding and reconfiguring both the MEP and MUSA programs. The DOL should also be mandated to develop workforce training for firms participating in MEP and MUSA in order to enable workers to adapt to new production processes. And the federal government should take a more deliberate approach to buying manufactured goods, directing its purchases to high-performing domestic firms with high productivity, high wages, and good workforce training. A systematic effort to carefully map supply chains for strategically important manufactured products is also necessary, and where important risks exist, there may be a need to create domestic manufacturing capacity.

Addressing both challenges is critical. Sustained and improved competitiveness is necessary if America's manufacturing sector is to provide expanded, high-wage employment to workers. Eliminating significant health care, defense, and other risks caused by global manufacturing supply chains is crucial for the safety and well-being of U.S. citizens. Given the importance of both these challenges, the policy changes recommended in this report ought to be a priority.

About the author

Marc Jarsulic is a senior fellow and chief economist at the Center for American Progress.

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Endnotes

1 Martin Neil Baily, Barry Bosworth, and Siddhi Doshi, "Productivity comparisons: Lessons from Japan, the United States and Germany" (Washington: Brookings Institution, 2020), p. 11, available at https://www.brookings.edu/wp-content/uploads/2020/01/ES-1.30.20-BailyBosworthDoshi.pdf.

2 See Robert Shackleton, "Total Factor Productivity Growth in Historical Perspective" (Washington: Congressional Budget Office, 2013), available at https://www.semanticscholar.org/paper/Total-Factor-Productivity-Growth-in-Historical-Shackleton/b436d848641fd396e13094d-3327255cb777348cd.

3 Baily, Bosworth, and Doshi, "Productivity comparisons," pp. 35–36.

4 Ibid.

5 Susan Houseman and others, "Offshoring Bias in U.S. Manufacturing," *Journal of Economic Perspectives* 25 (2) (2011): 111–132, available at https://pubs.aeaweb.org/doi/pdfplus/10.1257/jep.25.2.111.

6 See National Research Council, *21st Century Manufacturing: The Role of the Manufacturing Extension Partnership Program* (Washington: The National Academies Press, 2013), pp. 29–32.

7 Joseph Parilla, Jesus Leal Trujillo, and Alan Berube, "Skills and Innovation Strategies to Strengthen U.S. Manufacturing: Lessons from Germany" (Washington: Brookings Institution, 2015), p. 7, available at https://www.brookings.edu/wp-content/uploads/2016/06/LessonsFromGermany.pdf.

8 Ibid.

9 Value added is the difference between the price of a product and the costs of producing it.

10 Marc Levinson, "U.S. Manufacturing in International Perspective" (Washington: Congressional Research Service, 2018), p. 2, available at https://fas.org/sgp/crs/misc/R42135.pdf; World Trade Organization, "World Trade Statistical Review 2020, Chapter VI: Statistical tables, Table A16" (Geneva: 2020), available at https://www.wto.org/english/res_e/statis_e/wts2020_e/wts2020chapter06_e.pdf.

11 David H. Autor, David Dorn, and Gordon H. Hanson, "The China Shock: Learning from Labor-Market Adjustment to Large Changes in Trade," *Annual Review of Economics* 8 (2016): 205–240, p. 223, available at http://www.ddorn.net/papers/Autor-Dorn-Hanson-ChinaShock.pdf; Daron Acemoglu and others, "Import Competition and the Great US Employment Sag of the 2000s," *Journal of Labor Economics* 34 (S1) (2016): S141–S198, available at https://economics.mit.edu/files/11560; Christoph E. Boehm, Aaron Flaaen, and Nitya Pandalai-Nayar, "Multinationals, Offshoring and the Decline of U.S. Manufacturing" (Cambridge, MA: National Bureau of Economic Research, 2019), available at https://www.nber.org/papers/w25824.

12 An estimate of Chinese manufacturing wages can be found in Levinson, "U.S. Manufacturing in International Perspective," p. 11. For a description of the government's fiscal and financial role in the Chinese economy, see Barry Naughton, *The Chinese Economy: Adaptation and Growth* (Cambridge, MA: The MIT Press, 2018), chapters 14–15, 19–20.

13 Loren Brandt, Johannes Van Biesebroeck, and Yifan Zhang, "Creative Accounting or Creative Destruction? Firm-level Productivity Growth in Chinese Manufacturing" (Cambridge, MA: National Bureau of Economic Research, 2009), available at https://www.nber.org/papers/w15152.

14 Made in China 2025 is described in James McBride and Andrew Chatzky, "Is 'Made in China 2025' a Threat to Global Trade?", Council on Foreign Relations, May 13, 2019, available at https://www.cfr.org/backgrounder/made-china-2025-threat-global-trade; Karen M. Sutter, "'Made in China 2025' Industrial Policies: Issues for Congress (Washington: Congressional Research Service, 2020), available at https://fas.org/sgp/crs/row/IF10964.pdf.

15 Gregory Tassey, "Competing in Advanced Manufacturing: The Need for Improved Growth Models and Policies," *Journal of Economic Perspectives* 28 (1) (2014): 27–48, available at https://www.aeaweb.org/articles?id=10.1257/jep.28.1.27.

16 Ibid., p. 28.

17 Ibid.

18 Michael Riordan, "The End of AT&T," IEEE Spectrum, July 1, 2005, available at https://spectrum.ieee.org/tech-history/dawn-of-electronics/the-end-of-att.

19 Ibid.

20 E.M., "Sematech: Model Project Gets Mixed Reviews," *Science* 255 (5051) (1992): 1501, available at https://science.sciencemag.org/content/255/5051/1501.

21 Douglas A. Irwin and Peter J. Klenow, "Sematech: Purpose and Performance," *Proceedings of the National Academy of Science* 93 (23) (1996): 12739–12742, available at https://doi.org/10.1073/pnas.93.23.12739.

22 After its first 10 years, SEMATECH began operating without government support, but public support apparently played a role in overcoming public goods obstacles. For additional history of SEMATECH, see Robert D. Hof, "Lessons from Sematech," *MIT Technology Review*, July 25, 2011, available at https://www.technologyreview.com/2011/07/25/192832/lessons-from-sematech/.

23 Michael P. Gallaher and others, "Economic Impact of Measurement in the Semiconductor Industry" (Gaithersburg, MD: National Institute for Standards and Technology, 2007), Table ES-1, p. ES-10, available at http://www.nist.gov/director/planning/upload/report07-2.pdf.

24 National Research Council, *21st Century Manufacturing*, pp. 228–229.

25 A description of the institute research areas is available at Fraunhofer, "Institutes and Research Establishments in Germany," available at https://www.fraunhofer.de/en/institutes/institutes-and-research-establishments-in-germany.html (last accessed March 2021).

26 National Research Council, *21st Century Manufacturing,* p. 138.

27 Fraunhofer, "Annual Report 2019" (Munich, 2019), p. 1, available at https://www.fraunhofer.de/content/dam/zv/en/Publications/Annual-Report/2019/Fraunhofer-Annual-Report-2019.pdf.

28 National Research Council, *21st Century Manufacturing*, p. 230.

29 See David Madland, "The Future of Worker Voice and Power" (Washington: Center for American Progress, 2016), available at https://www.americanprogress.org/issues/economy/reports/2016/10/11/143072/the-future-of-worker-voice-and-power/.

30 The limitations of the existing manufacturing workforce training system are discussed in detail in National Academies of Sciences, Engineering, and Medicine, *Building America's Skilled Technical Workforce* (Washington: The National Academies Press, 2017), pp. 73–78, 87–92, 146–151.

31 The need to condition support for workforce training on the delivery of quality jobs is emphasized in Jonathan F. Harris and Livia Lam, "Is There a Right to Job Quality? Reenvisioning Workforce Development," *California Law Review Online* 339 (2020), available at https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3644346.

32 Potomac Institute for Policy Studies, "Consortia Analysis and Recommendations Trade Study" (Arlington, VA: 2017), p. 15, available at https://potomacinstitute.org/images/studies/CARTSsm.pdf.

33 Directorate-General for Environment, "Bridging the Valley of Death: public support for commercialisation of eco-innovation" (Brussels: European Commission, 2009), p. 2, available at https://ec.europa.eu/environment/enveco/rd_innovation/pdf/studies/bridging_valley_report.pdf.

34 Christian Binz and Laura Diaz Anadon, "Unrelated diversification in latecomer contexts: Emergence of the Chinese solar photovoltaics industry," *Environmental Innovation and Societal Transitions* 28 (2018): 14–34, p. 25, available at https://doi.org/10.1016/j.eist.2018.03.005.

35 Bloomberg News, "The Solar-Powered Future is Being Assembled in China," September 14, 2020, available at https://www.bloomberg.com/features/2020-china-solar-giant-longi/.

36 See Lazard, "Levelized Cost of Energy and Levelized Cost of Storage – 2020," October 19, 2020, available at https://www.lazard.com/perspective/levelized-cost-of-energy-and-levelized-cost-of-storage-2020/.

37 Binz and Anadon, "Unrelated diversification in latecomer contexts," pp. 23–25.

38 Ibid., p. 27.

39 Government Accountability Office, "U.S. Manufacturing: Federal Programs Reported Providing Support and Addressing Trends" (Washington: 2017), available at https://www.gao.gov/assets/690/683753.pdf.

40 Congressional Research Service, "The Manufacturing Extension Partnership Program" (Washington: 2019), p. 1, available at https://fas.org/sgp/crs/misc/R44308.pdf. The current configuration of centers was determined in a 2017 competition. Support for a center is initially promised for five years, contingent on performance, and support can be extended for an additional five-year period.

41 Ibid.

42 Ibid.

43 Following the practice of the Small Business Administration, SMEs are defined as those with fewer than 500 employees. Data on SMEs cited in this report are from U.S. Census Bureau, "2017 SUSB Annual Data Tables by Establishment Industry," March 2020, available at https://www.census.gov/data/tables/2017/econ/susb/2017-susb-annual.html.

44 Daniel Luria and Joel Rogers, "Manufacturing, Regional Prosperity, and Public Policy," in Richard M. McGahey and Jennifer S. Vey, eds., *Retooling for Growth: Building a 21st Century Economy in America's Older Industrial Areas* (Washington: Brookings Institution Press, 2007), 257–262, available at https://www.brookings.edu/book/retooling-for-growth/.

45 Susan Helper, "The High Road for U.S. Manufacturing," *Issues in Science and Technology* 25 (2) (2009), available at https://issues.org/helper/#; Susan Helper, "Renewing U.S. Manufacturing: Promoting a High-Road Strategy" (Washington: Economic Policy Institute, 2008), available at https://www.epi.org/publication/bp212/.

46 Clifford A. Lipscomb and others, "Evaluating the Long-Term Effect of NIST MEP Services on Establishment Performance" (Washington: U.S. Census Bureau Center for Economic Studies, 2015), available at https://www.researchgate.net/publication/273781832_Evaluating_the_Long-Term_Effect_of_NIST_MEP_Services_on_Establishment_Performance; Jim Robey and others, "The National-Level Economic Impact of the Manufacturing Extension Partnership (MEP): Estimates for Fiscal Year 2018" (Kalamazoo, MI: W.E. Upjohn Institute for Employment Research, 2019), available at https://research.upjohn.org/reports/239/.

47 For Fraunhofer employment, see Fraunhofer, "Employees: Growth in the Fraunhofer-Gesellschaft's workforce 2015–2019," available at https://www.fraunhofer.de/en/about-fraunhofer/profile-structure/facts-and-figures/employees.html (last accessed March 2021).

48 Revitalize American Manufacturing and Innovation Act of 2014, H.R. 2996, 113th Cong., 2nd sess. (September 16, 2014), available at https://www.congress.gov/bill/113th-congress/house-bill/2996.

49 For a description of the structure of the program see Manufacturing USA, "Report to Congress Fiscal Year 2019" (2020), pp. 1–13, available at https://www.manufacturingusa.com/sites/manufacturingusa.com/files/2021-01/Manufacturing%20USA%20Annual%20ReportToCongress%20FY2019%20final.pdf.

50 Ibid., p. iii.

51 Ibid.

52 Ibid, p. 12.

53 William B. Bonvillian and Peter L. Singer, *Advanced Manufacturing: The New American Innovation Policies* (Cambridge, MA: The MIT Press, 2017); National Academies of Sciences, Engineering, and Medicine, *Securing Advanced Manufacturing in the United States: The Role of Manufacturing USA, Proceedings of a Workshop*. (Washington: The National Academies Press, 2017).

54 National Academies of Sciences, Engineering, and Medicine, *Securing Advanced Manufacturing in the United States*, pp. 6–7, 25–29.

55 Ibid., p. 7; Bonvillian and Singer, *Advanced Manufacturing,* pp. 170–171.

56 National Academies of Sciences, Engineering, and Medicine, *Securing Advanced Manufacturing in the United States,* pp. 17-23.

57 Ibid., p. 36; Bonvillian and Singer, *Advanced Manufacturing,* pp. 166–168.

58 National Academies of Sciences, Engineering, and Medicine, *Securing Advanced Manufacturing in the United States,* pp. 35–36; Bonvillian and Singer, *Advanced Manufacturing,* pp. 174–175; Manufacturing USA, "Report to Congress Fiscal Year 2019," pp. 6–14.

59 See Helper, "Renewing U.S. Manufacturing," p. 22.

60 Congressional Research Service, "WTO Agreement on Government Procurement (GPA)" (Washington: 2020), available at https://crsreports.congress.gov/product/pdf/IF/IF11651. Note that the GPA does not cover every member of the WTO, not all government entities or categories of goods and services are covered, and national security purchases are exempt.

61 Peter Kunzlik, "International Procurement Regimes and the Scope for the Inclusion of Environmental Factors in Public Procurement," in Organization for Economic Cooperation and Development, *The Environmental Performance of Public Procurement: Issues of Policy Coherence* (Paris: 2003), p. 114, available at https://www.oecd-ilibrary.org/environment/the-environmental-performance-of-public-procurement/international-procurement-regimes-and-the-scope-for-the-inclusion-of-environmental-factors-in-public-procurement_9789264101562-7-en.

62 Francesco Guarascio and Jonas Ekblom, "Explainer: What an EU carbon border adjustment tax might look like and who would be hit," Reuters, December 10, 2019, available at https://www.reuters.com/article/us-climate-change-eu-carbontax-explainer/explainer-what-an-eu-carbon-border-tax-might-look-like-and-who-would-be-hit-idUSKBN1YE1C4.

63 Netherlands Environmental Assessment Agency, "Trends in Global CO2 Emissions: 2016 Report" (The Hague: 2016), p. 65, available at https://edgar.jrc.ec.europa.eu/news_docs/jrc-2016-trends-in-global-co2-emissions-2016-report-103425.pdf.

64 Descriptions of the technological challenges and developments in cement and steel production are available at Chris Bataille, "Low and zero emissions in the steel and cement industries: Barriers, technologies and policies" (Paris: Organization for Economic Cooperation and Development Green Growth and Sustainable Development Forum, 2019), available https://www.oecd.org/greengrowth/GGSD2019_Steel%20and%20Cemement_Final.pdf. See also Maddie Stone, "Cement has a carbon problem. Here are some concrete solutions," Grist, November 20, 2019, available at https://grist.org/politics/cement-has-a-carbon-problem-here-are-some-concrete-solutions/.

65 U.S. Energy Information Administration, "Manufacturing Energy Consumption Survey (MECS), Steel Industry Analysis Brief," available at https://www.eia.gov/consumption/manufacturing/briefs/steel/ (last accessed March 2021).

66 Thomas Koch Blank, "The Disruptive Potential of Green Steel" (Washington: Rocky Mountain Institute, 2019), p. 1, available at https://rmi.org/wp-content/uploads/2019/09/green-steel-insight-brief.pdf.

67 See Ibid., pp. 3–7; Bataille, "Low and zero emissions in the steel and cement industries," pp. 19–22.

68 U.S. Department of Energy Office of Energy Efficiency and Renewable Energy, "Hydrogen Production: Electrolysis," available at https://www.energy.gov/eere/fuelcells/hydrogen-production-electrolysis#:~:text=Electrolysis%20is%20a%20promising%20option,a%20unit%20called%20an%20electrolyzer (last accessed March 2021).

69 U.S. Government Accountability Office, "Trusted Defense Microelectronics: Future Access and Capabilities Are Uncertain" (Washington: 2015), available at https://www.gao.gov/products/GAO-16-185T; U.S. Department of Defense, "Assessing and Strengthening the Manufacturing and Defense Industrial Base and Supply Chain Resiliency of the United States" (Washington: 2018), available at https://media.defense.gov/2018/Oct/05/2002048904/-1/-1/1/ASSESSING-AND-STRENGTHENING-THE-MANUFACTURING-AND%20DEFENSE-INDUSTRIAL-BASE-AND-SUPPLY-CHAIN-RESILIENCY.PDF.

70 Topher Spiro and Zeke Emmanuel, "A Comprehensive COVID-19 Vaccine Plan: Efficient Manufacturing, Financing, and Distribution of a COVID-19 Vaccine" (Washington: Center For American Progress, 2020), available at https://www.americanprogress.org/issues/healthcare/reports/2020/07/28/488196/comprehensive-covid-19-vaccine-plan/.

71 Center for Infectious Disease Research and Policy, "COVID-19: The CIDRAP Viewpoint, Part 6: Ensuring a Resilient US Prescription Drug Supply" (Minneapolis: University of Minnesota, 2020), p. 2, available at https://www.cidrap.umn.edu/sites/default/files/public/downloads/cidrap-covid19-viewpoint-part6.pdf.

72 Ibid, p. 7

73 Janet Woodcock, "Testimony Before the House Committee on Energy and Commerce, Subcommittee on Health, Safeguarding Pharmaceutical Supply Chains in a Global Economy," October 30, 2019, available at https://www.fda.gov/news-events/congressional-testimony/safeguarding-pharmaceutical-supply-chains-global-economy-10302019.

74 Ibid.

75 Text of the CARES Act is available at Coronavirus Aid, Relief, and Economic Security Act, Public Law 116-136, 116th Cong., 2nd sess. (March 27, 2020), available at https://www.congress.gov/bill/116th-congress/senate-bill/3548/text.

76 Thomas Jenkin, Philipp Beiter, and Robert Margolis, "Capacity Payments in Restructured Markets under Low and High Penetration Levels of Renewable Energy" (Golden, CO: National Renewable Energy Laboratory, 2016), available at https://www.nrel.gov/docs/fy16osti/65491.pdf.

77 U.S. Department of Defense, Assessing and Strengthening the Manufacturing and Defense Industrial Base and Supply Chain Resiliency of the United States."

78 U.S. Department of Defense, "Fiscal Year 2019 Industrial Capabilities Report to Congress" (Washington: 2020), pp. 105–106, available at https://www.businessdefense.gov/Portals/51/Documents/Resources/USA000954-20%20RPT%20Subj%20FY19%20ICR%2007092020.pdf?ver=2020-07-10-124452-180.

79 Ibid.

80 Ibid.

81 The recently announced decision of Taiwan Semiconductor Manufacturing Co. to build a fabrication plant in Arizona is an exception to the locational trend. See Ryan Whitwam, "TSMC Will Open $3.5 Billion Semiconductor Fab in Arizona," ExtremeTech, November 13, 2020, available at https://www.extremetech.com/electronics/317329-tsmc-will-open-3-5-billion-semiconductor-fab-in-arizona.

82 See American Geosciences Institute, "What are rare earth elements, and why are they important?", available at https://www.americangeosciences.org/critical-issues/faq/what-are-rare-earth-elements-and-why-are-they-important (last accessed March 2021).

83 See Wyoming State Geological Survey, "Wyoming's Rare Earth Elements," available at https://www.wsgs.wyo.gov/minerals/rare-earths (last accessed March 2021).

84 See James Kennedy, "On Rare Earths, the Pentagon Is Making the Same Mistake Twice," Defense One, August 10, 2020, https://www.defenseone.com/ideas/2020/08/rare-earths-pentagon-making-same-mistake-twice/167585/.

85 Connie Lee, "Heavy Rocket Competition Coming to Conclusion (Updated)," *National Defense Magazine*, July 10, 2020, available at https://www.nationaldefensemagazine.org/articles/2020/7/10/heavy-lift-rocket-competition-coming-to-conclusion; Congressional Research Service, "Defense Primer: National Security Space Launch" (Washington: 2020), available at https://fas.org/sgp/crs/natsec/IF11531.pdf.

86 Lee, "Heavy Rocket Competition Coming to Conclusion (Updated)."

87 Congressional Research Service, "Defense Primer."

88 See U.S. Department of Defense Office of Industrial Policy, "Defense Production Act (DPA) Title III," available at https://www.businessdefense.gov/Programs/DPA-Title-III/ (last accessed March 2021).

89 See U.S. Department of Defense Office of Industrial Policy, "Industrial Base Analysis and Sustainment Opportunities," available at https://www.businessdefense.gov/IBAS/Opportunities/ (last accessed March 2021).

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