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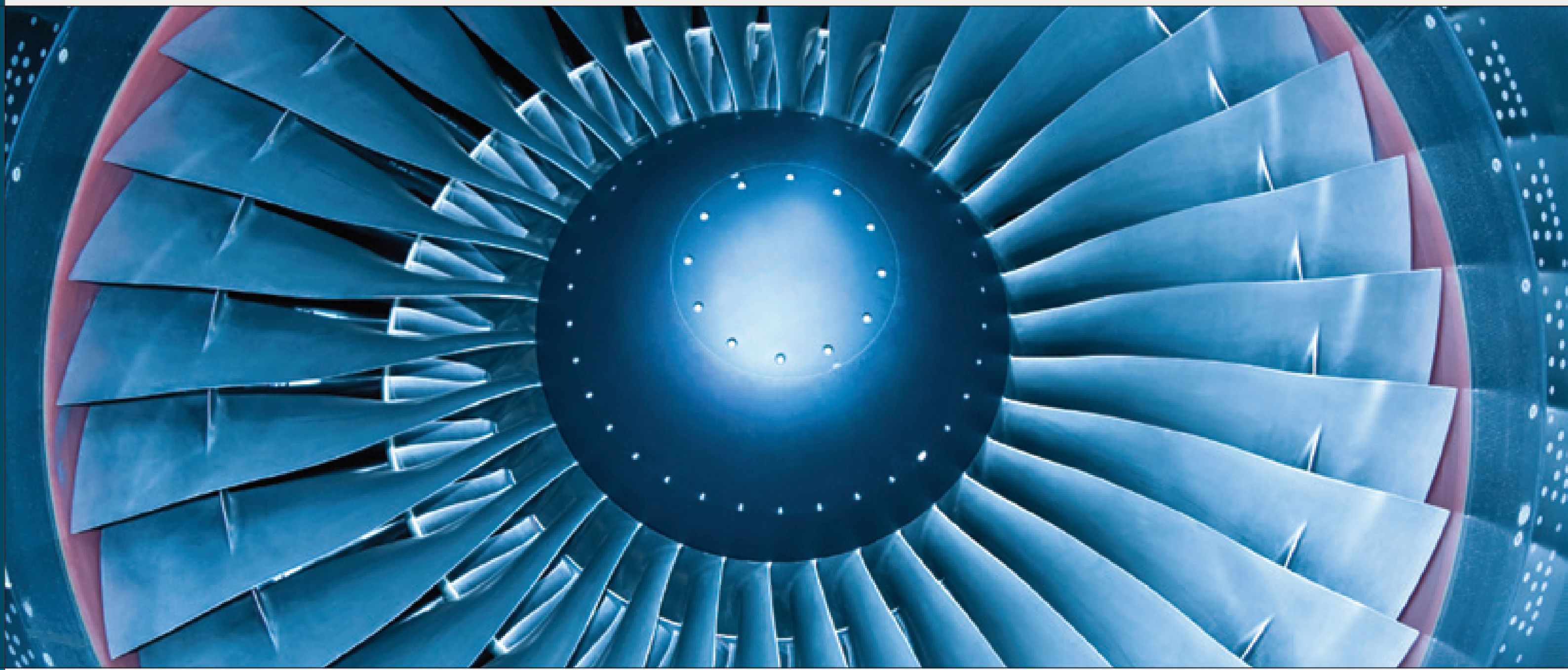
Value Added: America's Manufacturing Future

Michael Lind and Joshua Freedman



Economic Growth Program

New America Foundation

The New America Foundation is a nonprofit, nonpartisan public policy institute that invests in new thinkers and new ideas to address the next generation of challenges facing the United States.

The Economic Growth Program at New America aims to chart a balanced growth path through the post-bubble world economy by advancing pro-growth policy reforms and bringing innovative solutions to the forefront of public debate.

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Executive Summary

Manufacturing matters. That is the rapidly emerging consensus in the United States, after a generation in which leading policymakers, economists and journalists dismissed the importance of the U.S. manufacturing sector to the American economy. Transcending partisan divides, there is a deepening appreciation for the many ways in which a world-class, dynamic manufacturing sector contributes to innovation and American prosperity.

Manufacturing's contribution to the economic recovery and long-term economic growth extends to other economic sectors, including commodities and professional services, through forward and backward linkages and spillover effects. America's manufacturing companies also anchor America's innovation ecosystem, providing demand for American researchers and a supply of investment in R&D in the U.S. Innovation in the U.S. cannot be severed from domestic production; the two belong to an innovation system whose elements benefit each other and flourish or fail together.

But manufacturing is changing, and the contribution of manufacturing to the American economy makes it all the more important for the U.S. to capture the gains of the next generation of manufacturing innovation. Advanced manufacturing encompasses the wave of revolutionary technologies that includes robotics, nanotechnology, photonics, biomanufacturing, the synthesis of new materials and additive manufacturing or rapid prototyping, which promises to replace mass production with customized production in many industries. New kinds of business organization, made possible by advanced communication and information technology, are transforming the way manufacturing firms operate. Servitization is the process by which a product-centered firm adopts a product-service strategy in which revenues from services throughout the product's lifecycle are as or more important than the sale of the original product. While some companies have long pursued product-service strategies, that business model is becoming available to many more firms in industries ranging from aerospace to medicine.

To remain competitive, the U.S. needs a strategy to ensure that breakthroughs in technology and their diffusion and commercialization continue to take place in America. Public policy needs to focus on the imperative of revitalizing and upgrading America's manufacturing base, by methods that include:

R&D and Technology Diffusion. Public policy needs to encourage private sector R&D, including through a permanent R&D tax credit. Public investment in R&D and support for manufacturing should be financed in part by new federal development banks and federally-favored municipal bonds. Breakthroughs in R&D must be followed by development at scale and the diffusion of new transformative technologies across sectors, with the help of government procurement, credit and technology extension programs.

Infrastructure and Energy Strategy. In addition to these forms of direct assistance, infrastructure and energy policies can indirectly retain or onshore manufacturing in the U.S. by lowering the costs of energy and chemical feedstocks and by reducing bottle-necks in the transportation and communications infrastructures. In addition to lowering the costs of manufacturing, the energy sector, revitalized by natural gas, and the construction of new, more efficient transportation and communications systems can provide sources of demand for domestic manufacturing firms.

Tax and Regulatory Reform. Tax policy should encourage investment in American manufacturing by foreign and domestic firms alike. Legacy regulatory systems need to be updated as cutting-edge technology blurs or destroys the boundaries among kinds of manufacturing or between manufacturing and services.

Training Workers for Advanced Manufacturing Jobs. Rapid technological change in manufacturing means that the U.S. needs a new social contract in education which rationally allocates responsibility for learning and upgrading skills among government, employers and individuals.

Promoting Mutually Beneficial Rather than Adversarial Trade. The U.S. needs to do a better job of defending its industries against predatory policies by mercantilist nations, without sacrificing the benefits of access to foreign markets and foreign talent.

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In cutting-edge American laboratories, scientists and engineers explore breakthroughs in advanced manufacturing techniques including additive manufacturing or rapid prototyping, biomanufacturing and the use of innovative metamaterials. In clean, well-lit factories across the United States, lasers guided by software cut metal with unprecedented precision. On American farms, tractors aided by software and satellites minimize waste in cultivation. On the streets of American cities, companies pioneer computer-enabled models of leasing as an alternative to ownership, reducing congestion, waste and environmental costs. These are a few of the stories that make up the narrative of the transformation of American manufacturing.

The story of the evolution of manufacturing processes and business models, enabled by advanced manufacturing technology and software, is at odds with other narratives that have become embedded in the conventional wisdom. In particular, the story that manufacturing is being replaced by services is misleading.

At the same time, however, the manufacturing sector in America and the world is being transformed by trends that include an increasing erosion of the boundaries between the manufacturing sector and the service sector. Aided by well-designed public policy, the manufacturing sector can continue to play a central role in the American economy in producing economy-wide growth and significant numbers of jobs as well as ever-improved goods and services. But it will be a manufacturing sector radically different from the one to which we have been accustomed.

Manufacturing: Leading the U.S. Economy to Recovery

There is a growing bipartisan consensus on the importance of retaining and strengthening the manufacturing sector in the U.S., a consensus reflected by pro-manufacturing policy proposals by presidential candidates and other members of the major political parties. U.S. manufacturing remains an important, leading sector in both the American and global economies. If American manufacturing were a separate nation, it would have the eighth largest economy in the world.[1]

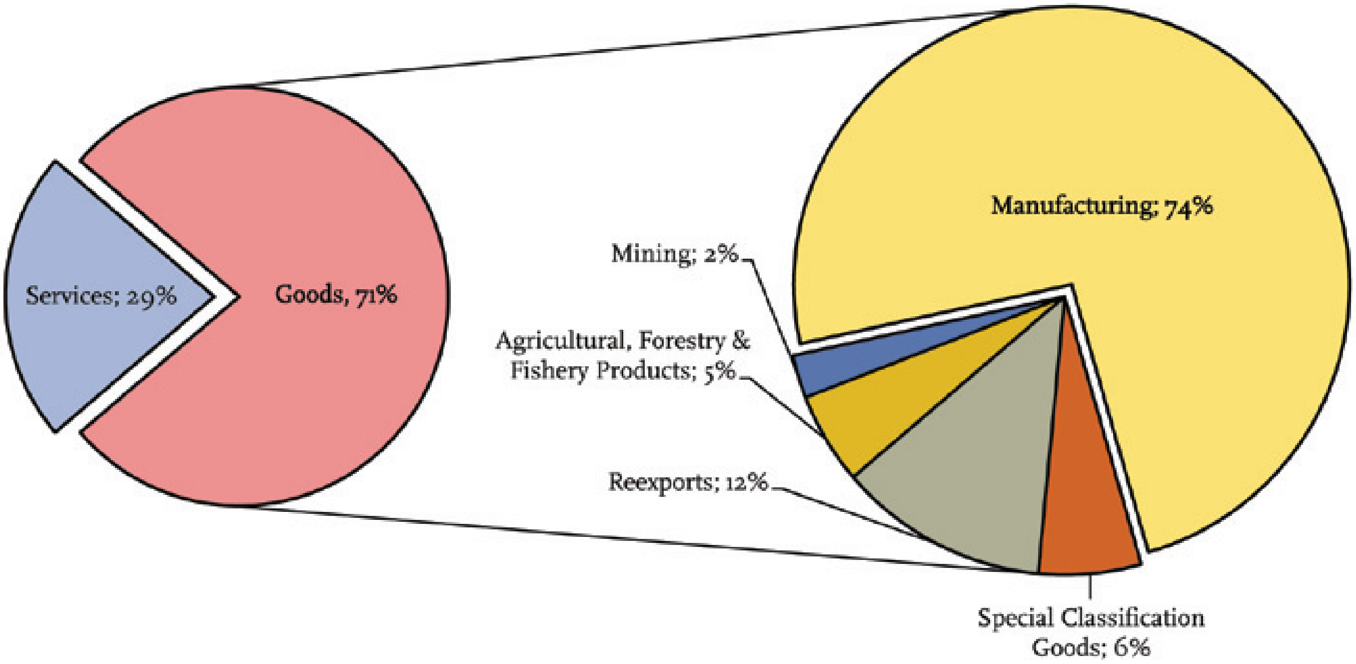
Manufacturing has led the recovery from the Great Recession in the U.S. The strongest two-year period of growth in manufacturing jobs since the late 1990s was the two-year period of 2010-2011, which added 342,000 jobs in manufacturing.[2]

One sign of the revival of American manufacturing is the decision of some multinationals to engage in "insourcing," or the return to or retention of production in the U.S. Large manufacturing companies like Caterpillar and Ford as well as smaller firms like Master Lock in Milwaukee, Wisconsin have announced decisions to insource production to the United States. The revival of American manufacturing has a variety of causes. To begin with, the combination of increased labor costs in China and elsewhere with U.S. manufacturing productivity growth, which compensates for higher American wages, has made it more cost competitive to invest in American manufacturing.

Another factor in the revival of American manufacturing has been the increase in natural gas production by 24 percent between 2006 and the end of 2011.[3] The growth in natural gas production, resulting from advances in hydraulic fracturing ("fracking") technology, has helped U.S. manufacturing both directly, by creating demand for domestically-manufactured inputs to the energy industry, and indirectly, by lowering the cost of energy and chemical feedstocks.

Abundant sources of domestic natural gas, particularly ethane, could lead to a boom in manufacturing as domestic natural gas replaces imported oil in the production of polymers and petrochemicals. According to estimates from the American Chemistry Council, a 25 percent increase in eth-

Share of U.S. Exports in Goods and Services, 2011



Source: Authors' analysis of U.S. Census Bureau, Foreign Trade Division and Bureau of Economic Analysis data.

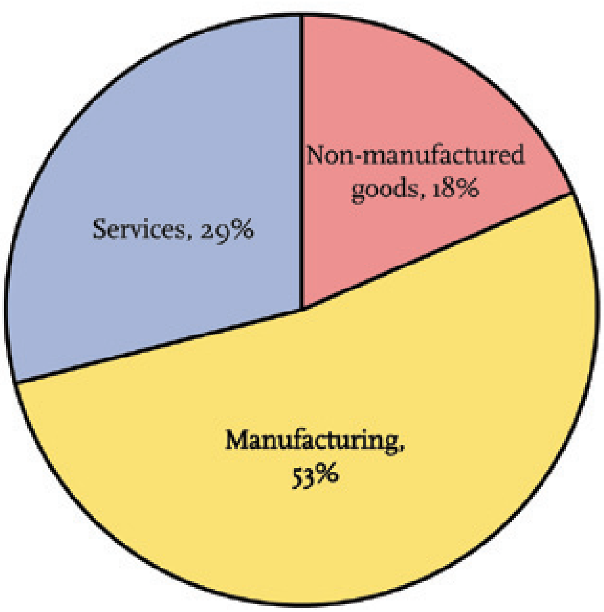
ane supply would lead to the direct creation of 17,000 jobs in the chemical industry and an additional 395,000 jobs in other industries. It would increase U.S. chemical production by $32.8 billion and lead to increased economic output of $132.4 billion.[4]

But manufacturing in the U.S. still faces serious challenges. Despite job growth in the last two years, manufacturing employment is still in a hole. Between 2000 and 2011, the U.S. economy lost 5.4 million jobs in manufacturing, which translates into an average of 1,276 manufacturing jobs and 17 manufacturing establishments lost per day. Economists have typically attributed this employment decline to increased productivity gains, but research by the Information Technology and Information Foundation (ITIF) finds that official data has overstated labor productivity growth by 122 percent. Instead of productivity leading to greater output, manufacturing output in the last decade has decreased in 13 of the 19 manufacturing sectors.[5] Intelligent and sustained public policy will be needed in order for the American economy to realize the benefits of manufacturing.

The Importance of Manufacturing to the U.S. Economy

Manufacturing dominates American exports. Manufactured goods account for about 53 percent of total U.S. exports,

Manufacturing Share of Total U.S. Exports, 2011



Source: Authors' analysis of U.S. Census Bureau, Foreign Trade Division and Bureau of Economic Analysis data

**Note: BEA and Census foreign trade data is separated into two distinct measures: Balance of Payments (BOP) and Census-level. NAICS-level data (by industry) is only done with census-level data, and services are not measured with census level data. Therefore, any measure of manufacturing exports as a percentage of total exports will include a small discrepancy; these numbers are a result of counting total exports as Census-level goods exports plus BOP services exports. When total exports are calculated only with BOP data, manufacturing (still Census-level) is less than one percent smaller, at just over 52 percent.*

compared to 29 percent for services.[6] With a 2011 trade deficit in goods and services of $560 billion, expanding manufactured exports will be crucial for more balanced economic growth.[7]

In addition to being a leading sector in its own right, manufacturing also generates jobs in other sectors by means of the multiplier effect. The Bureau of Economic Analysis (BEA) estimates that every dollar of final demand for manufactured products is comprised of $0.55 in the manufacturing sector and $0.45 in other sectors of the economy.[8] Millions of indirect manufacturing-related jobs do not show up in official statistics, which may understate the importance of manufacturing in the economy. This has led some to argue that service inputs to manufacturing should be counted as part of the manufacturing sector.[9]

The government's 2010 estimated multiplier effect of 1.34 for manufacturing means that every dollar in final sales of a manufactured good is responsible for $1.34 in output from other economic sectors. In contrast, retail trade and wholesale trade generate only 55 cents and 58 cents, respectively, of output in other sectors for every dollar of output.[10] In terms of employment, manufacturing generates jobs as well as economic output. The Manufacturing Institute estimates that manufacturing creates nearly 7 million jobs in other industries.[11] This figure only includes indirect effects, not induced benefits—the jobs that are created through the consumption of goods and services by those who benefit from new employment or economic activity from manufacturing—meaning the actual number is likely higher. A 2009 study estimated that Intel's operations in the state of Oregon had an employment multiplier of 4.1, generating numerous jobs outside of manufacturing in the state in sectors such as utilities, wholesale and retail, business, professional, management and employment services and manufactured materials.[12]

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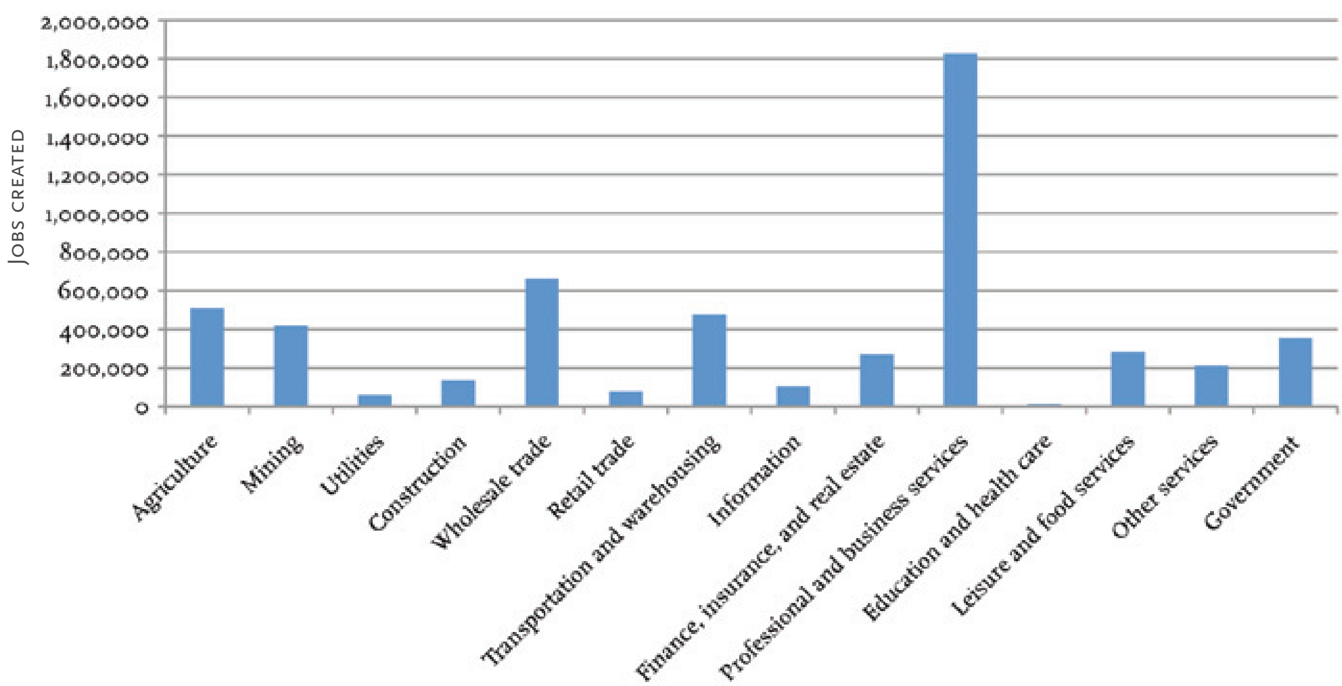
Estimated Employment in Other Industries Generated by the Manufacturing Industry (excluding induced benefits*)



Source: Bureau of Economic Analysis, 2010 Input/Output Tables and the Manufacturing Institute (estimates)

**These estimates are based on indirect and direct inputs only, which means the estimated effects are those that effect inputs to manufacturing. Induced effects, or benefits to the overall economy as a result of employees' contributions to the economy (such as new employees buying goods and services with the money they have earned, therefore spurring more employment in those industries), is not calculated here but would make the estimates even higher.*

In addition to providing customers for producer services, manufacturing also helps the service sector indirectly by producing innovations which are then adopted to increase productivity in a range of service industries. Much R&D in the service sector depends on software and hardware developed in the manufacturing sector.[13]

Manufacturing, R&D and the U.S. Innovation Ecosystem

Perhaps the greatest contribution of manufacturing to the U.S. economy as a whole involves the disproportionate role of the manufacturing sector in R&D. The expansion in the global market for high-value-added services has allowed the U.S. to play to its strengths by expanding its trade surplus in services, many of them linked to manufacturing, including R&D, engineering, software production and finance. Of these services, by far the most important is R&D.

The United States has long led the world in R&D. In 1981, U.S. gross domestic expenditure on R&D was more than three times as large as that of any other country in the world. And the U.S. still leads: in 2009, the most recent year for which there is available data, the United States spent more than 400 billion dollars. European countries spent just under 300 billion dollars combined, while China spent about 150 billion dollars.[14]

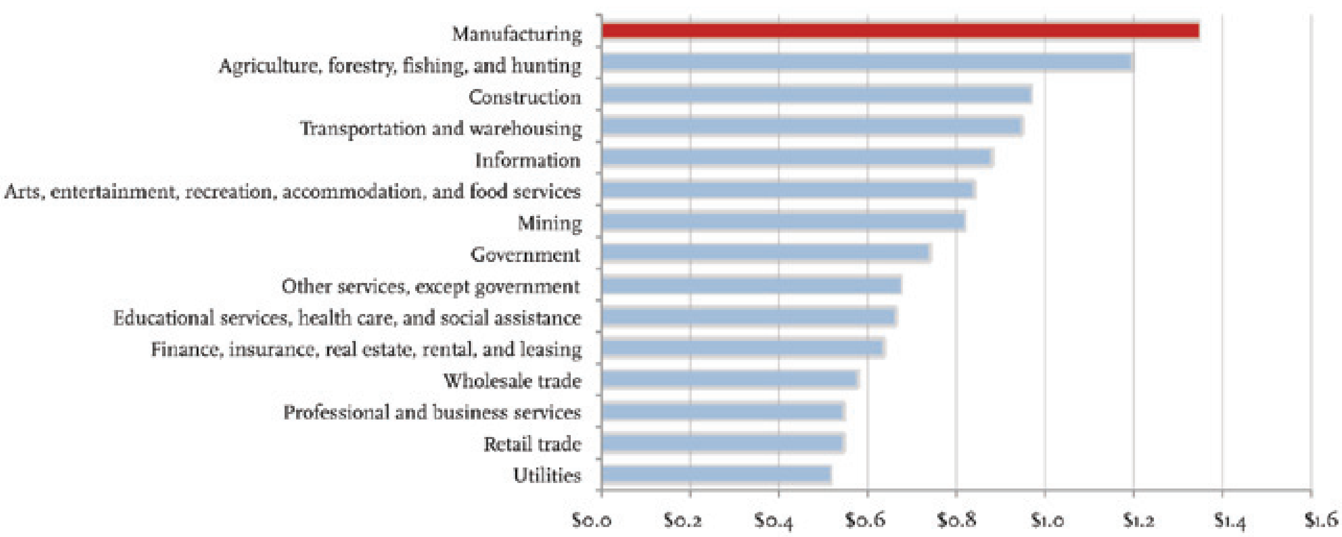
In the United States, private sector manufacturing is the largest source of R&D. The private sector itself accounts for 71 percent of total R&D in the United States, and although U.S. manufacturing accounts for only 11.7 percent of GDP in 2012, the manufacturing sector accounts for 70 percent of all R&D spending by the private sector in the U.S.[15] And R&D and innovation are inextricably connected: a National Science Foundation survey found that 22 percent of manufacturers had introduced product innovations and the same percentage introduced process innovations in the period 2006-2008, while only 8 percent of nonmanufacturers reported innovations of either kind.[16] Even as the manufacturing industry in the United States underwent major changes and suffered severe job losses during the last decade, R&D spending continued to follow a general upward growth path.

A disproportionate share of workers involved in R&D are employed directly or indirectly by manufacturing companies; for example, the US manufacturing sector employs more than a third of U.S. engineers.[17] This means that manufacturing provides much of the demand for the U.S. innovation ecosystem, supporting large numbers of scientists and engineers who might not find employment if R&D were offshored along with production.

Why America Needs the Industrial Commons

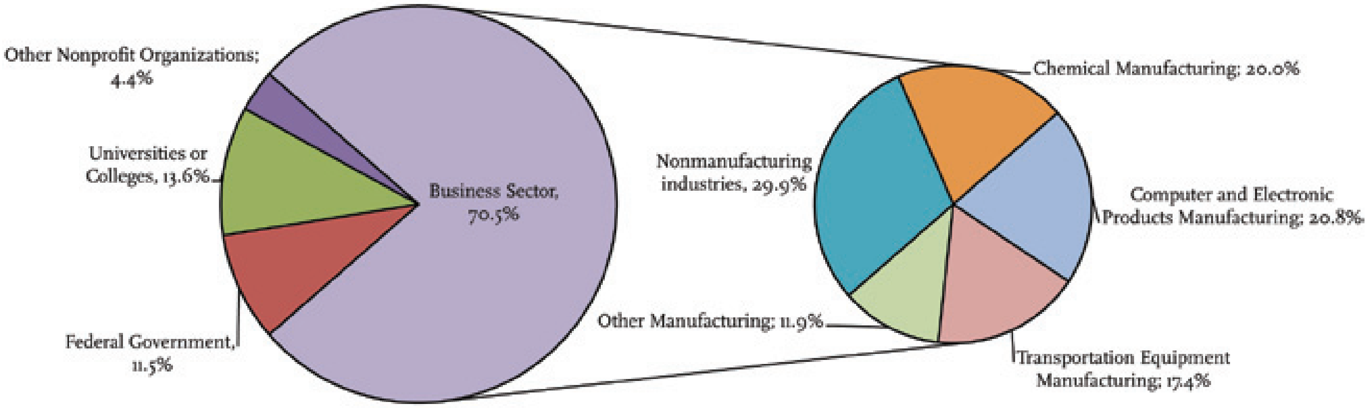
Manufacturing creates an industrial commons, which spurs growth in multiple sectors of the economy through linked

Economic Activity Multiplier by Industry Sector
(amount of economic activity generated by $1 of sector GDP)



Source: Bureau of Economic Analysis, 2010 Input/Output Tables and the Manufacturing Institute

Total R&D Expenditures by Performing Sector, 2009 (with Division of Business R&D by Industry)

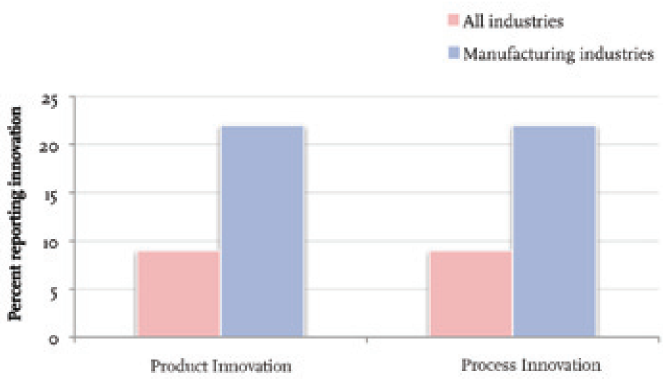


Source: National Science Foundation, Science and Engineering Indicators 2012

industries. An "industrial commons" is a base of shared physical facilities and intangible knowledge shared by a number of firms. The term "commons" comes from communally-shared pastures or fields in premodern Britain. The industrial commons in particular in the manufacturing sector includes not only large companies but also small and medium sized enterprises (SMEs), which employ 41 percent of the American manufacturing workforce and account for 86 percent of all manufacturing establishments in the U.S. Suppliers of materials, component parts, tools, and more are all interconnected; most of the time, Harvard Business School professors Gary Pisano and Willy Shih point out, these linkages are geographic because of the ease of interaction and knowledge transfer between firms.[18] Examples of industrial commons surrounding manufacturing are evident in the United States, including the I-85 corridor from Alabama to Virginia and upstate New York.[19]

Modern economic scholarship emphasizes the importance of geographic agglomeration effects and co-location synergies.[20] Manufacturers and researchers alike have long noted the symbiotic relationship that occurs when manufacturing and R&D are located near each other: the manufacturer benefits from the innovation, and the researchers are better positioned to understand where innovation can be found and to test new ideas. While some forms of knowledge can be easily recorded and transferred, much "know-how" in industry is tacit knowledge. This valuable tacit knowledge base can be damaged or destroyed by the erosion of geographic linkages, which in turn shrinks the pool of scientists and engineers in the national innovation ecosystem.

Companies Reporting Innovation in the U.S. By Industry, 2006-2008



Source: National Science Foundation/Division of Science Resources, Business R&D and Innovation Survey 2008

If an advanced manufacturing core is not retained, then the economy stands to lose not only the manufacturing industry itself but also the geographic synergies of the industrial commons, including R&D. Some have warned that this is already the case: a growing share of R&D by U.S. multinational corporations is taking place outside of the United States.[21] In particular, a number of large U.S. manufacturers have opened up or expanded R&D facilities in China over the last few years.[22]

Next Generation Manufacturing

A dynamic manufacturing sector in the U.S. is as important as ever. But thanks to advanced manufacturing technology and technology-enabled integration of manufacturing and services, the very nature of manufacturing is changing, often in radical ways. What will the next generation of manufacturing look like?

In 1942, the economist Joseph Schumpeter declared that "the process of creative destruction is the essential fact about capitalism." By creative destruction, Schumpeter did not mean the rise and fall of firms competing in a technologically-static marketplace. He referred to a "process of industrial mutation—if I may use that biological term—that incessantly revolutionizes the economic structure from within, incessantly destroying the old one, incessantly creating the new one." He noted that "these revolutions are not strictly incessant; they occurred in discrete rushes that are separated from each other by spaces of comparative quiet. The process as a whole works incessantly, however, in the sense that there is always either revolution or absorption of the results of revolution."[23]

As Schumpeter and others have observed, technological innovation tends to be clustered in bursts or waves, each dominated by one or a few transformative technologies that are sometimes called "general purpose technologies." Among the most world-transforming general purpose technologies of recent centuries have been the steam engine, electricity, the internal combustion engine, and information technology.[24]

As epochal as these earlier technology-driven innovations in manufacturing processes and business models proved to be, they are rapidly being superseded by new technology-driven changes as part of the never-ending process of Schumpeterian industrial mutation.

The latest wave of innovation in industrial technology has been termed "advanced manufacturing." The National Science and Technology Council of the Executive Office of the President defines advanced manufacturing as "a family of activities that (a) depend on the use and coordination of information, automation, computation, software, sensing, and networking, and/or (b) make use of cutting edge materials and emerging capabilities enabled by the physical and biological sciences, for example, nanotechnology, chemistry, and biology. It involves both new ways to manufacture existing products and the manufacture of new products emerging from new advanced technologies."[25]

The Limits of the Silicon Valley Model

Assumptions about innovation shaped by the information technology industry in Silicon Valley may not be useful guidelines for promoting innovation in advanced manufacturing. Silicon Valley operates on a "venture capital" model: entrepreneurs—often literally in a garage—come up with an idea. If the idea becomes marketable, the design can be separated from the production; many of our electronics and information technology products are designed and developed in the United States and produced overseas. Apple products designed in California and manufactured in China are the most prominent, and heavily scrutinized, example of this model.

Apple and its competitors, however, are unlike other areas of potential advanced manufacturing growth. These areas, including advanced materials and biotechnology, require far larger capital investments than fit within the paradigm of the venture capital funding model.[i] Attempts to innovate in some emerging technologies will likely require substantial public, corporate or academic investment in addition to venture capital funding. The Production in an Innovation Economy (PIE) program at MIT corroborates this, concluding that it is an "open question" as to whether the venture capital model can apply to most forms of advanced manufacturing technology.[ii]

Manufacturing technologies like additive manufacturing could alleviate some of these large up-front costs, but by combining rather than separating the design and production processes. Similarly, creative exchanges among designers and producers in a geographically-concentrated industrial commons will remain critical to spurring innovation and producing growth in advanced manufacturing. Ill-considered application of the same strategies for innovation that have succeeded so well in Silicon Valley could hinder innovation in new areas of advanced manufacturing.

i Peter Dizikes, "Standing up for Manufacturing," Technology Review, MIT, January/February 2012, http://mit.edu/pie/news/TechReview.pdf.
ii Ibid.

What is Advanced Manufacturing?

The definition of "advanced manufacturing" has morphed over the years, and no specific consensus on what constitutes advanced manufacturing exists. A 2010 white paper by the Science and Technology Policy Institute (STPI) for the President's Council of Advisors on Science and Technology (PCAST) lays out the two similar but distinct strands of thought.[i] On the one hand, STPI writes, some categorize advanced manufacturing by industry or sector: advanced manufacturing is that which occurs in highly technologically-driven fields and is distinct from traditional manufacturing.[ii]

Others do not draw a distinction between sectors but still focus on the prominence of accelerated technology. For example, the Department of Labor's Employment and Training Administration defines advanced manufacturing as "the accelerated use of high-tech processes in the manufacturing plant. This definition is not synonymous with 'high-tech manufacturing,' as the emphasis is on the high-tech processes used in production, rather than the output of high-tech products."[iii]

However, a report from Daniel Hecker at the Bureau of Labor and Statistics cites work from the Congressional Office of Technology Assessment that defines "high tech" firms as those that either incorporate technological advances into their processes or into innovation of new products.[iv] Hecker further categorizes high-tech firms into three levels based on "science, engineering and technician occupation intensity."[v] Unless high tech firms can perform advanced manufacturing while not performing high tech manufacturing—which seems unlikely—the distinction between advanced manufacturing and high-tech manufacturing is unclear. As such, most people use the terms "high tech manufacturing" and "advanced manufacturing" interchangeably.

Given the rapidly changing nature of manufacturing, the general consensus is that a definition of advanced manufacturing inherently needs to be flexible. The STPI report notes, "Experts characterize advanced manufacturing as 'new ways to manipulate and manufacture old materials or the processing of new materials for new applications.'"[vi]

The President's Council of Advisors on Science and Technology (PCAST), in its 2011 "Report to the President on Ensuring American Leadership in Advanced Manufacturing," gives the most comprehensive definition thus far, providing the definition we use for the purposes of this report. PCAST defines advanced manufacturing as "a family of activities that (a) depend on the use and coordination of information, automation, computation, software, sensing, and networking, and/or (b) make use of cutting edge materials and emerging capabilities enabled by the physical and biological sciences, for example nanotechnology, chemistry, and biology. This involves both new ways to manufacture existing products, and especially the manufacture of new products emerging from new advanced technologies." Like Hecker's definition, this definition of advanced manufacturing includes both product and process innovations. Most manufacturing firms can, and should, then be able to become advanced manufacturers through proper investment—even in the most typically "traditional" manufacturing sectors, like automobiles or agriculture.

i Science and Technology Policy Institute, "White Papers on Advanced Manufacturing Questions," Draft (prepared for the Advanced Manufacturing Workshop of the President's Council of Advisors on Science and Technology. April 5, 2010), http://www.whitehouse.gov/sites/default/files/microsites/ostp/advanced-manuf-papers.pdf.

ii Deloitte and the New England Council, "Reexamining Advanced Manufacturing in a Networked World: Prospects for Resurgence in New England," Report, December 2009, http://www.newenglandcouncil.com/assets/rep_2010.01.14_AdvancedManufacturing1.pdf.

iii U.S. Department of Labor, Employment and Training Administration, "Advanced Manufacturing Industry," Undated. http://www.doleta.gov/BRG/pdf/Advanced%20Manufacturing%20Report%2011.1.05.pdf.

iv Daniel Hecker, "High Technology Employment: a NAICS Update." Monthly Labor Review, Bureau of Labor and Statistics, July 2005, http://www.bls.gov/opub/mlr/2005/07/art6full.pdf.

v Bruce Kirchhoff and Aron Spencer, "New High Tech Firm Contributions To Economic Growth," International Council for Small Business, Undated, http://www.icsb.org/documents/New_High_Tech_Firms.pdf.

vi Science and Technology Policy Institute, p. 1-2.

Each of the robotic arms in the Kalypsys system at the National Human Genome Research Institute enables screening of small molecules. Credit: Maggie Bartlett, NHGRI.

Already computer-aided design (CAD) and computer-aided manufacturing (CAM) programs, combined with computer numerical control (CNC), allow precision manufacturing from complex designs, eliminating many wasteful trials and steps in finishing. CNC is now ubiquitous in the manufacturing sector and much of the employment growth occurring in the sector requires CNC skills or training. Information technology has allowed for enterprise resource planning (ERP) and other forms of enterprise software to connect parts of the production process (both between and within a firm), track systems, and limit waste when dealing with limited resources. Other areas in which advanced manufacturing will play a role in creating new products and sectors and changing current ones are:

Supercomputing. America's global leadership in technology depends in part on whether the U.S. can compete with Europe and Asia in the race to develop "exascale computing," a massive augmentation of computer calculating power that has the potential to revolutionize predictive sciences from meteorology to economics. According to the Advanced Scientific Computing Advisory Committee (ASCAC), "If the U.S. chooses to be a follower rather than a leader in exascale computing, we must be willing to cede leadership" in industries including aerospace, automobiles, energy, health care, novel material development, and information technology.[26]

Robotics: The long-delayed promise of robotics is coming closer to fulfillment. Google and other firms and research consortiums are testing robotic cars, and Nevada recently amended its laws to permit autonomous automobiles.[27] Amazon is experimenting with the use of robots in its warehouses.[28]

Nanotechnology may permit manufacturing at extremely small scales including the molecular and atomic levels.[29] Nanotechnology is also a key research component in the semiconductor industry, as government funding is sponsoring projects to create a "new switch" capable of supplanting current semiconductor technology.[30]

Photonics or optoelectronics, based on the conversion of information carried by electrons to photons and back, has potential applications in sectors as diverse as telecommunications, data storage, lighting and consumer electronics.

Biomanufacturing is the use of biological processes or living organisms to create inorganic structures, as well as food, drugs and fuel. Researchers at MIT have genetically modified a virus that generates cobalt oxide nanowires for silicon chips.[31]

Innovative materials include artificial "metamaterials" with novel properties. Carbon nanotubes, for example, have a strength-to-weight ratio that no other material can match.[32]

Advanced manufacturing using these and other cutting-edge technologies is not only creating new products and new methods of production but is also transforming familiar products like automobiles. The rapid growth in electronic and software content in automobiles, in forms like GPS-based guidance systems, information and entertainment technology, anti-lock brakes and engine control systems, will continue. According to Ford, around 30 percent of the value of one of its automobiles is comprised by intellectual property, electronics and software. In the German automobile market, electronic content as a share of production costs is expected to rise from 20-30 percent in 2007 to 50 percent by 2020.[33]

The Crumbling Distinction between Manufacturing and Services

The intangible results of the continuing IT revolution, in the form of reshaping entire economic sectors and business models, may prove to be even more consequential than innovation on the factory floor. One of the most important trends is the blurring of distinctions between the manufacturing sector and the service sector.

The traditional manufacturing firm specialized in converting raw materials into finished products. Services like consumer finance and maintenance, if provided by firms, were secondary to their emphasis on factory assembly. The need for maintenance and repair of the "installed base"—the total number of working products—was often addressed by independent mechanics rather than the manufacturer.

The term "servitization" or "servicization" for the combination of product sales and services in a single business model has become widespread since it was first used in 1988. Servitization can be thought of as a spectrum, from pure product manufacturing at one end to pure services at the other, with integrated *product-service systems* (PSS) in between.[34]

The integration of services with manufacturing provides manufacturing firms with a method of competing by providing services along with products, rather than competing merely on the basis of price. Companies that follow this strategy are in the business of selling solutions to problems encountered by their customers—solutions that include services as well as hardware. Suzanne Berger, Professor at the Massachusetts Institute of Technology (MIT) and co-chair of MIT's "Production in the Innovation Economy" study, highlighted this idea in an interview with Technology Review. "The distinction between manufacturing and services seems to me ultimately a false one," she told the magazine. "Most of the most valuable products, from the most valuable companies we see, are bundles of services and manufactured products. An iPod or iPhone is both hardware and services."[35]

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There have always been some companies, like Xerox and IBM, which sold a package of both manufactured goods and services to clients with whom they enjoyed long-term relationships. Servitization has also been used by firms to differentiate their products, in industries like commodity chemicals.[36] These relational manufacturing firms were a minority, however, compared to the transactional firms which had arm's-length dealings with the purchasers of their products. By enabling the creation of entirely new kinds of services to augment and complement existing product lines, IT is making it possible for many manufacturing firms to move from the transactional into the relational category. For example, John Deere, which has manufactured farm equipment since the nineteenth century, has evolved in the twenty-first century into a supplier of software-enabled services as well as hardware to its customers.

Diagnostic and prognostic technology embedded in products and communicating in networks can permit manufacturers to monitor the condition of goods in the installed base in order to correct defects before they cause the product to fail. In the automobile industry, GM pioneered this technology with its OnStar system over 15 years ago; now, GM offers OnStar service for any vehicle—not just GM cars—and Hyundai has released a competing version for its vehicles called BlueLink. BlueLink provides monthly

Advanced Manufacturing in Agricultural Equipment

Advanced manufacturing is not limited to new, emerging sectors; even manufacturing tied to one of the most "traditional" industries, agriculture, has heavily incorporated technology into its new products.

The need for more accurate and efficient farming, as well as the rise of "precision agriculture"—the utilization of technology to accommodate variations within a field—has changed the agricultural manufacturing industry.[i] Agricultural equipment manufacturers are now creating products that are a far cry from the farm equipment of earlier generations. Replete with LED alerts, touchscreen monitors, and GPS-enabled systems, a modern farm equipment brochure looks like a consumer electronics guide.

John Deere, the iconic American tractor and agricultural equipment manufacturer based in Moline, Illinois, has embraced the use of new technology in its products, as has one of its leading competitors, Case IH, headquartered in Racine, Wisconsin. This advanced agricultural manufacturing does not necessarily require creating completely new technology but rather finding ways to adapt and utilize existing technology that has previously only been applied in other industries.

GPS can tell farmers in real time exactly where they are in a field or the specific location of a problem up to an accuracy of plus or minus 2 centimeters. GPS combined with geographic information systems (GIS) gives farmers the ability to map their fields and treat sections independently. Pesticides, water, or other treatments can be varied, depending on the needs of different segments of the field, which minimizes waste and improves productivity. As agricultural equipment manufacturing continues to advance, experts also see continued growth in farming telematics—the integration and communication of all of this data.

In a modern tractor, for example, a farmer controls much of the operations on one or more small touchscreen displays that take information from GPS inputs. Depending on the software installed, a farmer can vary application rates of seeds, water, or nutrients; the tractor can guide itself, realigning its trajectory if it moves off of a specified path; the tractor can make its own turns at the end of a row of crops; and a farmer can see behind the tractor through video. Some harvesting can be done "hands-free" without the tractor operator needing to drive the machine. Beyond operations in the cab of the tractor itself, telematics software tracks all of the data and incorporates it into a program that can be run on a personal computer. These innovations come with names that befit their technology: at John Deere, names include iTecPro (hands-free turning), iGuide (off-track prevention), StarFire SF2 (GPS differential correction), and GreenStar 3 2630 (display).

The shift to high-technology manufactured goods also means that these products will need to be serviced. As with other industries, evidence points to a decreasing distinction between the manufacturing of farm equipment and farm equipment services: John Deere's telematics system, JDLink, allows farmers to track machine productivity and schedule preventative maintenance from a computer, and Case IH recently introduced 24-hour availability for support services for its Advanced Farming Systems products.

i "Agriculture." GPS.gov (web site), United States Government, last accessed: March 6, 2012. http://www.gps.gov/applications/agriculture/

Sustainability and Product Service Integration

From an environmental standpoint, as a society we want to minimize the number of new natural resource inputs that are used. Society thus benefits from having products last as long as possible and maximizing the reincorporation of previously-used material into new products. Since the current typical production model does not take environmental costs into account, there is a market imperfection: an accurate market would reflect all costs to society and properly place those costs.

Product-service systems (PSS) have attracted attention for their potentially beneficial environmental effects. Regardless of whether manufacturers actively seek to reduce resource use and waste, adoption of a product-service system model could achieve these effects through shifted incentives and reallocation of costs.

In a typical production model, a manufacturer profits based on volume of original sales: the more products it sells, the better. Once the product is sold, the manufacturer will only make money from that same customer by selling a new product or new replacement parts. The manufacturer wants to find ways to sell as many new products or parts as possible, rather than elongate the lifespan of existing ones.

In contrast, a manufacturing product-service system, such as a leasing or pay-per-use arrangement, internalizes the environmental costs to the producer and therefore aligns benefit to the environment with a company's profits. When the manufacturer remains active in servicing the product throughout its lifetime, the manufacturer, customer, and environment all gain from increased longevity of the product. The manufacturer also reduces its own costs by increasing recycling of materials, thereby lessening the need to purchase as many new inputs. A report from the Tellus Institute on the chemical industry noted that implementation of the chemical industry's version of PSS created "mutual incentives to reduce costs, chemical use, and waste generation while improving overall resource efficiency."[i]

An increasingly popular transport option for people in urban areas and college campuses is car sharing, which illustrates leasing-based PSS. The car sharing company Zipcar owns over 9,000 vehicles; members pay an annual fee and a per-hour rate to use the cars, while Zipcar retains ownership of the cars and covers gas, repairs, and insurance. Zipcar claims that each shared car in use removes between 15 and 20 private cars from the road and that many of its users save hundreds of dollars per month in car ownership fees.

While Zipcar employs a Product-Service System model, it is not a manufacturer. But the startup UK car company Riversimple is attempting both the manufacturing and the car sharing model. Riversimple is designing and building a hydrogen fuel cell-powered car that will be leased to users with a fixed monthly fee and per-use cost. Whether Riversimple will succeed remains to be seen, but the fact that both it and Zipcar—which were founded chiefly for environmental reasons—operate as product-service systems lends further credence to the substantial environmental benefits of the model.

The exact quantifiable effect on the environment remains unclear, and experts conclude that environmental impact can only be determined on a case by case basis. An Environmental Protection Agency report, however, determined that PSS implementation could have an eco-efficiency gain up to a factor of two.[ii] The level of gain is dependent on reuse and remanufacturing of materials, which indicates that manufacturers—who, by virtue of their role in the production process, should be better positioned to find ways to recycle materials—would create larger environmental benefits through adoption of PSS than companies that do not manufacture their products.

i Edward D. Reiskin and Allen L. White, et al, "Servicizing the Chemical Supply Chain," Massachusetts Institute of Technology and Yale University, Journal of Industrial Ecology 3, nos. 2 and 3 (2000): 19-31.

ii Arnold Tukker and Ursula Tischner, eds., New Business for Old Europe (United Kingdom: Greenleaf, 2006), as cited in: United States Environmental Protection Agency, Office of Resource Conservation and Recovery, "Green Servicizing for a More Sustainable U.S. Economy: Key concepts, tools and analyses to inform policy engagement," Report, September 2009. http://www.epa.gov/osw/partnerships/stewardship/docs/green-service.pdf. See also: Ezio Manzini and Carlo Vezzoli, United Nations Environment Programme, "Product Services Systems and Sustainability. Opportunities for Sustainable Solutions," UNEP-DTIE, Report, 2002, http://www.unep.fr/scp/design/pdf/pss-imp-7.pdf.

diagnostic information for a car and an integrated digital-plus-operator mechanism for providing support.[37]

In some cases, this may lead to the replacement of final sales by leasing arrangements in which the manufacturer is committed to the product for its lifetime. For example, the three major aerospace engine manufacturers—GE, Pratt & Whitney and Rolls-Royce—all offer a "Power by the Hour" type of model. Instead of selling the engines, the manufacturers retain ownership of the engines and airlines pay for using them on a per-hour basis. The shift from simply selling an engine to providing service throughout the engine's lifetime better aligns incentives between the manufacturers and the customers: both the airline and the manufacturer benefit from minimizing downtime and returning broken engines to service as quickly as possible. The move to integrate manufacturing with services also goes beyond the engine industry to larger aerospace manufacturing. Boeing, long held as a beacon of advanced manufacturing in the United States, now offers a similar integrated service option for its 787 Dreamliner aircraft called GoldCare. After introducing GoldCare for the 787, the company expanded it to the 737 as well in 2011. [38]

Manufacturers are also more connected to the product even past the end of its lifetime. "Remanufacturing" is the process by which manufacturers recycle products at the end of their lifetimes into new products. Companies organized along a product-service model would be responsible for the product life cycle as a closed loop, from the product's original assembly through years of maintenance and repair to its final recycling. Where it is relevant, such a closed-loop system could have environmental as well as economic benefits, by reducing material and energy inputs and pollution.

Studies have shown that servitization is not necessarily the best strategy for all manufacturing firms.[39] But the increased adoption of relational models based on a blend of product manufacturing and services by a growing number of firms has implications for the structure of American capitalism in its familiar form. Since the late twentieth century, there has been a consensus in favor of "shareholder capitalism," the theory that the firm exists to maximize the short-term gains to shareholders. In practice, critics have alleged, this has led many companies to focus on boosting short-term share prices at the expense of long-term investments. A business model in which much or most of a company's revenue comes from long-term maintenance and other services following the sale of the manufactured good to customers might necessitate a rethinking of shareholder value and its alternative, stakeholder value.[40]

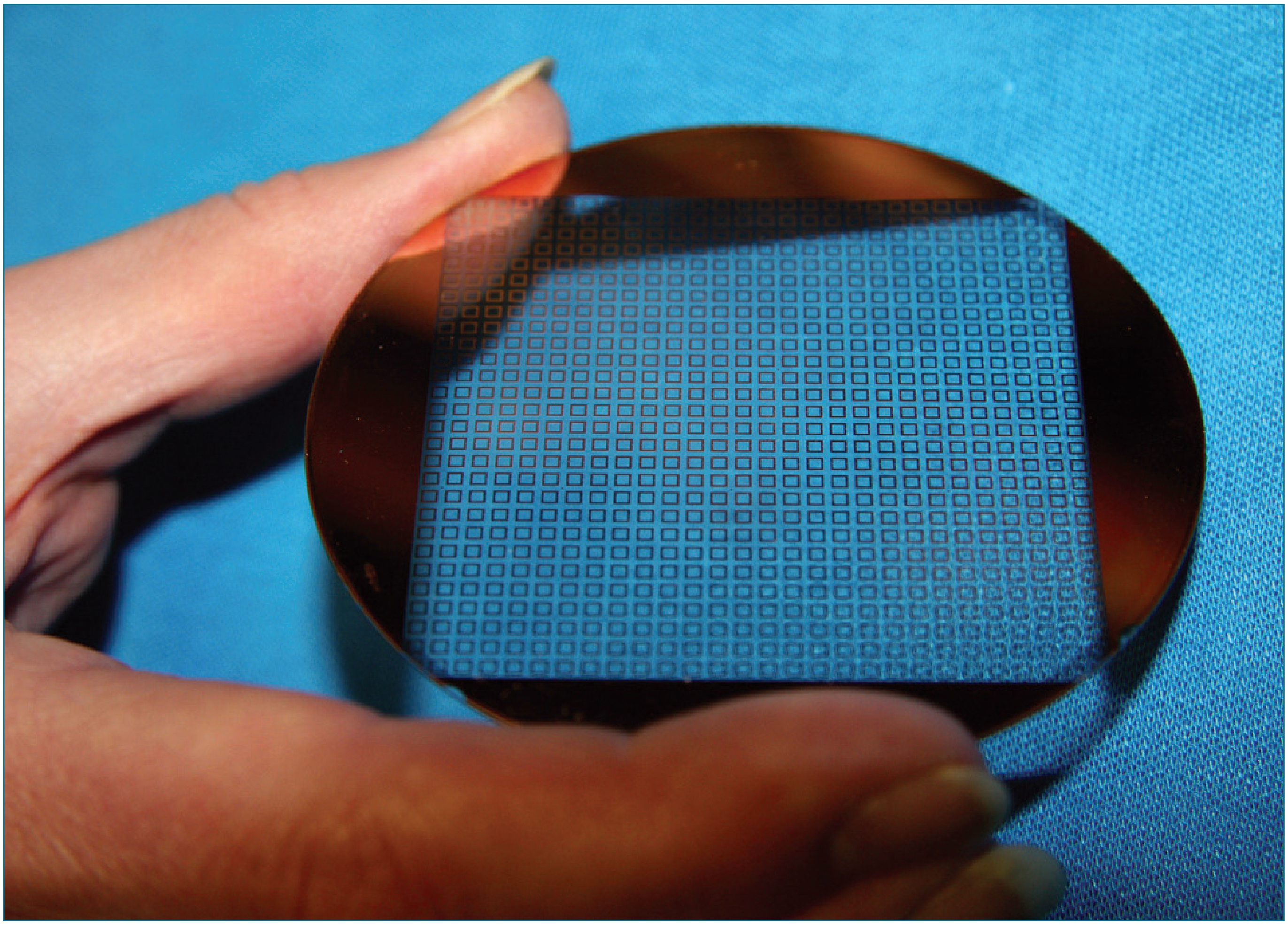
Manufacturing and the Transformation of Medicine

The revolutionary changes in both products and processes extend to the medical industry, which will encompass both manufacturing and services in the future.

> Software-guided medical tools may go from assisting highly-skilled doctors in diagnosis and surgery to replacing them, in some cases. Already, some surgeries like those for prostate cancer are often performed remotely by a doctor operating a machine outside of the operating room.

If it seems odd to mention medicine and manufacturing in the same breath, it is because until very recently medicine was not only a service occupation but a premodern craft profession, complete with its own guild of practitioners. In the second half of the twentieth century, medical technology became increasingly sophisticated and important. But it was grafted onto a business model that still relied on highly-skilled, highly-compensated individual practitioners. This archaic, practitioner-centered business model for providing medical services has been one reason for the "productivity bottleneck" in the American health care sector, which until recently suffered from decades of cost growth outstripping overall economic growth.

Advanced manufacturing and increasingly sophisticated software, however, may change the medical profession into a far more efficient medical industry in which the service components share importance with manufactured goods. On the equivalent of the production side—the interaction of doctors with patients—software-guided medical tools may go from assisting highly-skilled doctors in diagnosis and surgery to replacing them, in some cases. Already, some surgeries like those for prostate cancer are often performed remotely by a



Metamaterials, such as this thin film, allow manufacturers to continue to make products smaller and more compact. Credit: C. Holloway/NIST.

doctor operating a machine outside of the operating room.[41] Robot-assisted surgeries, similarly to laparoscopic techniques, have been shown to result in less blood loss and quicker recovery times than traditional surgeries.[42] Mobile technology may replace many or most visits to the doctor. Cell phone applications, such as the FDA-approved DiabetesMonitor, provide patients with accurate treatment information from anywhere.[43] Continuing innovations in wireless sensor technology could lead to the idea of "pervasive healthcare." Sensors built into the home, clothing, or implanted directly in the body allow for early detection of health problems and less time spent in hospitals, since monitoring does not require on-site care.[44] The monitoring of medical implants naturally lends itself to the kind of relational business model described above. Technological innovation holds out the possibility of personalized medicine—the tailoring of pharmaceuticals and other medical products to individuals.

In the longer term, the differences between manufacturing for medicine and medicine as manufacturing may erode. From building specialized prostheses and devices for particular patients it is only a step to the more radical reconstruction of body parts, by methods including additive manufacturing and the growth of organs from stem cells. The first custom-made steel jawbone was built through additive manufacturing in February, 2012,[45] and the employment of additive manufacturing techniques in building up tissues has blurred the boundaries between traditional manufacturing and biotechnology.[46] Two firms, Organovo and Invetech, are building the first bioprinter to create human organs and tissues by manufacturing.[47] The Fraunhofer Institute is also developing biocompatible materials for use in additive manufacturing.[48]

The potential market for advanced medical services in the U.S. and the world is vast. The economist Robert Fogel has estimated that the price elasticity for medical services is 1.6, meaning that with every additional dollar of income people desire up to $1.60 in services. Because health is the good that makes it possible to enjoy other goods, Fogel argues that affluent societies as well as affluent individuals will spend proportionately more on health care as they become more prosperous.[49] And by minimizing sick days and prolonging working lives, better health care contributes to a higher GDP, all other things being equal.

Twenty-first century medicine could be the very model of a knowledge-intensive, capital-intensive, highly productive sector that synthesizes advanced manufacturing and advanced services.

It is a mistake to treat health care as pure "consumption" that diverts precious resources from investment in the productive economy. On the contrary, twenty-first century medicine could be the very model of a knowledge-intensive, capital-intensive, highly productive sector that synthesizes advanced manufacturing and advanced services.

The Next Industrial Revolution? Beyond Mass Production

Innovations in advanced manufacturing and advanced software technology have the potential to converge to produce the greatest change in production systems and business models since the industrial era began.

Before the steam engine inaugurated the first industrial era, most manufacturing consisted of household production, supplemented by the work of small craftsmen like village blacksmiths. All of this changed with the early industrial era. Increasing returns to scale meant that large production runs were more economical than small batch production. Giant manufacturing firms could accumulate enormous quantities of inventory and then hire advertisers to try to find customers for it. In the automobile industry and others, this in turn led to the strategy of "planned obsolescence," in which frequent fashion changes, encouraging consumers to sell last year's model and buy this year's model, kept the expensive factories running.

What if decreases in the cost of production reduce the importance of increasing returns to scale in manufacturing? This is the possibility held out by a number of innovations in advanced manufacturing technology, from additive manufacturing or rapid prototyping and nanotechnology on the production side to computer-enabled advances in customization and niche marketing.

Additive manufacturing, also called rapid prototyping or 3D printing, is the term for a number of techniques such as stereolithography (SLA), selected laser sintering (SLS), fused deposition modeling (FDM), laminated object manufacturing (LOM), and reaction injection molding (RIM). Whereas traditional manufacturing was subtractive, based on cutting, stamping or bending metal and other materials, additive manufacturing uses computer-guided tools to build up products—for example, out of plastic or metal powder.

The combination of falling entry costs for additive manufacturing with customization for particular clients holds out the possibility of a transition, at least in some industries, from mass production to a high-tech version of the premodern model of single products or small batches with short production runs created for individual customers according to their specifications. Even large companies have seen the potential for additive manufacturing. GE, Boeing, and Northrop Grumman, among others, all produce some of their parts with additive manufacturing.[50] Current estimates suggest that by 2030, additive manufacturing will have improved to the point at which it can create multi-material products quickly and accurately enough to compete directly with more traditional processes across a broad range of sectors.[51]

Innovations in advanced manufacturing and advanced software technology have the potential to converge to produce the greatest change in production systems and business models since the industrial era began.

The ultimate result could be more widespread adoption of "single-unit" manufacturing and customization of products for particular clients. When combined with advances in IT, single-unit manufacturing can provide greater responsiveness and flexibility within the entire value chain from conception to production and after-sales maintenance. While true household or "desk-top manufacturing"

Innovative Public Purpose Finance for a Renaissance of American Manufacturing

Large-scale borrowing by government is justified, outside of emergencies like wars and recessions, when the funds are used for investments that make the economy more productive over the long term, thereby raising tax revenues and making it easier to pay down debt. This principle has usually been accepted in the case of physical assets like roads, schools and power plants. Like infrastructure and energy assets, manufacturing assets, basic and applied R&D and human capital are long-term investments that pay off in enhanced productivity and also should be financed chiefly by borrowing, not by legislative appropriations out of current revenue. Unfortunately, while state and local governments routinely use bond finance and special credit programs to promote manufacturing projects and related infrastructure and energy projects, the federal government lacks similar capabilities in these areas.

To aid American manufacturing, the federal government could emulate American state governments as well as many foreign countries by creating specialized economic development agencies. Among these the most effective might be one or more federal public investment banks which, like state level and foreign models, provide low-interest loans or grants and broker partnerships among entrepreneurs, academic institutions and federal, state and local government agencies. Proposals for a national infrastructure bank, while generating controversy, have won supporters from all sides in the partisan debate. Similar public purpose finance institutions dedicated to promoting R&D and encouraging domestic manufacturing deserve consideration and debate.

Another way that the federal government can leverage the resources of the private sector to promote the public purpose of investment in American manufacturing involves the federal tax treatment of state and local municipal bonds to promote these sectors.

For example, tax credit bonds are taxable bonds for which investors receive a tax credit against a certain percentage of the interest income, at a rate set by the Treasury. The American Recovery and Reinvestment Act (ARRA) temporarily established Build America Bonds (BABs), a new class of tax credit and direct pay bonds subsidized by the federal government and issued by state and local governments to finance infrastructure. National policymakers might consider similar federal legislation to create new kinds of state and local tax credit bonds to promote manufacturing projects, fund R&D and technology extension programs, and pay for public and private skill development programs.

For more details, see Michael Lind, "Public Purpose Finance: Investing in America's Future with Regional Development Banks" from the New America Foundation in 2010.

may be a long time in coming, a shift from large, expensive, highly-specialized national or global manufacturing centers to a more dispersed pattern of smaller, regional and local plants that can use the same equipment to manufacture different kinds of products on demand may be visible on the horizon. Demand for customized medical products, like prostheses and implants tailored to individuals, might be particularly important.

The implications for the structure of markets as well as corporations could be substantial. In the last generation, the combination of IT, satellite technology and container shipping allowed China and other East Asian countries to specialize in low-end assembly work for multinational enterprises, in an extreme version of the global division of economic labor facilitated by extensive and complex global supply chains. On-demand manufacturing centers, in contrast, might best be located in or near the markets that they serve, particularly if a high degree of automation would minimize the role of labor costs in decisions about location. The value added in manufacturing by design might grow in importance, and with it concern about the enforcement of intellectual property rights, as it became easier for local factories to build stolen designs (the "Napsterization" of manufacturing). With shorter supply chains, the role of rare minerals, commodities and energy in long-distance trade might increase, even as the long-distance shipment of finished manufactured goods and manufactured components declines. Eventually the result might be a high-tech version of the premodern economic order, in which most production was local and customized, with trade limited to rare materials and precious, hand-crafted trophy goods. This is not a step back, but rather a step forward: more small-scale production means that the cost of production is low enough that consumers now reap the benefits of both low costs and more customized production.

Capturing the Benefits of Manufacturing Innovation for America: A Policy Agenda

In order to take advantage of the promise of innovative manufacturing, the U.S. needs a more intelligent strategy. What exists now is an unsatisfactory set of policies that push companies in different directions, and an incoherent mix of local and national policies affecting and sometimes distorting the pattern of investment. An adequate manufacturing strategy would aim to lower the cost of doing business in the U.S. and help to provide companies with the essential elements—R&D, infrastructure and skilled workers—that they need to be successful, while also protecting American producers from the unfair trade practices of mercantilist economies.

To be more specific, a sound policy agenda would include the following:

R&D and Technology Diffusion

Public policy needs to encourage private sector R&D, by methods including a permanent R&D tax credit. Collaborative efforts to devise and diffuse innovative technologies among businesses, research universities and government at the federal, state and local levels also should be encouraged. Public funding for basic R&D should be increased. Because of the budgetary constraints that will linger long after the Great Recession, investment in R&D should be funded in part by bonds, like those issued by the National R&D Bank that we have proposed elsewhere.[52]

Breakthroughs in R&D must be followed by development at scale and the diffusion of new transformative technologies across sectors. Government agencies can help in the early development stage of new technologies, by means of procurement policies. Credit programs focused on small and medium enterprises (SMEs) may need to be revised in part to help those companies grow. Technology extension programs like the Hollings Manufacturing Extension Partnership (MEP) play a vital role in the diffusion of new technologies through the entire economy and need to have adequate resources. While the U.S. continues to lead the world in both public R&D and private venture capital, Americans can learn from other countries like Germany that have devised institutions to help the scaling up of fledgling firms and the diffusion of new technologies to SMEs.[53]

Infrastructure and Energy Policies

In addition to these forms of direct assistance, infrastructure and energy policies can indirectly retain or promote onshoring of manufacturing in the U.S. Reducing congestion and bottle-necks in road, rail, air and marine transportation of goods and people, by expanding capacity and using IT to create smart, networked transportation and delivery systems, can reduce the costs of manufacturing in America. So can low energy prices, made possible by environmentally-sound exploitation of the abundant new natural gas reserves opened up by hydraulic fracturing (fracking) and by renewable energy technologies, where those are appropriate.

In addition to lowering the costs of manufacturing, the construction of new, more efficient transportation and communications systems can provide a source of demand for manufacturing firms. This is particularly important in the recovery from the Great Recession, as markets in emerging economies like China and India replace debt-fueled domestic consumption in the U.S.

Tax and Regulatory Policies

Reforming America's tax and regulatory frameworks must also be part of an agenda to renew American manufacturing. To help the U.S. compete with other jurisdictions for investment, the corporate income tax rate should be lowered, with lost revenue made up by other taxes such as a value-added tax (VAT).[54] In addition, the U.S. should consider transitioning to the territorially-based taxation system used by other leading industrial nations. State and local tax abatement policies, all too often used in a race to the bottom strategy of luring national and global companies, should be coordinated as much as possible in a high-road strategy based on collaboration rather than competition among the federal, state and local governments.

While regulation is necessary, regulatory policy should be designed with an eye not only to averting particular risks but also to minimizing the drag imposed by compliance on economic innovation and growth. Legacy regulatory systems, based on archaic divisions among economic sec-

Lessons from Germany for American Manufacturing Policy

Institutions and policies from one country cannot always be grafted successfully onto other countries with different traditions and forms of political and economic organization. Even so, the United States, which leads the world in basic research and innovative commercialization of new technologies, can learn lessons from the Germany, a manufacturing powerhouse, in areas in which the U.S. is relatively weak: applied research, lending to small and medium enterprises (SMEs), and training in manufacturing-relevant skills.

Applied research. The U.S. could benefit from a system of federal support for applied research to complement its world-class basic R&D programs like those of the Defense Advanced Research Projects Agency (DARPA) and the National Institutes of Health (NIH).

A model for federal support of American industry in the area of applied product and process research is provided by Germany's Fraunhofer Society for the Advancement of Applied Research. Unlike Germany's Max Planck Institute, which focuses on basic science, most of Fraunhofer's nearly 20,000 personnel are scientists and engineers who engage in applied research. Much of the funding for Fraunhofer comes from industry or government-backed projects. With 60 specialized institutes in Germany, Fraunhofer has also opened branches in Asia, Latin America and the U.S. Fraunhofer USA institutes, which take part in partnerships with universities, state and local governments and businesses, focus on applied research in areas including sustainable energy systems, molecular biotechnology, coatings and laser applications, laser technology, digital media technologies, experimental software engineering and manufacturing innovation.[i]

Lending to SMEs. As they seek to revitalize American manufacturing, policymakers can also learn from Germany's highly successful KfW system of public banks. The Federal Republic of Germany manages to be an export superpower while maintaining a flourishing small- and medium-sized manufacturing sector in part because of its successful public development bank system.

One of Germany's largest banks, the KfW is owned in part by the German federal government (80 percent) and in part by Germany's Länder, or states (20 percent). The bonds that the KfW issues raise funds from domestic and global capital markets and are considered to be as safe as obligations of the German federal government. Through specialized banks, the KfW system provides low-cost financing to thousands of projects in Germany and developing countries. KfW plays a critical role in providing credit for Germany's small and medium enterprises (SMEs), as well as for Germany's steel, coal and energy industry, infrastructure, housing and environmental protection. The KfW system, originally created in 1948 to help rebuild postwar Germany with Marshall Plan funds, was based on an American prototype: the Reconstruction Finance Corporation (RFC), which recapitalized failing banks and businesses and paid for public works projects during the Great Depression and funded the mobilization of American industry during World War II.

Training in Manufacturing-Relevant Skills. Another feature of the German model is Germany's industrial apprenticeship system, financed partly by employer contributions and partly by the public sector.[ii] The German system of early vocational tracking in education should not be transplanted directly to the U.S, but it makes sense for employers in the U.S. to undertake some specific job-relevant skills training. Because employers have little incentive to train workers whom they might lose to other employers, the costs of this kind of specialized training (or retraining, in the case of older workers) might need to be assumed in part by the public sector. Increases in intangible human capital as a result of on-the-job training funded by the public sector can benefit the national economy just as much as investments in tangible assets like infrastructure networks and factories.

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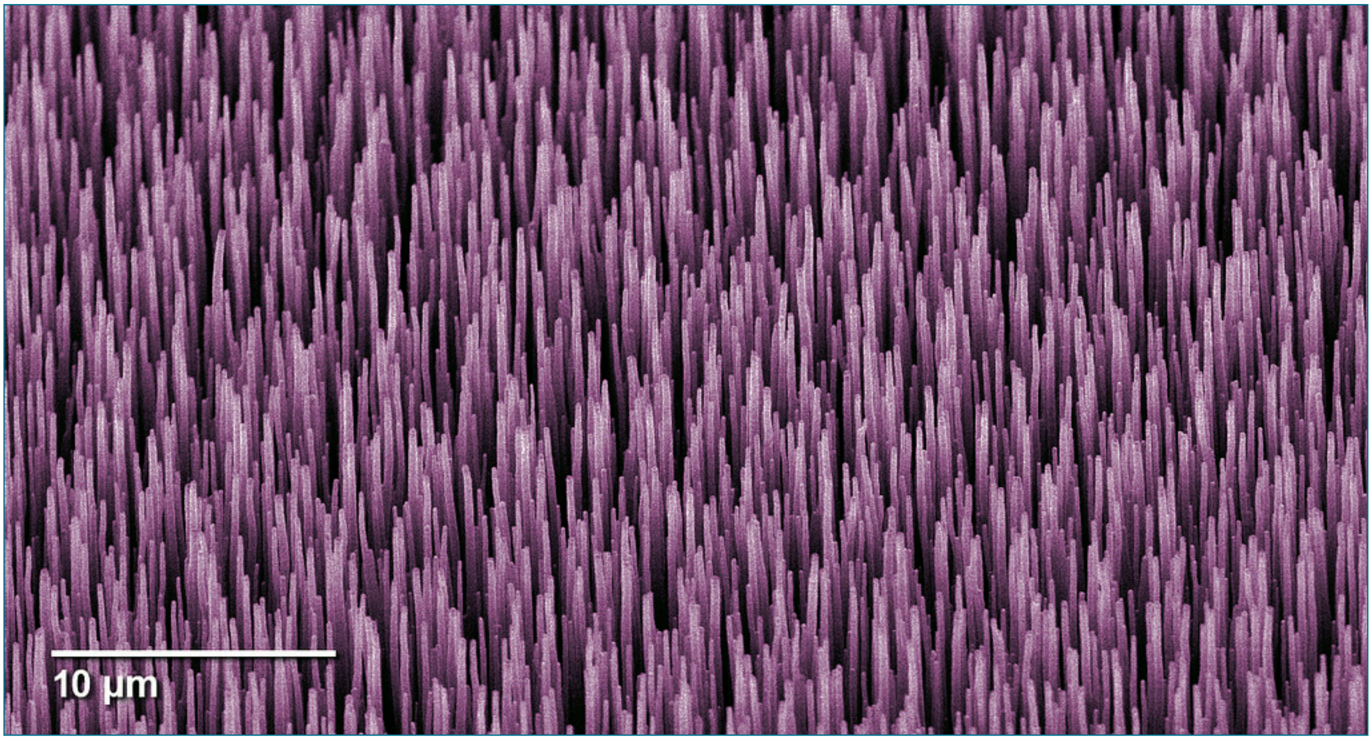
i "Fraunhofer USA," Fraunhofer (web site), last accessed April 2, 2012, http://www.fraunhofer.org.

ii Heinrich Harries, "Co-financing Between Public and Private Institutions for Development Financing: The Practice of the German Development Finance Bank as a Public Institution," American University Law Review 32, no. 1: 1982.



Carbon nanotubes (colorized in this image) that can more efficiently make ultraprecise calculations could have applications for telecommunications and medical devices. Credit: Huang/NanoLab, colorized by Talbott/NIST.

tors, may need to be reconsidered as cutting-edge technology blurs or destroys the boundaries among kinds of manufacturing or between manufacturing and services. What is needed is a more accurate conceptual map of the economy's actual sectors, like the schema provided by the McKinsey Global Institute in a recent report on sectors and growth, and a strong regulatory system that reflects these divisions.[55]

Human Capital

Rapid technological change means that the skills of workers must be repeatedly upgraded. The U.S. needs a new social contract in education that rationally allocates responsibility among government, employers and individuals. Admitting more skilled immigrants—preferably by means of a points system like those used by the UK, Canada, Australia and other countries—at best can only be a temporary stopgap.

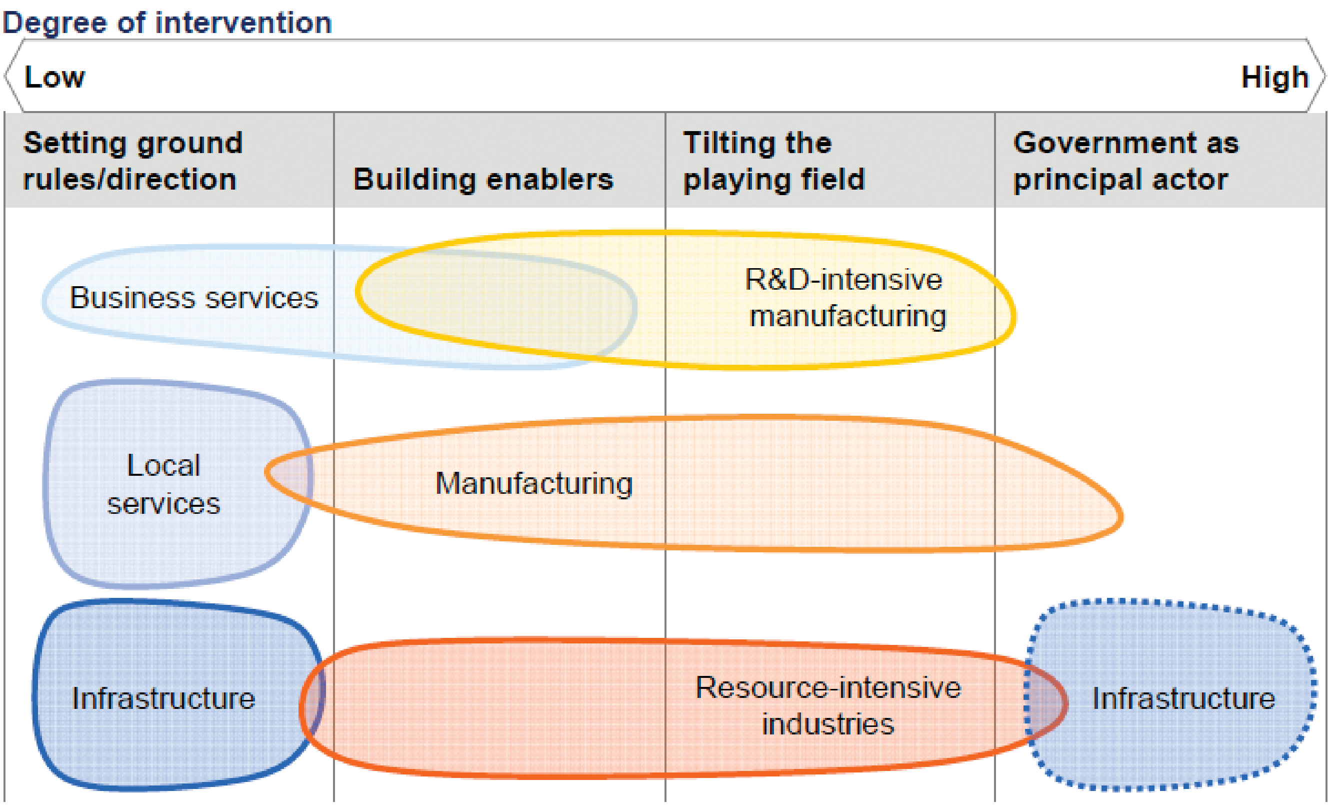
The best place for much training is on the job and at the workplace. Employers, however, are often unwilling to invest time and resources in training workers who can then leave and take that investment in human capital to another firm. The result is a shortage of skilled workers and insufficient methods of fixing this skills gap.[56] For this reason, the government should defray some of the costs of on-the-job training that can benefit all of the firms in an industrial commons that draw on a common labor pool.

Promoting Mutually Beneficial Rather than Adversarial Trade

In a world in which most population increases and economic growth will take place outside of America's borders, American producers can benefit more than ever from access to foreign customers. At the same time, the U.S. economy as a whole would benefit from an increase in exports based on foreign consumer demand as part of a long-term strategy of correcting the imbalances in the American economy that grew during the bubble years preceding the Great Recession. The U.S. should continue its historic post-World War II policy of promoting greater and deeper economic integration among the leading economic regions of the world, qualified by the recognition that major nations or trade zones, including the U.S., have a legitimate interest in preserving the dynamism and health of their domestic manufacturing sectors and other important traded sector industries.

To this end, the U.S. needs a trade and investment policy that better protects companies based in America from the unfair trade practices of mercantilist economies, such as the dumping of excess production in supply surges and the use of unfair subsidies and forced technology transfers. In

Government Policy Tools Need to be Tailored to Suit Sector Competitiveness Drivers



Source: McKinsey Global Institute/Public Sector Office Competitiveness Project

addition, the U.S. needs to do a better job of working with other nations to provide stable and predictable exchange rates, so that national currency policies do not create significant, artificial shifts in international competitiveness that provide additional and unnecessary levels of risk to long-term investments in the U.S.

In general, a successful strategy for taking advantage of breakthrough innovations in manufacturing technologies requires a recognition that the health not merely of particular industries and sectors but also of the public-private-nonprofit innovation and manufacturing system as a whole must be the object of public policy.[57] One study notes that "U.S. manufacturing firms are attempting to compete largely as independent entities against a growing number of national economies in Europe and Asia in which government, industry, and a broad infrastructure (technical, education, economic, and information) are evolving into increasingly effective technology-based ecosystems."[58]

Even as it evolves through a process of endless Schumpeterian "industrial mutation," in directions far from the traditional stereotype of mass production workers on conveyor belt assembly lines, American manufacturing continues to play a disproportionate role in innovation and growth. With the help of private sector innovation, academic creativity, enlightened public policy and the understanding of an educated public, American manufacturing can continue to lead the nation and the world to a more prosperous future.

Notes

1 United States Department of Commerce, National Institute for Standards and Technology (NIST), "The Future of the Manufacturing Extension Partnership" Document, Hollings Manufacturing Extension Partnership, December 2008, accessed March 14, 2012, http://www.nist.gov/mep/ngs.cfm

2 Authors' analysis of Bureau of Labor and Statistics data. U.S. Department of Labor, Bureau of Labor and Statistics Databases ("Employment, Hours, and Earnings from the Current Employment Statistics survey," accessed April 9, 2012), http://www.bls.gov/data/.

3 Nicholas Lardy, *Sustaining China's Economic Growth After the Global Financial Crisis*, Peter G. Peterson Institute for International Economics, Washington, DC, 2012. As cited in: White House, "Investing in America: Building an Economy That Lasts," Report, January 2012, http://www.whitehouse.gov/sites/default/files/investing_in_america_report_final.pdf.

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5 Robert D. Atkinson, Luke A. Stewart, Scott M. Andes, and Stephen J. Ezell, "Worse Than the Great Depression: What Experts Are Missing About American Manufacturing Decline," Report, The Information Technology & Innovation Foundation, March 2012.

6 Authors' analysis of U.S. Census Bureau, Foreign Trade Division and Bureau of Economic Analysis Statistics statistics. U.S. Census Bureau, U.S. Bureau of Economic Analysis, "U.S. International Trade in Goods and Services, December 2011" News Release, Friday, February 10, 2012; accessed March 12, 2012, http://www.census.gov/foreign-trade/Press-Release/2011pr/12/ft900.pdf.

Methodological note: BEA and Census foreign trade data is separated into two distinct measures: Balance of Payments (BOP) and Census-level. NAICS-level data (by industry) is only done with census-level data, and services are not measured with census level data. Therefore, any measure of manufacturing exports as a percentage of total exports will include a small discrepancy; these numbers are a result of counting total exports as Census-level goods exports plus BOP services exports. When total exports are calculated only with BOP data, manufacturing (still Census-level) is less than one percent smaller, at just over 52 percent.

7 United States Department of Commerce, Bureau of Economic Analysis, "U.S. International Transactions: Fourth Quarter and Year 2011," News Release, March 14, 2012, p. 5; accessed March 19, 2012, http://www.bea.gov/newsreleases/international/transactions/2012/pdf/trans411.pdf.

8 United States Department of Commerce, Bureau of Economic Analysis, "Manufacturing in America: A Comprehensive Strategy to Address the Challenges to U.S. Manufacturers," Report, January 2004. Accessed March 14, 2012, http://www.trade.gov/media/publications/pdf/manuam0104final.pdf.

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