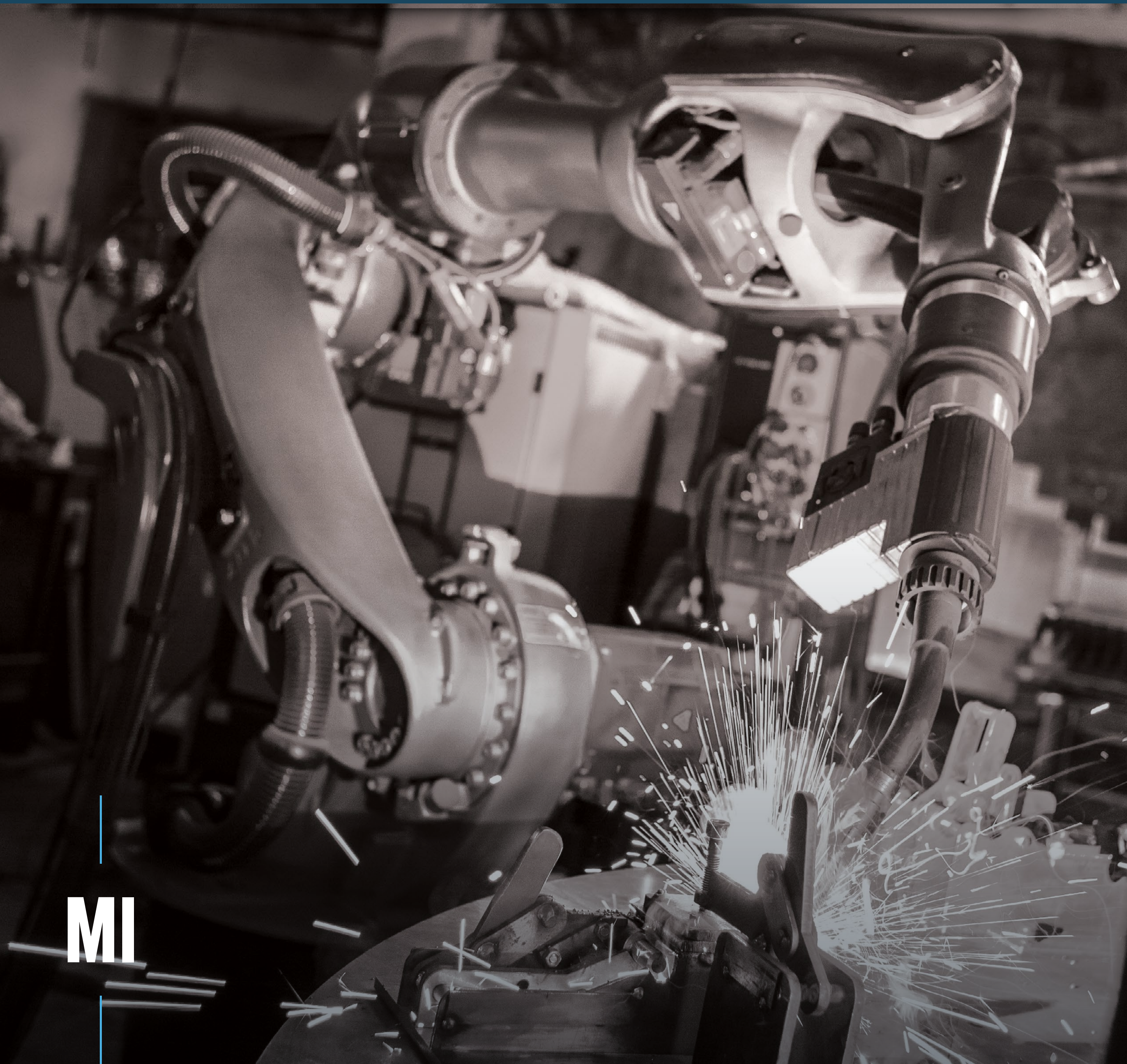
REPORT | December 2016

THE COMING REVOLUTION OF AMERICAN MANUFACTURING

Mark P. Mills
Senior Fellow



MI

About the Author

Mark P. Mills is a senior fellow at the Manhattan Institute, CEO of the Digital Power Group (a tech-centric capital advisory group), faculty fellow at Northwestern's McCormick School of Engineering and Applied Science, and an advisory board member of Notre Dame University's Reilly Center for Science, Technology, and Values. Previously, he cofounded and was chief tech strategist of Digital Power Capital, a boutique venture fund, and was chairman and CTO of ICx Technologies, helping take it public in a 2007 IPO. Mills is a contributor to Forbes.com and coauthor of *The Bottomless Well: The Twilight of Fuel, the Virtue of Waste, and Why We Will Never Run Out of Energy* (2005).His articles have been published in the *Wall Street Journal* and *New York Times Magazine*. Mills is a frequent guest on CNN, Fox, NBC, and PBS, and has appeared on *The Daily Show with Jon Stewart.*

Earlier, Mills was a technology advisor for Bank of America Securities and coauthor of the *Huber-Mills Digital Power Report*, an energy-tech investment newsletter. He has testified before Congress and has briefed many state public-service commissions and legislators. Mills served in the White House Science Office under President Reagan and subsequently provided science and technology policy counsel to numerous private-sector firms, the Department of Energy, and U.S. research laboratories.

Early in his career, Mills was an experimental physicist and development engineer at Bell Northern Research (Canada's Bell Labs) and at the RCA David Sarnoff Research Center on microprocessors, fiber optics, missile guidance, nuclear energy, and nonproliferation, earning several patents for his work. He holds a degree in physics from Queen's University in Ontario, Canada.

Contents

Executive Summary

No one seriously believes that robust growth in America's economy will come from clever smartphone apps or cheaper appendectomies. Consequently, it has become common wisdom that we are in a "new normal" of low growth in an economy destined to deindustrialize and become increasingly dominated by low-paying service-sector jobs.

While the manufacturing sector is credited with anchoring America's 20th-century growth, the "new normal" worldview sees that great industrial expansion as a one-time event, the result of a fortuitous convergence of yesterday's technological forces. This outlook is mistaken.

In the first place, manufacturing is a far bigger share of today's economy than is generally estimated: it is likely twice as big. Second, and most important, the U.S. is on the precipice of an industrial transformation as deep and impactful as the one that took hold in the early 20th century. Productivity growth is poised for a leap, thanks to the efforts of scientists, engineers, and innovators over the past decade.

A dizzying series of technologies are emerging: wholly new classes of materials, radically innovative machines, and unprecedented information analytics governing manufacturing methods. In all three domains, we are already witnessing the rapid emergence of new businesses entailing billions of dollars of revenues along with the inevitable rise of massive industries to fabricate the new classes of materials and products and to provide the interrelated services. We are in the early days of a burgeoning transformation similar to, but even broader than, the trajectory that began a half-century ago with the then-new semiconductor, electronics, and software industries.

As far-reaching as are the changes within each domain, it is in their symbiotic combination that we see the emergence of entirely new manufacturing systems. A radical—revolutionary—restructuring of the very means of production is under way and has been called "Industry 4.0" or the "digital" or "smart" factory, or even cybermanufacturing. The transformation is more accurately and descriptively labeled the emergence of manufacturing-as-a-service (MaaS). This is as deep a shift, with implications as far-reaching, as was the migration from craft production to mass production over a century ago. The new era of MaaS production will add trillions of dollars to the U.S. economy and generate millions of new well-paying jobs in manufacturing and allied economic sectors in the years to come.

THE COMING REVOLUTION OF AMERICAN MANUFACTURING

I. Introduction

Over the past dozen years, America's share of global manufacturing has declined to 17%, after holding at the 25% level for the prior two decades. Meanwhile, China's share of global manufacturing rose from less than 10% a dozen years ago to about 25% now.[1] In 2001, 17 million Americans were employed in what the government counts as manufacturing. That number is now just over 12 million.[2] And America's trade deficit in goods and services has been creeping up over the past two decades (**Figure 1**).

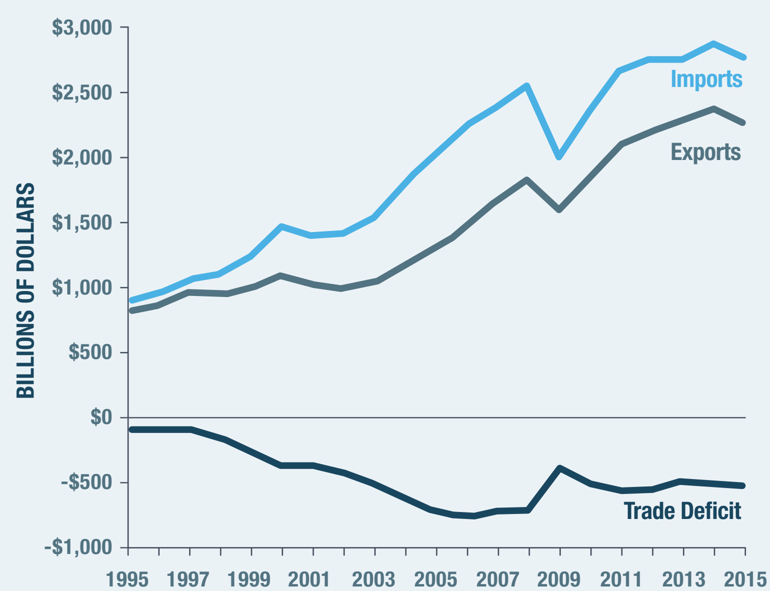
The central issue for manufacturing, however, is not whether and how to restrict imports—Americans' demand for products has clearly grown faster than America's supply—but whether manufacturing matters very much to the overall economy today, and whether it will matter in the future. The clear evidence is that it does.

FIGURE 1.

America's Trade in Goods & Services

While America's trade deficit in goods & services has grown in the past two decades, far more remarkable has been the enormous rise in U.S. exports.

Source: Data drawn from the St. Louis Federal Reserve[3]



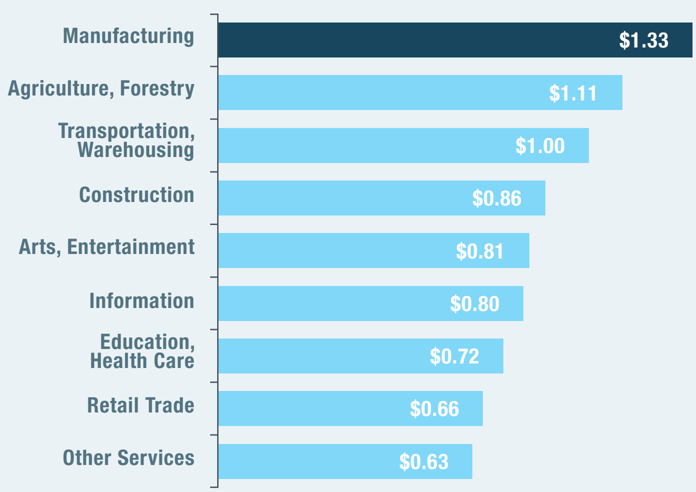
II. The Power of Manufacturing

The economic importance of manufacturing begins with the widely recognized role of the so-called multiplier effect.[4] The multiplier measures the money and jobs directly associated with inputs of products, services, and support that make any business possible, as well as the many indirect effects from spending by the employees and the companies. Not all multipliers are created equal. A job processing health-care forms, say, is far less valuable to the overall economy than one in a factory.[5] Not only are average manufacturing wages far higher—on average, 50% higher[6]—but there is a nearly twofold loss in spillover economic activity for every dollar of GDP shifted from manufacturing to health-care services.

For each $1 of GDP associated with a service business, for example, there is $0.60 to $0.70 worth of economic activity generated in the broader economy. Compare this with the multiplier for "hard" industries, which ranges from $0.86 for construction to $1.33 for manufacturing[7] (**Figure 2**). Some researchers believe that the real multiplier for manufacturing is even higher—more like $1.92, when undercounted ancillary impacts of manufacturing are incorporated.[8]

FIGURE 2.

Economic Activity Generated by $1 of GDP by Sector



A dollar of activity, or a job, in the manufacturing sector generates a greater indirect impact in the overall economy than for any other sector.

Source: Manufacturing Institute[9]

Apart from the multiplier, however, the very size of the manufacturing sector is underestimated in conventional government statistics. The 12% share of GDP attributed to manufacturing is an artifact of how government accounts for business activities, not how businesses actually operate or what they actually do. U.S. statistical agencies count work performed by a "services" establishment as a service without regard to whether some or much of that "service" is, in fact, a manufacturing activity. Conversely, current accounting conventions wrongly count some aspects of manufacturing as a service.[10]

Consider this example: truck drivers or code writers are counted in "services" or "manufacturing" on the basis of whether the manufacturer owns the trucks or directly employs the coders, not whether the activity is an integral part of manufacturing a product. Let's say that a manufacturer does directly employs code writers, or owns a software business essential for designing a computer chip or car part, or owns the trucks to deliver its products: if those "service" operations are at a different location from the factory, there is no rule or clarity on whether that employee or the revenue should be counted as part of services or as manufacturing.

Adding to this confusion: if final assembly of (often customized) products—unequivocally a manufacturing process—takes place in a warehouse, those employees are counted in "services." By one estimate, there already are some 30,000 warehouse workers engaged in manufacturing today.[11] And this economically efficient merging of services and manufacturing is just beginning. Firms like Amazon and UPS and their competitors (don't expect Walmart to stand by) are rapidly expanding into and deeply integrating with manufacturing activities.[12]

Sophisticated supply-chain management has always been an integral part of manufacturing operations in order to reduce the cost and time to acquire critical materials and ship final products, while collaterally increasing both flexibility and quality across the supply ecosystem. As manufacturers embed Amazon logistics directly inside their own factories and warehouses,[13] and vice versa,[14] counting up what truly constitutes manufacturing will become ever more challenging. The accounting lines are further blurred as manufacturing companies increasingly use off-site "Cloud" data analytics and services instead of on-site employees and computing equipment. Coming next to add economic power but accounting confusion: using 3D printers to directly manufacture products from raw materials located in warehouses and even on customer premises.

The service/hardware dividing line is also blurring, thanks to a category that the Commerce Department labels "digitally delivered services"—services "shipped" in digital format on the worldwide web. Digitally enabled services are the fastest-growing share of the services sector and comprise a rapidly expanding part of exports.[15] But digitally enabled services necessarily require enormous and power-hungry hardware-centric infrastructures. The U.S. is host to the majority of the world's data centers: thousands of massive Walmart-size buildings filled with computing hardware.[16]

Finally, the manufacturing sector accounts for two-thirds of all private sector R&D spending in the U.S.[17] Private industrial research spending is twice as great as the total federal nondefense R&D budget.[18] Notably, compared with other nations, U.S. manufacturing R&D is more focused on high-tech products such as electronics, pharmaceuticals, and aviation.[19] Whether performed on-site, with service providers, or in universities, such R&D is an integral part of manufacturing.

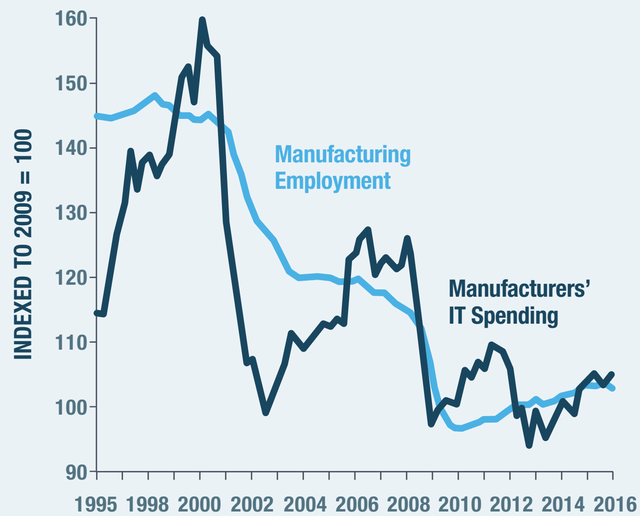
Still, the fact that manufacturing has a bigger than commonly understood role in the economy is of little comfort for those seeking to revitalize employment in this sector if the future simply means more output but fewer jobs.

III. What About Robots?

Manufacturing employment has unequivocally trended down in the past 15 years. Even adding back in relevant service jobs that should be counted as manufacturing doesn't change the trend. There is a growing body of popular literature claiming that the end of work, at least manufacturing work, is in sight as automation accelerates. While this is a complex subject, this simplistic notion is not visible in the overall manufacturing record.

FIGURE 3.

Manufacturers' IT Spending vs. Employment



Over the past two decades, increased spending by manufacturers on automation and software does not correlate with overall job destruction.

Source: Data drawn from the St. Louis Federal Reserve Bank[20]

Manufacturers' investment in tech doubled in the decade before the 2001 recession; but rather than wiping out jobs, manufacturing employment remained stable (**Figure 3**). Then, during the period between the 2001 and 2008 recessions, manufacturing spending on tech slowed to about one-third that of the previous period, and contemporaneously there was a slight decline in employment. In the post-2008 recession period, manufacturing spending on tech did not return to previous growth patterns, and employment also remained essentially flat. Whatever the cause and effect, when tech spending was growing faster, it was associated with more stable total employment and not the inverse.

And when it comes to software—the "purest" form of IT spending—analyses of trends within specific industrial sectors find that, on average, more job growth is associated in those industrial segments with greater increases in software spending.[21] This result doesn't include the collateral job growth within the software industry itself—jobs, as noted earlier, that should be counted, at least in part, within manufacturing. (Note that software-sector employment has risen over the past several decades, from 0.9% to 2.2% of all jobs, now matching the agricultural sector's share of employment.)[22]

None of these results rebuts the reality that automation can and does directly replace specific jobs. Still, the evidence does not support the unequivocal claim commonly offered that robots are the reason for depressed manufacturing employment in recent years. And while the character and mix of jobs will doubtless continue to change, the data also show that job opportunities are not opening up mainly for coders and the college-educated. There are an estimated half-million more "skilled trades" jobs (i.e., for non-college-educated workers) available than people trained to fill them,[23] with 88% of manufacturers reporting trouble finding skilled workers.[24] As for the future, a recent survey found 37% of manufacturing executives saying that automation will lead to more hiring, with only 17% claiming that it would reduce hiring (45% said no change).[25]

So why is manufacturing employment depressed? Most likely, it's because of the historically unprecedented tepid growth following the end of the Great Recession, in June 2009. Princeton's Alan S. Blinder notes that the U.S. economy would be $2.5 trillion bigger now if productivity growth—averaging an anemic 0.4% a year for the past five years—had returned to the long-term average (2.6% a year during 1995–2010).[26] Productivity growth, it bears noting, comes nearly entirely from technological progress.

The Productivity Paradox Points to the Next Manufacturing Boom

Can anything propel U.S. productivity? Or are we finally witnessing the end of fundamental tech-driven innovation cycles? Robert Gordon, a Northwestern University economics professor, gained international attention for his recent book putting forward that thesis.[27] Gordon (correctly) notes, for example, that even a flurry of innovations around smartphones is trivial compared with the invention of, say, plumbing, the car, aircraft, telephony, and electric power. And, as he notes, such foundational innovations are one-time deals. A widening circle of economists either subscribes to Gordon's view or at least worries that Gordon could be right.

But economists and economics models look backward and utterly fail at predicting the consequences of discontinuities created by technological innovation. As Dennis Gabor, a physics Nobel Prize winner and the inventor of holography, wrote in 1963: "The future cannot be predicted, but futures can be invented."[28] To see future possibilities and to ensure that policies facilitate them, one has to look beyond trends relating to innovating existing products and focus instead on the foundational advances in science and technology—the domains where the future is being invented.

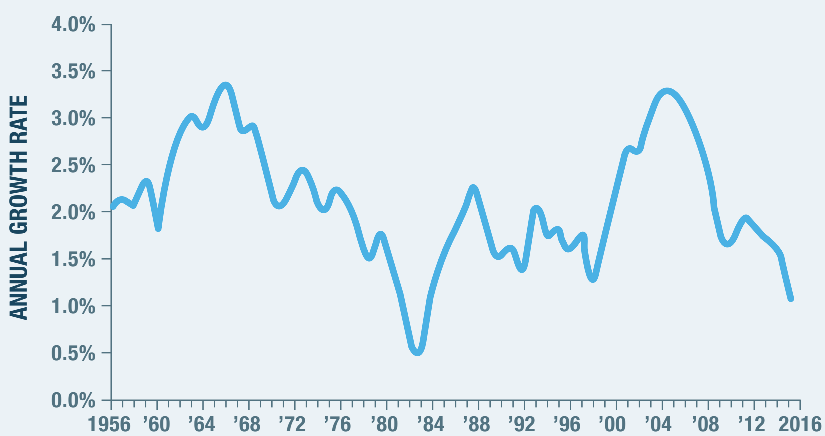
Consider: When productivity growth was collapsing in the 1970s, economists did not forecast the emergence of computing as an entirely new class of products that would create an entirely new manufacturing sector. Nor did they model or foresee the derivative emergence of new corporations (such as Microsoft, Cisco, Apple)

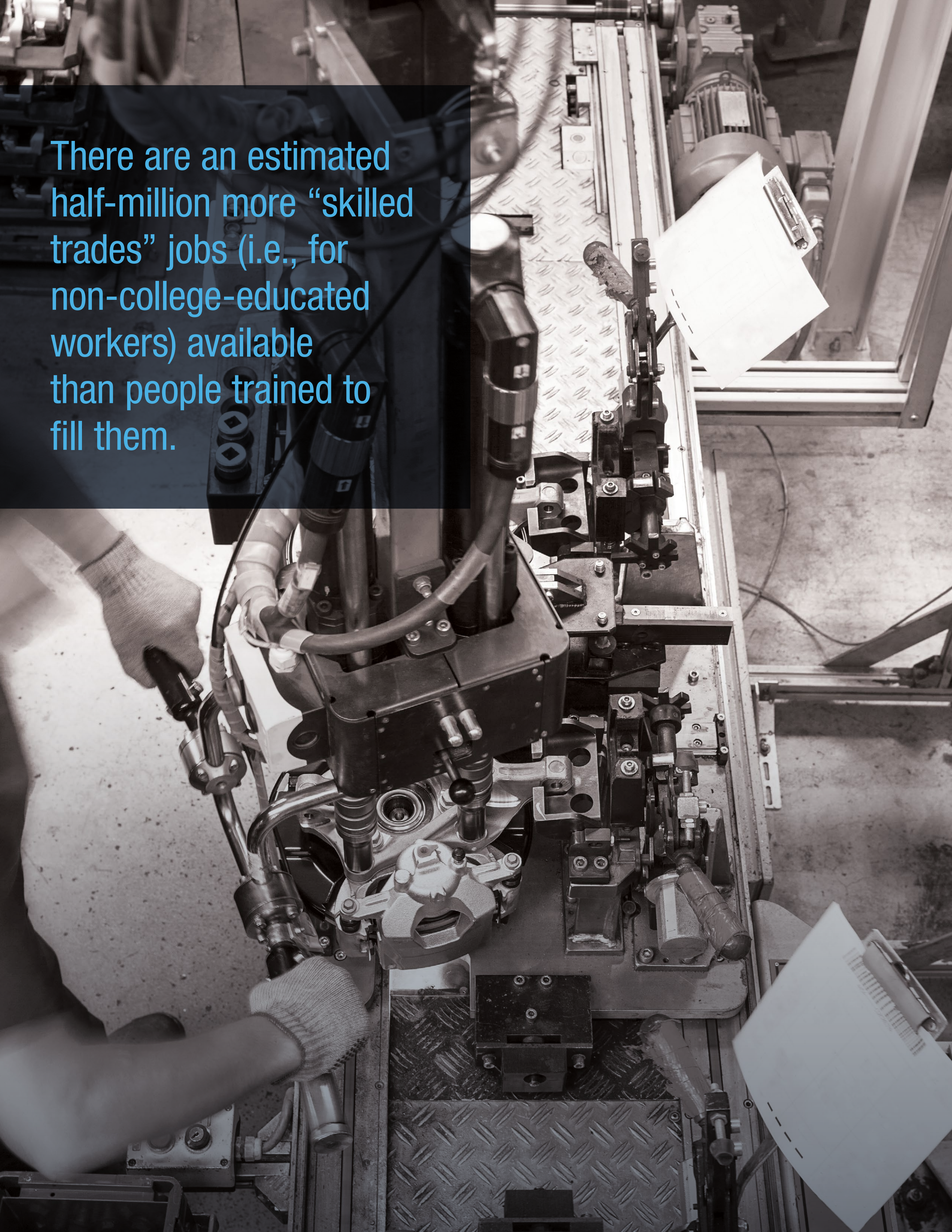
FIGURE 4.

U.S. Productivity Growth
(Nonfarm business productivity, year-over-year change)

Given the long-observed cyclical patterns in the economy, the claim that cycles in productivity growth have ended—that there is a "new normal" of permanent low growth—is an evidence-free assumption.

Source: Data drawn from the St. Louis Federal Reserve Bank[33]





There are an estimated half-million more "skilled trades" jobs (i.e., for non-college-educated workers) available than people trained to fill them.

that went from employing a handful of people to tens of thousands and even 100,000 each. The 1976 Economic Report of the President, led by Alan Greenspan, then chairman of the Council of Economic Advisers, does not contain a word about computers.[29] Missing the computer revolution in forecasts was entirely understandable. But it was hardly a small error.

U.S. manufacturing output grew at an average rate of 2.6% from 1987 through 2015, but that growth was utterly dominated by the emergence of computer and electronics manufacturing; take those out of the data, and the rest of the manufacturing sector grew at an average of only 0.6% annually.[30] And the U.S. has continued its global dominance in semiconductor manufacturing for more than three decades, with a roughly 50% market share.

The global manufacture of computing hardware is now a $1.5 trillion-per-year industry, and software is now a $400 billion-per-year industry.[31] The rise of computing and communications is what made possible the derivative classes of companies and services like those epitomized by Uber, Airbnb, Amazon, and Facebook. The semiconductor revolution disrupted old industries as well; electronics, once a negligible share of the cost to build a car, now accounts for one-third of the cost and is on track to rise to 50% within a decade.[32]

But all that is history. The prevailing thesis is that America and the world face a "new normal" of low productivity growth that will be unmoved by episodic bursts of relatively minor innovation in niches such as consumer drones, or better apps for listening to music or making airline reservations. It is not a sufficiently persuasive counterpoint to note that long-run patterns of productivity growth suggest that we are merely at the bottom of a cycle (**Figure 4**). Rather, we need evidence of what is specifically on the horizon that could cause an uptick in productivity growth. Is there anything in the future that can have an impact equal to what occurred a half-century and a century ago?

IV. Revolution Just Around the Corner

I suggest that there is such a series of events on the horizon. There is a blizzard of science- and technology-driven innovations under way, any one of which could drive a mini-renaissance in manufacturing enterprises. But it is the combination of them that signals the beginning of a new long boom in economic growth. Explaining in detail the constellation of transformations is beyond the scope of this paper. But some highlights are especially suggestive, particularly if we recall that it wasn't one specific innovation that ignited the great economic expansion of the 20th century. It was the convergence of radical advances in three interrelated domains: new materials, new kinds of machines, and new ways to control processes and machines:

Controls: The emergence of mass production radically improved the ability of manufacturers to control processes and supply chains. And the contemporaneous advent of electrical communications and electrification of power did much more than replace water, wind, belts, muscles, and steam; it enabled unprecedented flexibility and control over machines and collaterally expanded the geographic options for the placement of factories.

Machines: Industrial change in the past hundred years was also fueled by the emergence of new kinds of mechanical and electrical machine tools (milling, cutting, welding, "numerical control," etc.) and devices, including new kinds of precision measurement and monitoring instruments (e.g., the invention of spectroscopy).

Materials: Finally, 20th-century manufacturing accelerated thanks to the emergence of profoundly better and different materials: metals (especially high-strength steels and aluminum), high-strength concrete, and chemicals (especially plastics).

And today? Radical transformations are under way in each of the same three domains that revolutionized manufacturing a hundred years ago. Here is a *tour d'horizon*:

Controls—IoT and the Cloud

The combination of electrification and the assembly line in the early 20th century enabled profound improvements in the control of manufacturing processes. There is a similar confluence today, epitomized by a combination of the Internet of Things (IoT) and data analytics.

The IoT makes possible a communications revolution centered on gathering, sending, and exchanging vast amounts of data among things, not between people.[34]

The connectivity comes from tiny, wirelessly connected microchip sensors attached to or embedded in nearly anything. Constructively using the flood of information will increasingly require big-data analytics and "machine learning" tools now rapidly emerging from computer labs and becoming ubiquitously available via the Cloud.

To be sure, big things like trucks, big motors, power plants, and commercial HVAC systems have long been networked, and those networks have grown as connection costs declined. Today every Uber car is connected; so are most new cars and fleet trucks and GE aircraft engines. But the IoT can do far more than track and monitor things like luggage, medical supplies, or boxes in warehouses or on trucks. It can also monitor farm animals and food (for spoilage and safety) and anything in every part of the world's massive labyrinthine supply chains. IoT-driven economic and environmental efficiencies and productivity can be derived from everything that is grown, synthesized, produced, moved, and used.

In its June 2016 forecast, Cisco sees machine-to-machine connections as the fastest-growing contributor to total overall Internet traffic over the coming five years, all of which requires billions of dollars in hardware to be manufactured and digital infrastructures built.[35] Industry analysts at IC Insights, for example, estimate that there are already $18 billion in semiconductor sales for IoT applications, and they expect that figure to double in the next few years alone.[36] And the sheer quantity of data from the future IoT may require building as many as 4,000 new enterprise-class data centers, each typically costing $0.5 billion to $1 billion.[37]

The IoT will become an integral part of industrial operations, infrastructures, retail trade, transportation, and health care. The emergence of new classes of implantable and even ingestible devices (summarized shortly) and the associated tsunami of data is expected to yield radical medical advances. But all that will also entail entirely new manufacturing enterprises to fabricate the underlying components.[38] Analysts at Grand View Research forecast a global health-care IoT market alone that will exceed $400 billion in another half-dozen years.[39] Cisco, McKinsey, and others estimate that the collective economic value of the entire IoT and associated analytics ecosystems could exceed $10 trillion before a decade is out.[40]

Machines

The most talked-about manufacturing innovations today involve autonomous machines, from warehouse robots to human-friendly factory robots. The latter are called "cobots" because the design and control systems enable people to work alongside and collaborate with the robot, both intuitively and without injury.[41] (Automated machines and production today are almost entirely isolated from people, often in caged-off areas.)

Robots are fundamentally productivity-enhancing machines. But without regard to those benefits, the manufacturing and servicing of industrial and health-care robots are already a $70 billion-per-year global industry[42] that is forecast to rise to $135 billion annually before 2020.[43]

Drones that can deliver products and food direct to the consumer's door get the most attention, but their potential applications in industry and agriculture (monitoring plant and animal health), geological and environmental surveillance, mapping factory operations and safety, and even tool and equipment delivery are only beginning to be realized.[44] (There is, as well, the enormous military market.) Drones not only offer radically lower-cost ways to perform existing airborne services; they enable entirely new services. This addition of drones to the traditional aviation business portends a cumulative $100 billion market just to manufacture those machines over the coming five years.[45]

Then there is 3D printing—machines that "print" in three dimensions instead of two and print a product directly from a computer image or design, using "inks" of plastic, metal, or other materials.[46] The vast majority of 3D printers sold today work with plastics, but machines that can produce metal parts are rapidly improving.

GE, for example, recently opened a 125,000-square-foot, $40 million operation in Pittsburgh devoted to 3D printing to make (more effectively and less expensively) the complex components for aircraft engines. Similar activities are under way at Boeing, Rolls Royce, and Airbus, to note only a few. The capabilities are opening new markets (e.g., fabricating custom-fit medical hip joints) and even enhancing old markets (by accelerating the design cycle with rapid prototyping).[47] 3D printing technology simultaneously enables capabilities in manufacturing processes not possible with traditional machining and requires the emergence of businesses to produce the printers themselves.

3D printing is becoming a rapidly expanding corner of the $80 billion-per-year machine-tool industry.[48] While the business of manufacturing the 3D printers themselves is today under $200 million annually,[49] the total industrial ecosystem for the printers and associated materials and services is already $5 billion and forecast to approach $20 billion a year before 2020.[50]

3D printers will further blur the distinction between manufacturing and services. The technology will enable many more people—not just engineers but artists and students—to design and directly manufacture products, and these machines can be located in warehouses (where both Amazon and UPS are reportedly experimenting) as well as on customer premises where the only "product" shipped to that location would be raw materials (the "inks"). As parts and customized consumer products are increasingly fabricated on demand—whether in warehouses, offices, or homes—those "services" remain a manufacturing process.

High-power industrial lasers are becoming the fastest-rising segment of the machine-tool industry. Industrial lasers enable not just higher speeds and precision but often production techniques impossible with mechanical tools. Some $8 billion a year in industrial lasers are now produced and sold for metal cutting, welding, and processing.[51] (Most 3D printers for metals use high-power lasers.)

There are now measurement instruments superior to anything previously available. For example, spectroscopy is leaving the laboratory to undertake real-time, continuous, and precision monitoring of the chemical makeup of liquids and other materials. This technology has enormous potential for reducing costs as well as improving the quality and safety, not just in chemical but also pharmaceutical and food production.[52] Finally, emerging now is a new class of microscopes with so-called superresolution, enabling direct viewing of small molecules, both organic (biological) and inorganic, creating the potential for revolutionary advances in chemistry and medicines.

All these new instruments in combination enable not only better but also new classes of products, and the manufacture of today's class of instruments already comprises a $40 billion-a-year industry.[53] Sales of instruments for life-sciences applications alone are projected to reach $65 billion annually by 2021.[54]

The machine world is, collectively, at a pivot in history equal in scope and scale to the one that took place a century ago. And, as these new machines become integral parts of a digitally networked manufacturing ecosystem, not only will there be a multibillion-dollar market to produce them but also billions more in economic benefits from using them.

Materials

We're witnessing today the emergence of entirely new classes of basic materials (chemicals), structural materials, and electronics.

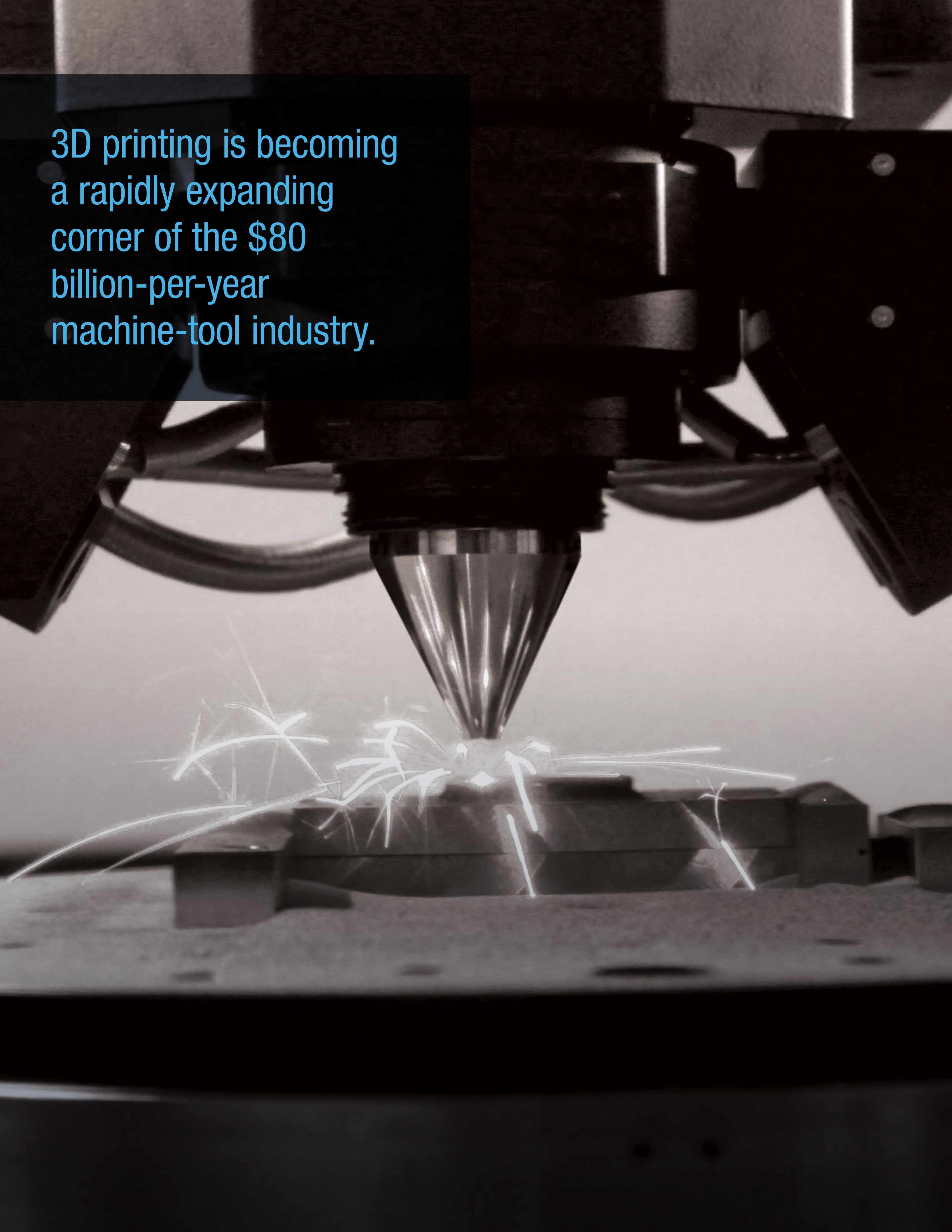
Bio-electronics may be the most significant single transformation under way. Researchers, engineers, and entrepreneurs are developing pliable, biocompatible, and even consumable microchips and sensors made from polymers and other organic materials. Also emerging are "transient" (dissolvable or disappearing)[55] electronics based on formulations of silicon that allow them to be tattooed on or implanted in living tissue or widely distributed, harmlessly, into the environment.[56]

These kinds of materials will make it possible for smart sensors to wirelessly measure and connect on or within the body, enabling revolutionary advances in real-time health monitoring, diagnostics, and therapeutics. After surgery, for example, sensors embedded in the human body will be able to monitor infection in ways that cannot be done now—and then dissolve, eliminating for patients the risk (and cost) of minor surgery to remove today's class of sensors.

Drug delivery can become hyper-precise and potent, targeting specific organs and even cells; when the task is complete, the micro-tool that transported the drug can also dissolve.[57] There are also myriad applications for bio-electronics in agriculture and animal monitoring where traditional electronics are either not desirable, or difficult to deploy and remove. The FDA has already approved a number of key components.[58] And techniques are in development to fabricate transient electronics using the same type of production lines now widely deployed for the traditional silicon electronics industry.[59]

The need to continually produce transient (disappearing) or disposable bio-electronics will result in an entirely new manufacturing industry. Bio-electronics and "electroceuticals" will rival the scale of the pharmaceutical industry. While it will take time for FDA approval

3D printing is becoming a rapidly expanding corner of the $80 billion-per-year machine-tool industry.



for intrusive technologies of any kind, the easier-to-deploy (and smaller) subclass of bio-electronics—external biocompatible wearables (e.g., bandages as sensors)—is already expected to become a nearly $20 billion-per-year industry in a half-dozen years.[60]

As momentous as all these advances are, the materials renaissance under way is even broader. Also on the horizon are unprecedented classes of materials such as graphene that can, for example, be used to produce a true "electronic paper" that has the look and feel of paper but that operates like a computer screen.[61] Also emerging from laboratories are electroconductive yarns and self-repairing and even self-cleaning materials. In addition, emerging after years of development are new classes of semiconductors (e.g., gallium nitride and silicon carbide) superior to silicon for high-power applications that can enable far more pervasive and dynamic control of electricity on grids and in vehicles.

Finally, scientists and engineers are now advancing the frontier of computationally engineered materials by using powerful algorithms to create a materials genome.[62] Computer models using basic physics principles can calculate and create a vast library of possible properties from different combinations of atoms. Instead of trial-and-error, engineers will turn to algorithms to design new alloys and materials with properties tailored to specific applications—essentially the modern realization of alchemy.

The constellation of new products and services that all the new materials enable is half the story. All of the new classes of materials will necessarily lead to the rise and expansion of heretofore nonexistent manufacturing industries to produce those materials, just as the silicon semiconductor industry emerged a half-century ago from foundational material innovations of that era.

Revolution at the Convergence—Manufacturing as a Service (MaaS)

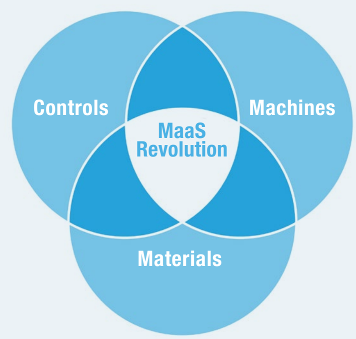
The future is not just about more efficiently and less expensively manufacturing more of the existing class of things that people now use. Nor is it simply about the emergence of new businesses to produce the range of entirely new kinds of materials and machines. The radical revolution is found in the integration of machines, materials, and control mechanisms.

No widely accepted term for this intersection yet exists. Industry 4.0 is a popular label, as are such terms as the Fourth Industrial Revolution, smart manufacturing, digital manufacturing,[63] Factory of the Future,[64] and Software Defined Manufacturing.[65] The National Science Foundation[66] prefers the term "cybermanufacturing," and Chinese pioneers started using the term "cloud manufacturing" several years ago.[67] But the most compelling label for this budding revolution is Manufacturing as a Service, aka MaaS (**Figure 5**).

FIGURE 5.

Manufacturing as a Service (MaaS)

The industrial revolution at the turn of the last century occurred because of the convergence of individual revolutions in controls, machines, and materials. We are now witnessing the early days of a similar convergence.



As researchers at Germany's Fraunhofer Institute noted: "Cloud manufacturing transfers the principles of cloud computing (Everything-as-a-Service, XaaS) to the manufacturing environment, where it propagates Manufacturing-as-a-Service (MaaS)."[68] Converting a manufactured product into a service is not a new idea. GE and other aircraft engine producers, for example, long ago moved from selling engines to selling airlines a fully supported "thrust" service by hour of use. GE calls its service "Power by the Hour." Industry analysts at IDC have found that a plurality of all manufacturers are now actively exploring the "product as a service" business model.[69]

The evolution of MaaS from a few isolated and extremely expensive products into the entire realm of manufacturing is a transformation identical in character to the one that took place in all kinds of factories over a century ago as a result of electrification and mass production. As MaaS becomes significant, and eventually dominant, it will democratize product design and delivery in unprecedented ways. It will also further confound the already misleading government classification of services vs. manufacturing.

V. Carpe Diem

The scientific and technological advances that could bring about a manufacturing renaissance are bubbling up from researchers in academia and corporations. Still, the government has a role. A crucial role is, of course, to forbear from hobbling or strangling the MaaS production revolution through unsound energy, tax, finance, and regulatory policies. This means:

Taking Advantage of the New Competitive Landscape

More than 90% of the world's goods are fabricated in 25 nations. While many Americans assume that most of them can manufacture these goods more cheaply than we can, a recent analysis by the Boston Consulting Group showed that the manufacturing cost index—a combination of labor and energy costs, and productivity—is now lower in the U.S. than anywhere other than in China, South Korea, and Mexico.[70] And China's overall cost index is only 5% lower now. (Mexico is a winner, by this measure.)[71]

It's not that American labor has become cheaper. But labor costs have rapidly escalated in places (especially China) that formerly had extraordinary low wages. Meanwhile, North American energy costs have plummeted, thanks to the fracking-led boom in shale oil and gas. The overall manufacturing "favorability" for the U.S. is further enhanced when one includes advantages in sophisticated supply-chain logistics, ease of doing business, and low corruption.

Dramatically lower energy costs have handed firms located in the U.S. an enormous competitive advantage in the energy-intensive production of chemical products. The $5 trillion global chemical-fabrication industry makes products used in nearly everything from polymers in cars and smartphones to fertilizers and pharmaceuticals.[72] This unplanned advantage for America's chemical subsector will have spillover benefits for other subsectors as the expansion stimulates local development of directly related service and manufacturing businesses.[73]

One effect of the favorable conditions in the U.S.: average annual foreign direct investment (FDI) into American manufacturing enterprises has more than tripled since 2004 (contemporaneous with the start of the shale boom), to over $250 billion, and has grown far faster than have domestic investments.[74]

Measuring Manufacturing Correctly

Evidence clearly points to the fact that the manufacturing sector is a substantially larger share of the GDP, likely 30%, rather than 12%, as popularly cited.[75] In his later years, Intel cofounder and CEO Andy Grove wrote passionately about the need to fix the categorization and perception errors that account for the misclassification of many services that actually belong in the manufacturing sector, especially software and related engineering support.[76] A recent Congressional Research Service report aptly summarizes the "imperfect line between manufacturing and services" with "often arbitrary distinctions" and points out that efforts to undertake a proper accounting of the size of today's manufacturing sector are "still in their infancy."[77] Manufacturing is too important to have a deeply flawed measure of its economic and employment scale.

I'd recommend a commission consisting of the best public and private analysts to revise the current federal definitions and reporting methodologies for accounting for jobs, revenues, and trade associated with manufacturing and services.

Facilitating the Availability of a Skilled Workforce

New technologies and tools will require greater numbers of men and women with the training to work in the skilled trades necessary to fabricate, maintain, and operate the machines of the future.[78] An Accenture survey of manufacturers found a dramatic rise of more than 20 percentage points over the past five years in the number of companies reporting a shortage in skilled trades, especially for operating and maintaining tech-centric equipment.[79] A recent Boston Consulting Group survey of more than 600 manufacturing firms (half each in the U.S. and Germany) found that companies see the "lack of qualified employees as their biggest challenge in implementing" the emerging manufacturing technologies.[80] Skilled-trade vacancies have been the hardest to fill for six consecutive years.[81]

Meanwhile, most high schools and community colleges have abandoned programs and tracks for developing interests in the skilled and so-called vocational trades. And the number of people completing apprenticeships has not changed significantly since 2008, despite the fact that most skilled trades pay well, don't require a costly education, and enjoy a high employment rate.[82] Even though about 150,000 Americans start an apprenticeship each year, that total would be 1 million to 3 million a year if as many U.S. millennials signed up as they do per capita in France, Germany, England, and Switzerland.[83] There are public and private initiatives to encourage more young men and women who are willing and capable of developing such skills. Efforts to expand these initiatives should be a priority.

Stimulate Innovation
The private sector is the largest single source of research and development. Thirteen of the world's top 20 R&D spenders are in the United States (e.g., Amazon, Intel, Microsoft, Apple, GM, Ford, Oracle).[84] Those 13 spend more than $120 billion annually on R&D. Another 14 million private American businesses engage in R&D, in one form or another, spending $260 billion.[85] To fuel the innovation pipeline from R&D and to facilitate more businesses created from that IP, the country needs to: (1) accelerate and enhance tax benefits for corporate R&D spent on basic science; (2) remove barriers to small business formation; and (3) reform regulations that inhibit private capital investments and initial public offerings.

Encourage Not Destroy Profits
The following recommendations are not new, but they bear repeating, thanks to their importance. Policymakers should: (1) reduce the U.S. corporate tax rate, which used to be the lowest but is now the highest among all but one of the OECD nations;[86] and (2) restructure the foreign withholding tax rules that are uniquely punitive to U.S. firms in order to allow repatriation of over $2 trillion in corporate profits held offshore that would be available for investment in the U.S., either by the corporations themselves or by their shareholders.

The world is on the precipice of a generational transformation of manufacturing as deep and impactful as the one that occurred at the turn of the 20th century. Innovation and productivity growth are not over but are poised for a leap upward in the next, inevitable cycle that has been quietly brewing in laboratories for the past decade. Companies and innovators in the United States are at the epicenter of the new materials, machines, and MaaS production revolutions. History will view as heroic those policymakers who have the vision to facilitate this change or, at the very least, to get out of the way.

Endnotes

1. Marc Levinson, "U.S. Manufacturing in International Perspective," Congressional Research Service, Report R42135, Apr. 26, 2016.
2. St. Louis Federal Reserve Bank, FRED (Federal Reserve Economic Data), October 2016.
3. St. Louis FRED, July 29, 2016.
4. Robert E. Scott, "The Manufacturing Footprint and the Importance of U.S. Manufacturing Jobs," Economic Policy Institute, Jan. 22, 2015.
5. Gary Sernovitz, "Why We Pine for Manufacturing," *New Yorker,* Aug. 6, 2016.
6. Marc Levinson, "Job Creation in the Manufacturing Revival," Congressional Research Service, Report R41898, June 28, 2016.
7. Manufacturing Institute, "Manufacturing's Multiplier Effect Is Stronger than Other Sectors,'" (updated April 2014). The Manufacturing Institute bases its calculations on the Bureau of Economic Analysis's annual input-output (IO) tables.
8. Stephen Gold, "The Competitive Edge: Manufacturing's Multiplier Effect—It's Bigger than You Think," *Industry Week,* Sep. 2, 2014.
9. Manufacturing Institute, "Facts About Manufacturing," April 2014.
10. Levinson, "U.S. Manufacturing in International Perspective."
11. Ibid.
12. UPS, "Is Your Small Business Ready to Expand Internationally?" October 2016; and NPR, "Moving in with Manufacturers, Amazon Delivers a New Approach," Oct. 28, 2013.
13. Serena Ng, "Soap Opera: Amazon Moves in with P&G," *Wall Street Journal,* Oct. 14, 2013.
14. "Amazon Assembly, Installation Services Bolster Big-Product Sales," *Today,* Mar. 31, 2016.
15. U.S. Department of Commerce, Economics & Statistics Administration, "Digitally Deliverable Services Remain an Important Component of Trade," May 28, 2015.
16. Synergy Research Group, "U.S. Accounts for Almost Half of All Major Cloud and Internet Data Centers," Mar. 21, 2016.
17. Nanette Byrnes, "Making Innovation," *Technology Review,* Sep. 16, 2014.
18. Mark P. Mills, "Basic Research and the Innovation Frontier," Manhattan Institute, February 2015.
19. Levinson, "U.S. Manufacturing in International Perspective."
20. St. Louis Federal Reserve, FRED, November 2016.
21. Robert Shapiro, "The U.S. Software Industry: An Engine for Economic Growth and Employment," Software & Information Industry Association, 2014.
22. St. Louis Federal Reserve, FRED, Nov. 4, 2016.
23. Deloitte Manufacturing Institute, "The Skills Gap in U.S. Manufacturing 2015 and Beyond," 2015.
24. Jeannine Kunz, "Manufacturers Are Unprepared for Growing Skills Gap," *Automation Alley,* Apr. 27, 2016.
25. PwC Manufacturing Institute, "Upskilling Manufacturing: How Technology Is Disrupting America's Industrial Labor Force," June 2016.
26. Alan S. Blinder, "The Mystery of Declining Productivity Growth," *Wall Street Journal,* May 14, 2015.
27. Robert J. Gordon, *The Rise and Fall of American Growth* (Princeton University Press, 2016).
28. Dennis Gabor, *Inventing the Future* (Secker & Warburg, 1963).
29. Council of Economic Advisers, *Economic Report of the President,* January 1976.
30. Martin Neil Baily and Barry P. Bosworth, "US Manufacturing: Understanding Its Past and Its Potential Future," Journal of Economic Perspectives 28, no. 1 (Winter 2014): 3–26.
31. Statista—The Portal for Statistics, "Total Revenue of the Global Chemical Industry from 2002 to 2015 (in Billion U.S. dollars)," 2016.
32. Samsung, "Bringing Intelligence on the Road," August 2015.
33. St. Louis FRED, November 2016.
34. Mark P. Mills, "The Internet of Things Won't Be Big It'll Be Huge," *Forbes,* Sep. 28, 2016.
35. Cisco, "The Zettabyte Era—Trends and Analysis," June 2, 2016.
36. IC Insights, "Updated Semiconductor Outlook for Internet of Things," Sep. 7, 2016.
37. Cisco, "The Zettabyte Era."
38. Louis Columbus, "Roundup of Internet of Things Forecasts and Market Estimates, 2015," *Forbes*, Dec. 27, 2015.
39. Semiconductor Engineering, "Medical IoT Showing Signs of Life," Aug. 4, 2016.
40. James Manyika et al., "Unlocking the Potential of the Internet of Things," McKinsey & Company, June 2015.
41. Northwestern University engineering professors Michael Peshkin and Edward Colgate are credited with inventing the word and concept of a "cobot" in 1996; see Jon Van, "Mechanical Advantage," *Chicago Tribune,* Dec. 11, 1996.
42. International Federation of Robotics (IFR), 2016.

[43] IDC, "Worldwide Commercial Robotics Spending Guide," Feb. 24, 2016.

[44] Mark P. Mills, "Drone Disruption: The Stakes, the Players, and the Opportunities," *Forbes,* Mar. 23, 2016.

[45] Goldman Sachs, "Drones: Flying into the Mainstream," May 5, 2016.

[46] Mark P. Mills, "Will Home Depot, Amazon, or Dell Launch the 3D Printer Revolution?" *Forbes,* July 16, 2014; and idem, "The 3D Printers Are Coming: Dig More Coal?" *Forbes*, Feb. 28, 2014.

[47] Boston Consulting Group, "3D Printing Will Change the Game," Sep. 26, 2013.

[48] Modern Machine Shop, "The 2016 World Machine Tool Survey," May 1, 2016.

[49] Wohlers Associates, 3D Printing and Additive Manufacturing State of the Industry*,* 2016.

[50] CONTEXT, "Global 3D Printer Market," July 13, 2016.

[51] David Belforte, "Industrial Lasers Outperform Machine Tool Sales Growth," *Laser Today,* July 11, 2016.

[52] Hank Hogan, "Spectroscopy: Going Small to Get the Whole Picture," *Photonics Spectra,* March 2015.

[53] "Top Instrument Firms in 2015," Chemical & Engineering News*,* Apr. 25, 2016.

[54] Markets and Markets, "Life Science Instrumentation Market by Technology," August 2016.

[55] David Chandler, "John Rogers and the Ultrathin Limits of Technology," IEEE Pulse*,* Jan. 25, 2016.

[56] Suk-Won Hwang et al., "A Physically Transient Form of Silicon Electronics," *Science,* Sep. 28, 2012.

[57] Seung-Kyun Kang, "Bioresorbable Silicon Electronic Sensors for the Brain," *Nature,* Jan. 18, 2016.

[58] Kim Tingley, "The Body Electric," *New Yorker,* Nov. 25, 2013.

[59] Lisa Zyga, "Water-Soluble Silicon Leads to Dissolvable Electronics," *PhysOrg,* Jan. 15, 2015.

[60] Tractica, "Healthcare Wearables Shipments to Rise to 98M Units Annually by 2021," Apr. 14, 2016.

[61] Dexter Johnson, "Graphene-Enabled Paper Makes for Flexible Display," IEEE Spectrum*,* July 31, 2016.

[62] Nicola Nosengo, "The Material Code," *Nature,* May 5, 2016.

[63] Cisco, "The Digital Manufacturer: Resolving the Service Dilemma," November 2015.

[64] Goldman Sachs, "Factory of the Future: Beyond the Assembly Line," June 2016.

[65] David Breitgand, "Collaborative Manufacturing as a Service in the Cloud," IBM Research, Dec. 3, 2014.

[66] National Science Foundation, "Dear Colleague Letter: Cybermanufacturing Systems," NSF 15-061, 2015.

[67] Wikipedia credits Chinese professors Bo Hu Li and Lin Zhang with proposing the concept in 2009.

[68] Fraunhofer Institute for Manufacturing Engineering and Automation, "Cloud Manufacturing," Nov. 14, 2012.

[69] Beth Stackpole, "IoT-Enabled Product as a Service Could Transform Manufacturing," *TechTarget,* April 2015.

[70] Harold Sirkin et al., "The Shifting Economics of Global Manufacturing," BCG, August, 2014.

[71] Note that the index does not include costs of raw material inputs or tax policies for equipment depreciation.

[72] Statista, "Total Revenue of the Global Chemical Industry."

[73] IHS Economics, "The Economic Benefits of Natural Gas Pipeline Development on the Manufacturing Sector" (prepared for the National Association of Manufacturers), May 2016.

[74] Bureau of Economic Analysis, "Foreign Direct Investment in the U.S.: Balance of Payments and Direct Investment Position Data," Nov. 21, 2016.

[75] SSTI, "Assessing Impact of Manufacturing Value Chain on U.S. Economy," Mar. 10, 2016,

[76] Andy Grove, "How America Can Create Jobs," *Business Week,* July 1, 2010.

[77] Levinson, "U.S. Manufacturing in International Perspective."

[78] KPMG, "Tech Companies to Significantly Grow Digital Labor and Human Workforce over Next Three Years: U.S. Tech CEO Study," July 2016.

[79] Accenture, "Cracking the Code on the Digital Factory," May 31, 2016.

[80] BCG Perspectives, "Time to Accelerate in the Race Toward Industry 4.0," May 19, 2016.

[81] ManpowerGroup, "2015 Talent Shortage Survey."

[82] U.S. Department of Labor, Registered Apprenticeship National Results: Fiscal Year (FY) 2015.

[83] Sarah Ayres Steinberg and Ethan Gurwitz, "The Underuse of Apprenticeships in America," Center for American Progress, July 22, 2014.

[84] PwC, "Top 20 R&D Spenders."

[85] IRS, "SOI Tax Stats—Corporation Research Credit," Nov. 16, 2016.

[86] National Association of Manufacturers, "The United States Needs a More Competitive Corporate Tax System," 2015.

December 2016

REPORT 27

Abstract

It has become common wisdom that we are in a "new normal" of low growth in an economy destined to deindustrialize and become increasingly dominated by low-paying service-sector jobs. This outlook is mistaken.

In the first place, the size of the manufacturing sector is underestimated. The 12% share of GDP attributed to manufacturing is an artifact of how government *accounts* for business activities, not how businesses actually *operate* or what they actually do.

Second, the U.S. is on the precipice of an industrial transformation as deep and impactful as the one that took hold in the early 20th century. Productivity growth is poised for a leap, thanks to the efforts of scientists, engineers, and innovators over the past decade.

Key Findings

1. U.S. statistical agencies count work performed by a "services" establishment as a service without regard to whether some or much of that service is, in fact, a manufacturing activity. Conversely, current accounting conventions wrongly count some aspects of manufacturing as a service.

2. A dizzying series of technologies are emerging in three domains: wholly new classes of materials, radically innovative machines, and unprecedented information analytics governing manufacturing methods. In all these areas, we are already witnessing the emergence of new businesses entailing billions of dollars of revenues along with the inevitable rise of massive industries to fabricate the new classes of materials and products and to provide the interrelated services.

3. As far-reaching as are the changes within each of these three domains, it is in their symbiotic combination that we see the emergence of entirely new manufacturing systems. A revolutionary restructuring of the means of production is under way, best called manufacturing-as-a-service (MaaS). In the years to come, MaaS production will add trillions of dollars to the U.S. economy and generate millions of new well-paying jobs in manufacturing and allied economic sectors.

MANHATTAN
INSTITUTE