

The Rise of the Internet of Goods

A New Perspective on the Digital Future for Manufacturers



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Executive Summary

It is relatively easy to digitize a song or a bank account. Yet fully digitizing physical industries such as manufacturing and agriculture has proven much more challenging. Manufacturers have taken the first step towards digitization by putting sensors into existing products such as turbines and tractors and using the resulting data to improve performance. The goal is now to turn data collection and analysis into a new revenue stream.

But data monetization is only one possible application of IT to manufacturing, and perhaps not the most effective at creating sustainable new markets or new business models. An alternative digital future for manufacturing, the “Internet of Goods,” is emerging. Three trends could lead to a manufacturing sector that uses information technology to boost productivity and create new markets.

1. The rise of ecommerce fulfillment centers and the digitization of distribution, pioneered by Amazon, opens up new ways for manufacturers to shift from a warehouse model to a more flexible distribution process.
2. The growth of robots and 3D printing, which give manufacturers the ability to offer customized products that are superior in some dimensions to mass production and can be delivered quickly and cheaply.
3. The use of cloud computing to build manufacturing platforms that treat design, production, sales, and

distribution as separate services running on a packet-switched network, enabling even small factories to tap into new technology and best practices.

This combination of digitized distribution, digitized production, and new manufacturing platforms—aka the “Internet of Goods”—will allow the creation of new business models for manufacturing capable of expanding the market and changing the geography of production.

The result will be a thickening network of small-batch and custom factories taking hold around the country. The new business models will give a sustained competitive advantage against foreign competitors, because who wants to buy a custom item from a supplier 10,000 miles away that will take two months to arrive? This will enable the U.S. to rebuild its industrial networks in areas like the Midwest and upstate New York.

We will likely see a new wave of industrial startups that take advantage of the new technologies. Similarly, there will be a new role for large industrial companies as the global hub of manufacturing platforms. Like the large tech companies that currently form the hubs of digital platforms, the global industrial giants will not only do much of the R&D and investment for developing new technologies but also take much of the risk. In exchange, they will take a share of the gain from increased productivity.

While manufacturing remains a very dynamic and essential part of the U.S. economy, most people have stopped looking at the industrial sector as a jobs and growth engine.

Introduction

For all of the catchphrases about Industry 4.0 and the fourth industrial revolution, the truth is that digitizing manufacturing is a long and difficult slog. The issue is that engineers in manufacturing and other physical industries have to manipulate and fit together real-world materials in ways that are consistent with the laws of nature and the limitations of current technology. Software developers in digital industries like entertainment and finance—where the final product is reduced to bits and bytes—have a much easier time.

Consider, for example, Tony Stark’s iconic Iron Man armor from the Marvel Cinematic Universe. To achieve \$7 billion in global ticket sales—the total revenues from Marvel movies featuring Iron Man—the filmmakers only had to be concerned with projecting a believable two-dimensional image on a screen. That is a difficult but doable task.

By contrast, actually building a flying suit of armor in real life would require a combination of metallurgy, robotics, and microelectronics that currently doesn’t exist. Digital objects—including even the most complicated software programs—are simple compared to the requirements of fully digitizing even the simplest of real-world objects.

Manufacturers have taken the first step towards digitization by putting sensors into existing products such as turbines and tractors and using the resulting data to improve performance.

The goal is to turn data collection and analysis into a new revenue stream.

But data monetization is only one possible application of the Internet of Things to manufacturing, and perhaps not the most effective at creating sustainable new markets. After all, it’s not clear how much customers are willing to pay to have their data sold back to them.

The cautionary tale here comes from GE, which bet huge sums on the industrial internet and the development of a software platform called Predix that uses data to help customers monitor and improve the performance of their equipment. GE Digital collected a sizable \$4 billion in revenue in 2017. Nevertheless, a perceived shortfall in the performance of GE Digital relative to expectations led to the CEO being replaced and the stock price dropping by 50% over the course of a year. As of June 2018, GE was removed from the Dow Jones Industrial Average and replaced by Walgreens. At the time, the committee in charge of the Dow Jones explained its decision this way:

“General Electric was an original member of the DJIA in 1896 and a member continuously since 1907... Since then the U.S. economy has changed: consumer, finance, health care and technology companies are more prominent today and the relative importance of industrial companies is less.”¹



While manufacturing remains a very dynamic and essential part of the U.S. economy, most people have stopped looking at the industrial sector as a jobs and growth engine. Eleven out of 19 major U.S. manufacturing industries are producing less than they did in 2000, including the iconic machinery and electrical equipment industries.² Eighteen out of 19 major manufacturing industries have fewer employees than they did in 2000, with the one exception being food manufacturing. Across the country, the number of manufacturing facilities employing more than 500 people has dropped by 35% since 2001.³

Domestic manufacturing productivity rose only 0.3% in the year ending in the first quarter of 2018, and is actually down

from its 2013 peak. Real domestic manufacturing operating profits are stalled at their 2007 level, with the latest figures from the U.S. Bureau of Economic Analysis (BEA) actually showing a decline in recent quarters. Moreover, the price of domestic manufactured goods is rising faster than the price of Chinese imports, as measured by the U.S. Bureau of Labor Statistics (BLS), reducing competitiveness.

A recent report from the McKinsey Global Institute observes that U.S. manufacturing has experienced two “lost decades.”⁴ The report goes on to say that “significant productivity gaps have opened up between large firms and small and midsize producers that are unable to invest in new equipment and technologies.”

New Opportunities

But the future of manufacturing, having come more slowly than expected, may now be on the verge of happening all at once. The ability to digitize the actual manufacturing and distribution process is rapidly approaching the point where new business models and new markets will emerge. Digitization of production and digitization of distribution will lead to a renewed emphasis on local manufacturers, which will provide rapid response customization and distribution that foreign competitors cannot. Moreover, we are entering a new era of manufacturing platforms, both open and proprietary, which may boost global productivity and innovation in manufacturing.

Recent research has identified several trends that may lead to a revival of localized manufacturing. First, the rise of ecommerce fulfillment centers is revolutionizing distribution. This factor cannot be underestimated in the next wave of manufacturing. For years, the efficiencies of scale associated with standardized shipping containers gave the entire manufacturing system a bias towards scale. It was often cheaper to ship a single container from Shanghai to New York than to ship the same goods in small lots by truck from Ohio.

But the advances in distribution technology introduced by Amazon change the economic equation. A technology designed to sort and ship packages to consumers efficiently

can give industrial businesses the ability to ship individual items directly to customers without going through distributors.

Second is the growth of robots and 3D printing. In different ways, these two technologies give manufacturers the ability to efficiently fulfill small-batch or custom production runs without incurring heavy retooling costs. That greatly expands the types of business models that are possible. For this paper, we will focus on 3D printing, but the extensions to robots are obvious.

Third, and most important, industrial companies now have the capability to create manufacturing platforms, both open and proprietary. These platforms would be analogous to today's multi-sided internet platforms, like app stores, social media, or advertising networks. Platforms are built upon a ceaseless flow of small packets of data that are rapidly routed to the desired destination. By contrast, these new manufacturing platforms would be mixed cyber-physical systems consisting of functions such as design, production, and distribution running as separate services on top of an advanced distribution network of goods. By analogy with the digital world, it is useful to think of this new physical network of goods as being "packet-switched," indicating greater flexibility and lower costs than the previous generation of distribution.

This next wave of manufacturing is usually called “Industry 4.0,” but we think it’s more descriptive to call it the “Internet of Goods.”

This next wave of manufacturing is usually called Industry 4.0, but it is more descriptive to call it the Internet of Goods.⁵ The result: anticipate a thickening network of small-batch and custom factories taking hold around the country. The new business models will give a sustained competitive advantage against foreign competitors, because who wants to buy a custom item from a supplier 10,000 miles away that will take two months to arrive? This will enable the U.S. to rebuild its industrial networks in areas like the Midwest and upstate New York.

Research also suggests that there is going to be a new wave of industrial startups, which take advantage of the new technologies. Carbon®, a 3D printing startup in Redwood City, is emblematic of this new wave of startups. The company offers its cutting-edge 3D printers on a subscription model—Hardware-as-a-Service. The printers connect to Carbon through the internet, allowing Carbon to offer printer upgrades and optimization on the fly.

Similarly, there will be a new role for large industrial companies as the global hub of manufacturing platforms. Like the large tech companies that currently form the hubs of digital platforms, the global industrial giants will do much of the R&D and investment developing new technologies and take much of the risk. In exchange, they will take a share of the gain from increased productivity.

As the Internet of Goods takes hold, state and local policy will play a powerful role in determining which areas are the big winners. The gains will depend on whether the local workforce is prepared for tech-enabled physical industries; the availability of capital for local entrepreneurs to start new businesses or expand existing ones; and the regulatory environment.

Digital Versus Physical Industries

Entrepreneur and venture capitalist Marc Andreessen famously said in 2011, “software is eating the world.”⁶ So far, he is half right. Software has devoured any industry where the final output can be easily reduced to bits. These are the digital industries—including communications, entertainment, finance, and even professional services. The full content of a daily newspaper can be put into a small digital file.

But so far software has not been able to eat the physical world. Data is important for physical industries like manufacturing, construction, agriculture, and healthcare, but it is not the main story. The construction of a building requires huge cranes, not just a digital twin of a crane. A physician treating a patient needs an actual tool like a surgical knife, a laser, or the appropriate drug. And a company building an airplane needs to work with materials that won’t fall apart in flight.

This divergence between the digital and physical sector has several important consequences.⁷ For one, companies in the digital sector invest far more in software and information technology equipment. In 2016, 65% of U.S. software investment went to the digital industries, which make up only 35% of private sector GDP and 30% of private sector employment.*

The digital sector is also outperforming the physical sector on a wide range of economic measures, including faster productivity growth, faster job growth, and faster wage growth. For example, between 2000 and 2017, productivity growth in the digital sector averaged 2.5% annually, compared to only 0.7% in the physical sector.⁸

The obvious question: why haven’t physical industries embraced digitization more enthusiastically? Making the business case for deep digitization has proven to be tough in many industries. Take healthcare, for example. Lockheed developed the first electronic health records (EHRs) in the 1960s.⁹ But it was hard to make a business case for the EHR, and widespread adoption did not take hold until spurred by the federal government. Even now, it’s not clear if the current version of EHRs contain all the clinical information that could be used to track treatment outcomes.

Similarly, most trucking companies have adopted GPS to keep track of their vehicles. But these relatively minor investments have not fundamentally changed the business model of the short-haul or long-haul trucking industry. Autonomous trucking is transformative, but widespread use of fully driverless trucks is further off than people expect.¹⁰

*The digital industries, in this definition, include computer and electronics manufacturing; the entire information sector, including software, telecom, and Internet search and publishing; the finance and insurance sector; the professional and technical services industries; and management establishments. Physical industries include the rest of the private sector, including manufacturing, construction, transportation, mining, and healthcare.

There are two good examples of the successful application of data to transform a physical industry. The first example is oil and gas mining. The ability to use data to visualize and analyze oil and gas formations made horizontal drilling cost-effective and opened up vast new reserves that were not accessible before. In the U.S., proved oil reserves went from roughly 21 billion barrels in 2006 to 33 billion barrels in 2016, according to the Energy Information Administration. Natural gas reserves grew at roughly the same rate, from 220 trillion cubic feet in 2006 to 341 trillion in 2016. In effect, data-driven oil and gas exploration and extraction increased the size of oil and gas reserves in the United States by roughly 50%.

Retail, or more precisely the distribution of goods to the household, is the other physical industry transforming by data. Historically it has always been too expensive to deliver most goods directly to households, so the solution was to have individuals pick up their goods at central storage locations—that is, stores.

In the 1980s and 1990s, big box retailers such as Walmart and Costco took that trend to the natural conclusions by effectively turning their stores into large warehouses, which reduced costs and let consumers do their own “picking and packing.” In that era, retailers developed sophisticated back-office digital solutions for managing their supply chains. But store employees were mostly doing the same tasks as they had always done—re-shelving inventory and ringing up the register. The result was an increase in low-wage workers.



The first wave of ecommerce pioneers in the 1990s used technology to improve the ordering stage of retail. The use of websites made it possible to order goods such as groceries (Webvan) and pet supplies (Pets.com) online, which seemed like a great innovation at the time.

However, it turned out that the main point of retail was to get goods into the hands of consumers, which was more difficult and expensive than it seemed. Webvan burnt through

\$1.2 billion in capital before going bankrupt in 2001. The company had a vision of robot-enabled fulfillment centers but did not realize how hard the task was.¹¹

Building on the lessons learned by Webvan and others, Amazon's great innovation was to apply robotics and machine learning to greatly improve the productivity of order fulfillment, picking and packing of individual items, and the best allocation of items across fulfillment centers.

It's worth noting that Kiva, the warehouse robot company bought by Amazon in 2012, was founded by a former Webvan manager, Mick Mountz. Mountz recounts his experience in talking to venture capitalists.

*"Still, in 2003 even I knew why VCs weren't biting. They looked at Kiva and saw a company that was complicated, because it was both a software and a hardware business. Software they liked. In fact, I remember potential investors saying to me, 'You've got so much data at the heart of this thing. Can't we just sell the data?' (We couldn't. We needed to physically move inventory around the warehouse to create value.)"*¹²

Amazon's technological advances in cutting costs and boosting productivity were then transformed into new business models. For one, the deceptively simple promise of two-day delivery at no extra cost for Amazon Prime members made e-commerce shopping almost as fast as bricks-and-

mortar, in terms of consumer perceptions. Fulfillment By Amazon (FBA) allowed Amazon to extend the same promise to goods sold by other online merchants.

Suddenly, e-commerce became a much better proposition for consumers. Rather than driving to the mall, parking, walking through the store and looking for the right aisle, waiting to check out, and driving back home, a harried parent could simply go online and get the desired goods within two days. In effect, they could pay someone else to do their driving, picking, and packing for them, at a price that was appealing.

In fact, Amazon boosted productivity so much in the ecommerce fulfillment centers that it could offer Amazon Prime at a low enough price to attract 100 million subscribers worldwide. And as demand soared, fulfillment center employment soared as well. Many fulfillment centers employ thousands of people to work alongside the robots. As a result, Amazon became the fastest private company to employ 300,000 workers in history, and its job growth curve since its IPO in 1997 looked identical to the first 20 years of General Motors.¹³

At this point, e-commerce offers the first full-scale example of how digitization can transform a physical industry. There was no magic wand of data that suddenly made everything different. Rather, years of hard work and incremental improvements increased the productivity of picking and packing enough to make new business models economically feasible.

Why Manufacturers Need a Digital Vision

Manufacturing is the quintessential physical industry. No matter how much data is involved, manufacturing is defined as “the mechanical, physical, or chemical transformation of materials, substances, or components into new products.” If it ain’t physical, it ain’t manufacturing.

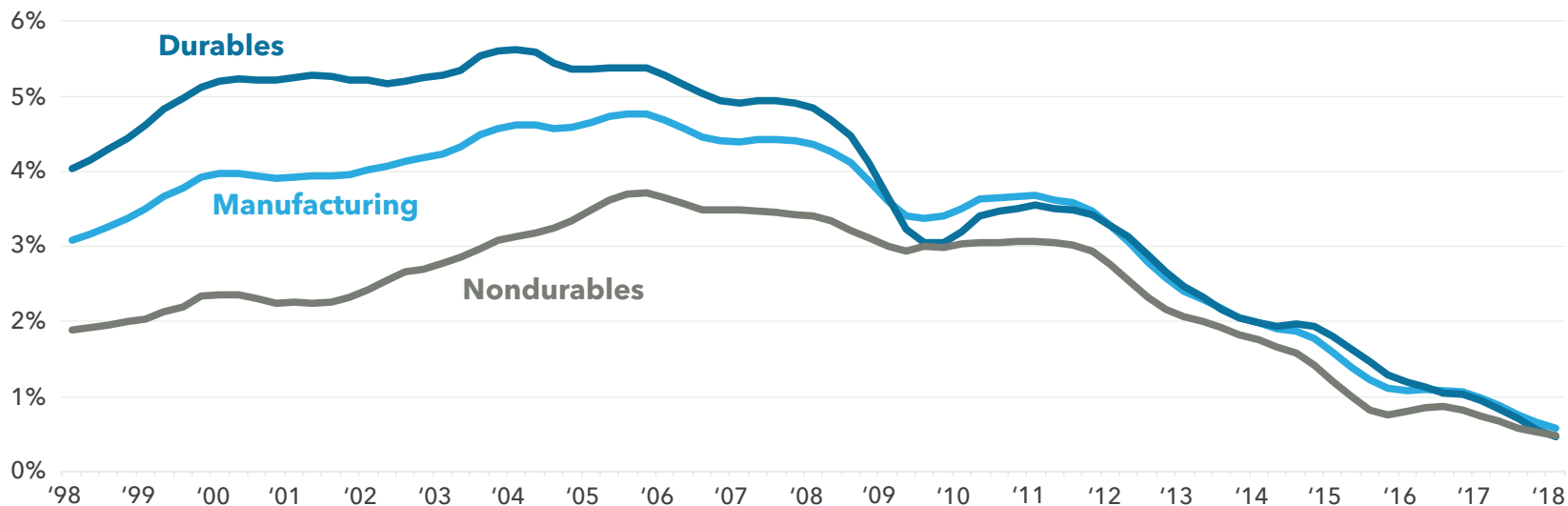
For many years, manufacturing was viewed as a productivity leader. But in recent years, that is no longer true. The growth rate of manufacturing productivity in the United States has slowed to a crawl, rising by only 0.3% in the year ending

with the first quarter of 2018 with no signs of an immediate turnaround.

To be fair, part of the apparent productivity slowdown may be due to our inability to measure increased sophistication of products correctly. For example, new airplanes and machine tools may have far better electronics built into them that cannot be correctly tracked by economic statisticians. Even something as simple as a valve might be evolving in materials and even functionality.

Manufacturing Productivity Growth Is Plunging

10-year growth rate (four quarter average)



Source: Bureau of Labor Statistics

But the productivity slowdown in manufacturing extends far beyond advanced goods. Nondurable industries such as food processing have seen productivity slowdowns as well. For example, labor productivity in the very important food manufacturing industry has not risen in 15 years, according to data from the Bureau of Labor Statistics. Meanwhile, the entire industry employs less than 1000 software developers.¹⁴

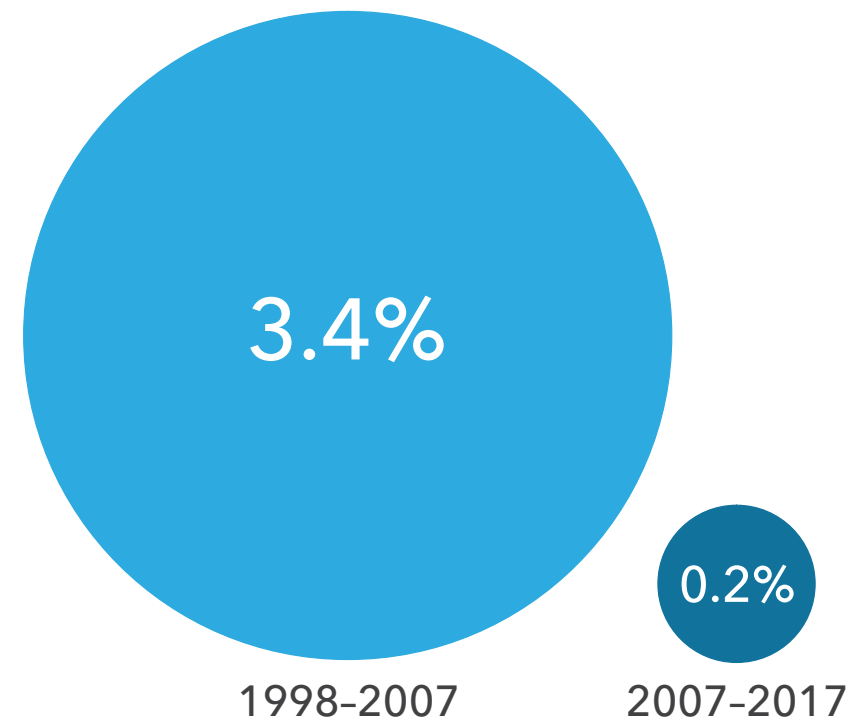
For a while, the weakness in U.S. manufacturing was obscured by the success of the largest American manufacturing multinationals. According to a study by McKinsey Global Institute, large U.S.-based manufacturers enjoyed returns on capital exceeding 20% in the 1997-2013 period, much higher than their European and Asian peers.¹⁵

In recent years, the profits malaise has hit the bigger industrial firms as well. Since 2007, there has been almost no growth in manufacturing profits as measured by the BEA, after adjusting for inflation.

How far back does the manufacturing productivity problem go? It matters which indicator you view. If we look at labor productivity—output per unit of labor—productivity growth was strong through the middle of the 2000s. Manufacturers followed a strategy of replacing people with machines or shifting labor-intensive low-value operations to other countries with cheaper labor. Non-core workers like cafeteria workers or cleaning staff were outsourced to other non-manufacturing companies. Fewer workers and the same output led to higher labor productivity.

Annual Growth of Manufacturing Profits

Adjusted for inflation



Source: Bureau of Economic Analysis, author calculations

But that is not the whole story. If we look at “multifactor productivity,” manufacturing’s problems go back much further. Multifactor productivity takes into account the usage of purchased services, energy, capital, and intermediate inputs. For example, if a manufacturing company buys a machine to replace some of its workers, labor productivity will rise. But multifactor productivity may or may not go up, depending on how expensive the machine is relative to workers.

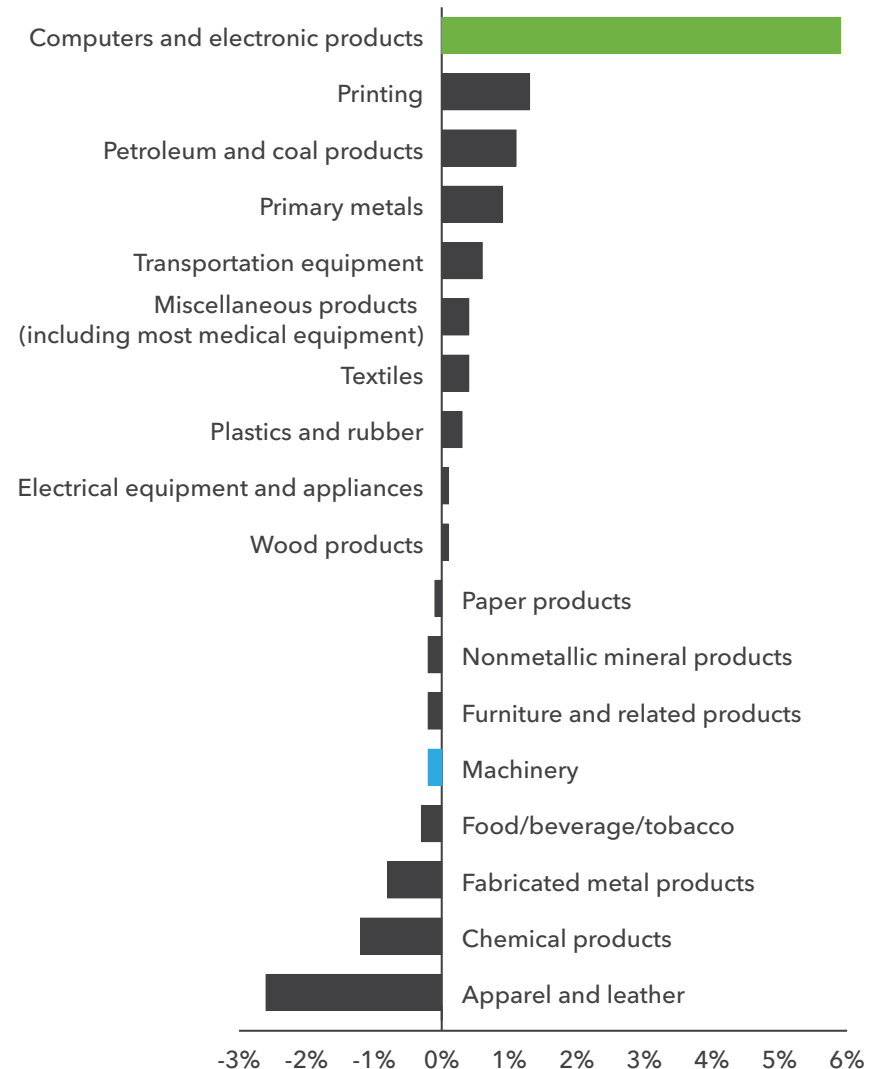
Similarly, if a manufacturer outsources part of its production process to another company, that will show up as a drop in labor but an increase in purchased parts. Labor productivity will go up, but multifactor productivity might rise or fall depending on the efficiency of the second company.

Multifactor productivity corresponds much more closely to competitiveness and profitability than pure labor productivity does. Unfortunately, when we look at multifactor productivity growth in manufacturing by industry over the past 20 years, the situation is rather discouraging.

One industry—computer and electronics products—shows very strong multifactor productivity growth over the past twenty years. But many manufacturing industries have weak or even negative multifactor productivity growth over the past 20 years. In other words, they have become less competitive.

Weak Multifactor Productivity Growth in Most Manufacturing Industries

Average annual growth of multifactor productivity, 1996-2016

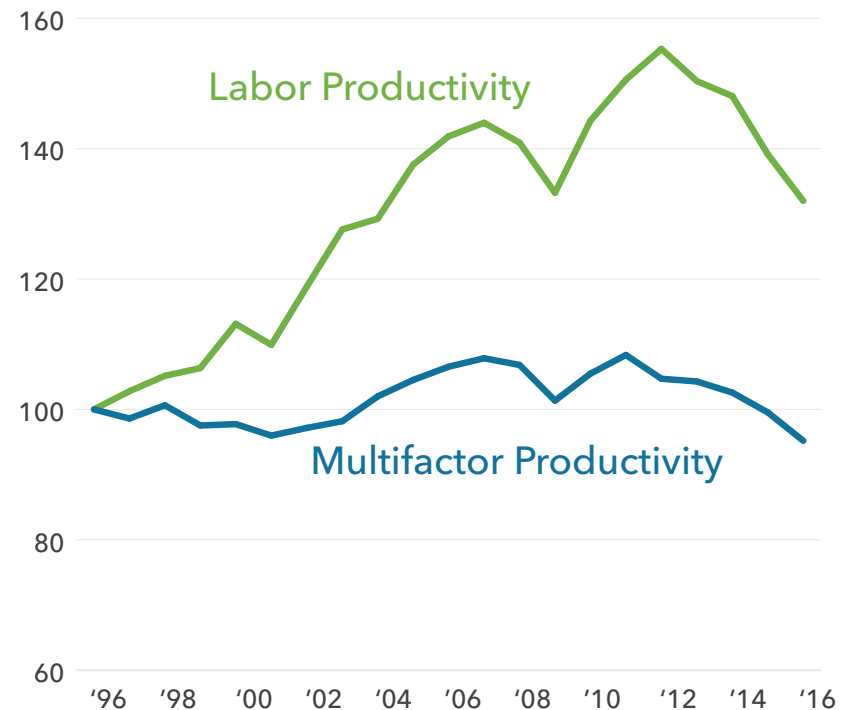


Source: Bureau of Labor Statistics

Take the machinery industry, which includes everything from agriculture, construction and mining machinery, to industrial machinery, to heating and air-conditioning equipment, to turbines and power transmission equipment. Labor productivity has risen because machinery manufacturers have become more automated, reduced workforce, and sourced more parts from overseas. That is good news.

However, multifactor productivity in the machinery industry has been flat for the past 20 years. That means the underlying productivity of the machinery industry has not risen for the past 20 years, taking into account the spending on capital equipment, purchased services, and materials. No economist or industry leader would have predicted that outcome in 1996, as the internet revolution started. That is why there have been two lost decades for manufacturing.

Focus on the Machinery Industry Productivity



Source: Bureau of Labor Statistics

The Digitization Paradox

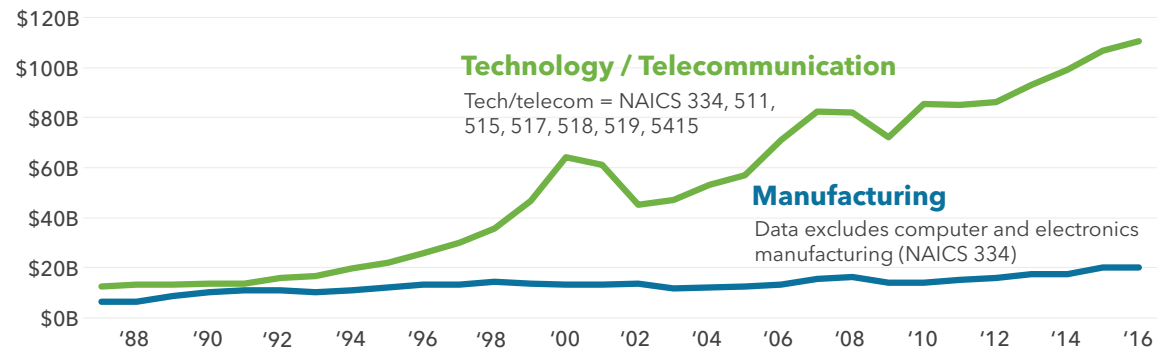
The next question, of course, is why the information revolution has not generated a productivity bonanza thus far for manufacturers. We first observe that manufacturers have far behind in the digitization race. There is a large disparity in investment in IT equipment and software for manufacturing and the tech/telecom sector. For this analysis, the manufacturing sector omits computer and electronic manufacturing, which is included in the tech/telecom sector. We use data from the BEA, which tracks software investment and tech equipment investment by industry.*

We see that the gap in IT equipment and software investment between the manufacturing sector and the tech/telecom sector started in the mid-1990s, and has continued to widen ever since. Indeed, a McKinsey survey found that roughly half of U.S. manufacturers had no digital roadmap.¹⁶

* In theory, the BEA data includes any spending on information technology equipment or software that would be capitalized.

Manufacturing Investment in IT Lags

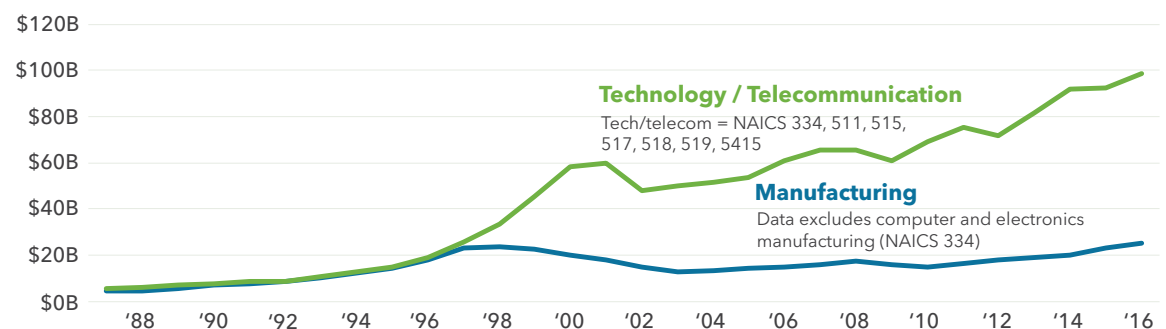
Spending on IT equipment in billions of dollars



Source: Bureau of Economic Analysis

Software Investment: Manufacturing vs Tech/Telecom

Billions of dollars



Source: Bureau of Economic Analysis

Moreover, there are big differences between manufacturing industries. The computer and electronics industry alone employs 90,000 software developers and programmers, while the transportation manufacturing industry, including motor vehicles, employ another 30,000.¹⁷ These industries also make heavy use of robots and automation. But far fewer robots and software developers are found in other manufacturing industries such as metals and food processing.

Here is another way of looking at the differences between manufacturing industries. The BEA tracks the average age of “intellectual property assets” like software and R&D. All else being equal, industries that report younger software investments are more likely to be using cutting-edge technology. Older software means that the industry is not keeping up.

The average software and intellectual property deployed by the motor vehicles industry and the computer and electronic products industry is less than three years old. That makes sense because the motor vehicle industry is the main place where robots have already been deployed.

By contrast, the average software and intellectual property in the machinery industry is 4.8 years old. That two-year gap looms large given the rapid pace of change in the digitization of manufacturing.

Which Manufacturing Industries Have the Newest Technology?

Average age of software, R&D, and other intellectual property



Software is assumed to have a 3-5 year service life.

Source: Bureau of Economic Analysis

The Globalization Indicator

Before discussing the potential future digital strategies for manufacturers, it is important to review the link between digitization and globalization. With weak multifactor productivity growth and lagging investment in information technology, it is little wonder that foreign competition has heavily impacted domestic manufacturing. One way to see this is to look at prices. The price gap for U.S. producer prices for finished goods (except energy) compared to the price of imports from China is widening.

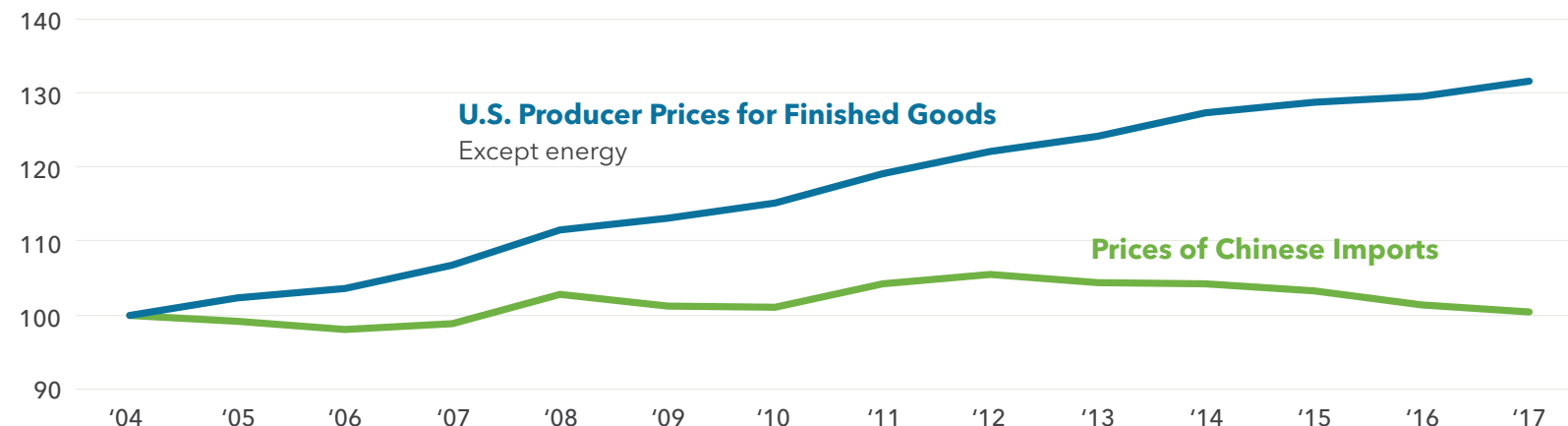
Since 2004, when the data began to be collected by the BLS, the price of imports from China has been basically flat, despite a tripling of Chinese manufacturing wages over the same period.*

By contrast, the producer price of U.S. finished goods (except energy) has risen roughly 30% over this stretch. The implication, if we take these numbers seriously, is that the price gap between U.S.-made goods and Chinese imports has been widening. This is consistent with the fact that Chinese imports continue to grow faster than domestic manufacturing production. In 2017, imports from China, adjusted for inflation, rose by 9.4%. By comparison, the gross output of domestic factories only rose by 2.2%.

The challenge for manufacturers is to develop a vision for digitization that makes business sense even if these price trends coming out of China continue.

*As reported by the Chinese government, average annual manufacturing wages increased from 24,192 yuan in 2008 to 64,452 yuan in 2017. That's roughly equivalent to \$10,000 per year, given the exchange rate of 6.7 yuan to the dollar in 2017.

The Price Gap Between U.S. Manufacturing Prices and Chinese Imports Is Still Widening



Source: Bureau of Labor Statistics

The “grand vision” of the industrial internet of things may not have been grand enough. Simply adding technology to existing processes doesn’t transform the factory floor, or give manufacturers new business models that create whole new markets.

Building the Digital Vision for Manufacturing

The term Industry 4.0 started out as an advertising slogan, with more flash than substance, coined by the German Federal Ministry of Education and Research. Its emphasis is on data and coordination added to existing equipment.

“Machines that communicate with each other, inform each other about defects in the production process, identify and re-order scarce material inventories—this is an intelligent factory. This vision is behind the keyword Industry 4.0.”¹⁸

Some manufacturers extended this emphasis on data to their customers. Samsung built and sold internet-enabled home appliances. John Deere added sensors to its farm machinery, to create a new source of revenue offering farmers information on precision farming.¹⁹

Most notably, GE staked its digital future on the industrial internet:

“The idea would be that, for instance, software could harness the data produced by a jet engine to predict when the engine needed maintenance, saving time and money. The technology could be used across GE’s businesses, whether medical equipment or wind turbines.”²⁰

A central part of GE’s plan was the development of Predix, a software platform that connects equipment like turbines and elevators to computers that can predict failures and reduce operating costs. But in 2017 and 2018, GE was forced to reset its strategy, replacing its CEO and cutting back on digital spending.

“No one disputes the overarching vision of the so-called industrial internet of things – which includes low-cost sensors and a flood of data and clever software that should deliver insights to cut costs, conserve fuel and design better products, faster. But the company greatly underestimated the challenges of creating all the software needed to achieve that grand vision, said analysts and former GE managers.”²¹

Moreover, the “grand vision” of the industrial internet of things may not have been grand enough. The emphasis on adding technology and data connections to existing equipment is good, as far as it goes. But simply adding technology to existing processes doesn’t transform the factory floor or give manufacturers new business models that create whole new markets.



So beyond data, what might an alternative digital future for manufacturers look like? The clues come from three places:

1

Amazon's re-imagining of the **distribution process**, the first successful full-scale digital transformation of a physical industry.

2

The rapidly growing momentum to digitize the **production process** through 3D printing, which in turn is putting new emphasis on innovation in materials to broaden the range of applications.

3

The use of cloud computing to build a **manufacturing platform** that treats design, production, sales, and distribution as separate services running on a network, enabling even small factories to tap into new technology and best practices rapidly.

The Importance of Distribution

Historically, production has been the central activity of manufacturing, while distribution was an afterthought. In the early 1960s for example, manufacturing accounted for more than 25% of the value-added in the economy. By contrast, the distribution sector was only 17% of the economy. If we look at corporate profits, the difference was even more extreme.

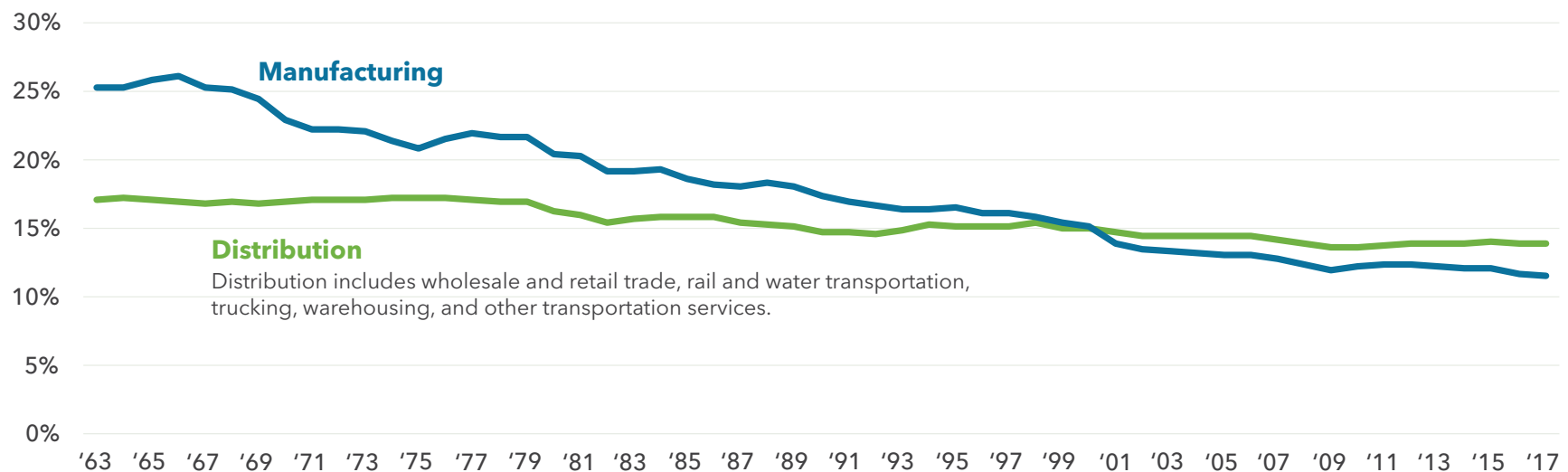
However, sometime in the late 1990s, value-added in the distribution sector exceeded that of manufacturing. Today, the distribution sector adds roughly 14% of GDP, compared to 12% for the manufacturing sector.²²

Until recently, the biggest innovation in distribution was the standardized container, also known as “the box.” The container was effectively a low-tech hack that dramatically lowered the cost of shipping by reducing the cost of handling and pilferage. A container could be loaded in Shanghai and shipped via sea, train, and truck directly to a warehouse or big box store anywhere in the United States at a very low cost. Recent economic research suggests that the impact of containerization on cross-border trade may be larger than the effect of tariff reductions.

But there is a kicker: the shift to containers also benefited the largest manufacturers and the largest retailers who

Distribution Takes a Larger Share of the Economy Than Manufacturing

Value-added as share of GDP



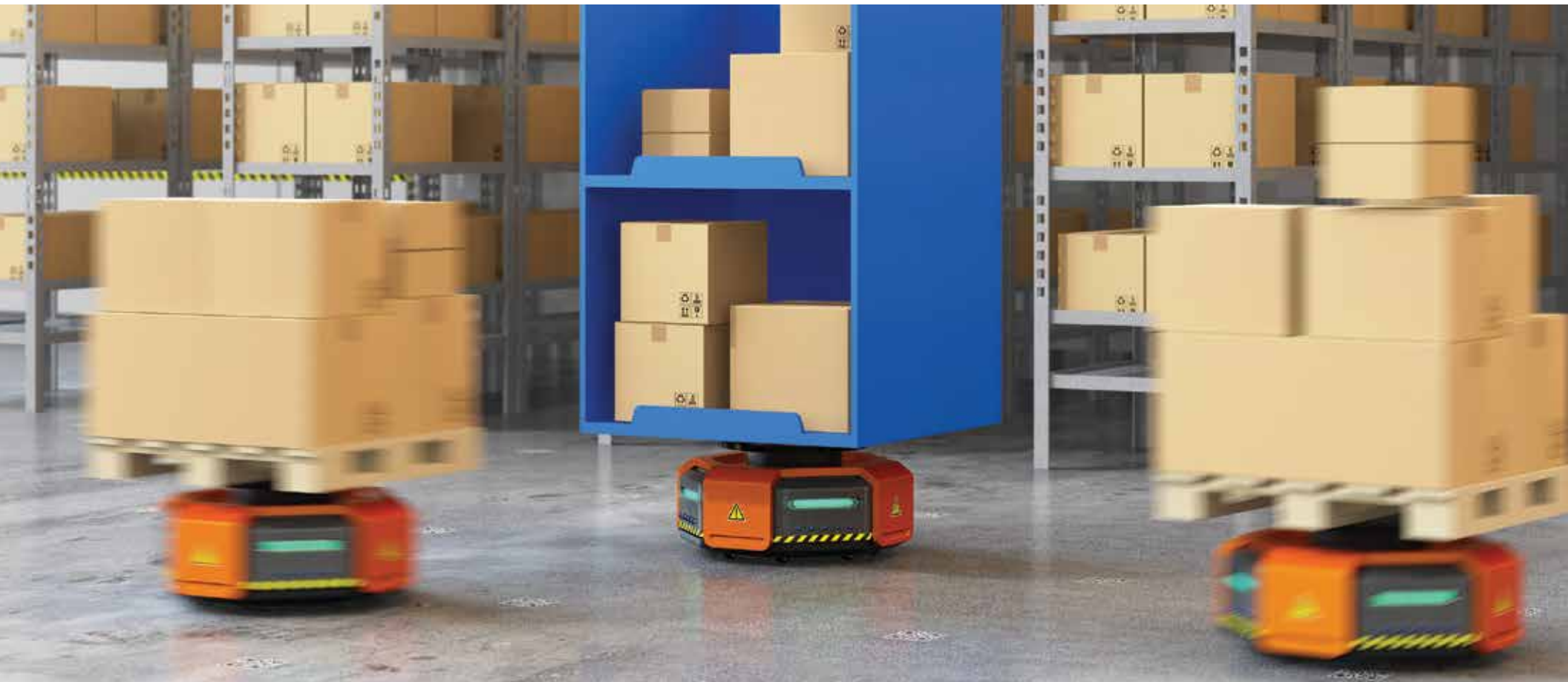
Source: Bureau of Economic Analysis

could take advantage of the economies of scale offered by the box. A furniture factory in North Carolina shipping to multiple domestic destinations could not use the efficiencies of containers, whereas a large factory in China shipping furniture to a Walmart distribution center could easily fill a container and pay less for transportation.

In fact, the economics of distribution gives us some important insights into the trends in U.S. manufacturing over the past 15 years. Usually, we think of large factories serving national

or global markets as being more efficient than smaller local establishments.

However, the advent of Chinese competition in the early 2000s had its biggest impact on the largest, most efficient domestic factories, rather than small, inefficient facilities. Between 2001 and 2017, the number of American manufacturing facilities with more than 500 employees fell by 35%. By comparison, the number of manufacturing facilities with fewer than 100 workers fell by only 13%.



The reasoning is simple: a large efficient factory typically makes a product that can be traded over wide areas—something that can be put into a container and shipped across the country or borders. But those very same product characteristics make it exposed to competition from China.²³

From this perspective, the rapid and unexpected loss of U.S. manufacturing jobs since 2000 was not simply about low-wage competition from China. Rather, the changes in the geography of production were also driven by the great economies of scale offered by containerization, which finally found their match in the huge scale of Chinese manufacturing. As Thomas Friedman said, the world is flat – but only at large enough production volumes.

But that is yesterday's news. Today the distribution sector is on its way to digitization and becoming phenomenally more productive and flexible. Amazon is showing that a combination of robotics, machine learning, and investment in fulfillment centers can dramatically transform the surprisingly complicated process of order fulfillment, picking and packing, and the best allocation of inventory geographically.

For example, Amazon's systems allow it to move to a "random stow" method for accepting new inventory.²⁴ Rather than having to store similar items together, they can be put

anywhere open. The system keeps track of their location much like modern random-access digital memory systems keep track of the location of information. Moreover, it allows related items that are often ordered together, like toothpaste and toothbrushes, to be paired together in the fulfillment centers.

The shift from a traditional warehouse to an Amazon fulfillment center is analogous to the shift from circuit-switched telephone lines to packet-switched broadband connections. Packet-switched connections are more flexible and enable much more innovation on the edges because internet routers don't care what's in the packets.

From that perspective, an Amazon fulfillment center becomes the equivalent of a packet-switched router. It can handle addressable goods coming from any source (like FBA) and send them out to individual recipients efficiently and quickly. And we know that it works at scale, because Amazon has built 75 fulfillment centers in North America alone, employing more than 125,000 fulltime Amazon workers.²⁵

The analogy can only be stretched so far. "Packets" of goods occupy space and require physical transportation, unlike packets of information. But it is useful to think about fulfillment centers as the routers of the Internet of Goods.

The Digitization of Production

So far, the digitization of production has been lagging the digitization of distribution—but that may be changing. The ultimate goal is to create the manufacturing equivalent of a general-purpose computer, which, given the appropriate design (program), can produce the desired good efficiently and quickly.

3D printers come closest to this ideal of digitization. But there are two enormous problems. First, they are far too slow compared to mass production. Second, current 3D printers only work on a limited set of materials.

New technologies are showing an increase in speed. Carbon, a startup with over \$400 million in funding, has a proprietary technology that goes up to 100 times faster than



conventional 3D printing techniques. As a result, Adidas is using Carbon fabricators to make midsoles for its new Futurecraft 4D line of athletic shoes. Other companies are also speeding up 3D printing, through either changes in technologies or changes in printing algorithms.

Are the new printers fast enough to compete with conventional manufacturing? Oddly enough, it depends on the distribution system. The traditional distribution system operates best at the scale of containers, mass production, and warehouse inventory. Shipping customized goods directly to the final user in individual lots is inefficient, either slow or expensive, and should be avoided wherever possible, especially for low-cost parts. And 3D printing is unlikely ever to be fast enough to compete directly with mass production.

By contrast, a digitized distribution system makes the rapid shipping and delivery of individual customized items more efficient. That allows for a new business model where 3D printers can offer a customized product that is superior in some dimensions to mass production and able to be delivered quickly and cheaply.

On an industrial level, the combination of digital production and digital distribution allows manufacturers to escape what Joseph DeSimone, founder of Carbon, calls the “tyranny of injection molding.” Having a digital fabrication technique that can quickly adapt to new parts can accelerate the entire economy by allowing businesses to innovate faster.



And the range of materials that can be 3D printed is constantly expanding. Desktop Metal is expected to come out with a metal 3D printing system for mass production in 2019. HP plans to launch a line of 3D printers that produce metal objects, an expansion from the company's existing 3D printers that produce plastic-based products.

Building a Manufacturing Platform

The third component of the Internet of Goods is the concept of a manufacturing platform. As seen in the digital world, platforms can be either open or proprietary. Startups can create them or anchored by large decentralized multinational manufacturers. Manufacturing platforms will host a variety of design, production, and distribution services, riding on the packet-switched network for moving goods and components. The key feature is that they provide a structured environment in which businesses and individual users can interact with each other.

We see the beginnings of manufacturing platforms. Xometry, launched in 2014, offers a proprietary platform for accessing production capabilities nationally, including various 3D printing technologies, computer numeric control (CNC) machining, and sheet metal fabrication.²⁷

Similarly, Carbon is creating a platform for its fabrication machines. Carbon collects data from all the machines that it leases and uses it to upgrade and accelerate algorithms. Then the machines receive over-the-air software upgrades, greatly accelerating their production capabilities without the need to change equipment. "The more people use our technology, the better it becomes," says DeSimone.

At the other end of the scale, Amazon, of course, offers a distribution and sales platform for sellers. GE's Predix is being

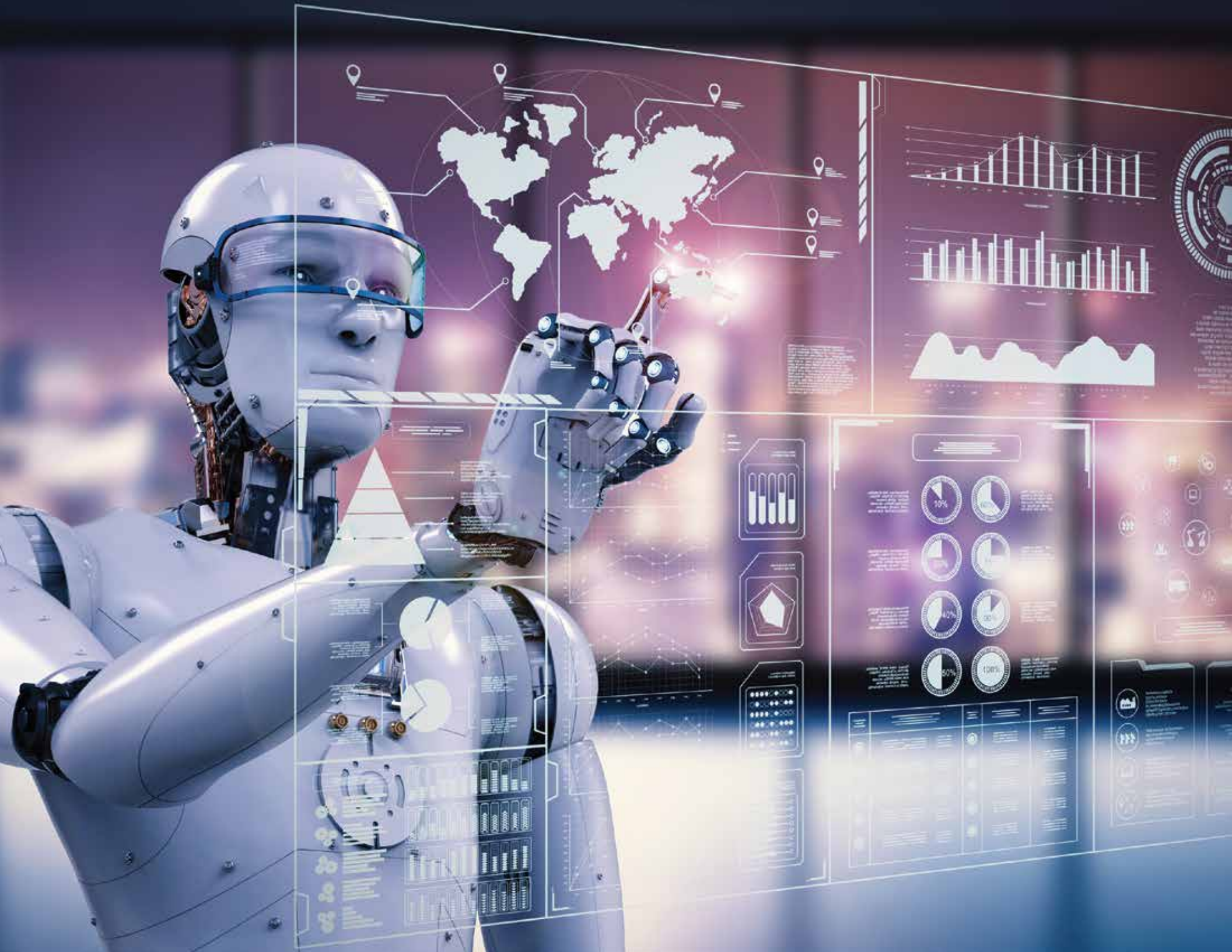


positioned as a secure and scalable platform for industrial applications. And in April 2018, Siemens launched the Additive Manufacturing Network:

"... a new online collaborative platform designed to bring on-demand design and engineering expertise, knowledge, digital tools, and production capacity for industrial 3D printing to the global manufacturing industry."²⁸

This is much like the early days of social networks when it wasn't clear whether the winner was going to be Friendster, MySpace, Facebook, or some other site. In this case, however, there is no need for the winning platform or platforms to come out of the United States since manufacturing knowledge is distributed around the world.

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The New Face of Manufacturing

The combination of digitized distribution, digitized production, and new manufacturing platforms – what we call the Internet of Goods – allows the creation of new business models for manufacturing that are capable of expanding the market and changing the geography of production.

Just as the internet would not be possible without fast connections, the Internet of Goods would not be possible without digital distribution. Some commodity goods will still be mass-produced and shipped around the world. But the ability to easily move around goods and parts means that economies of scale in production are no longer quite so compelling. Instead, there will likely be a move towards pushing manufacturing to the edge, into local facilities that can easily engage in short production runs.

How fast will the shift happen, and how far will it go? It depends on the creation of new business models rather than the technology itself. Remember that no one knew how to monetize search until Google paired it with targeted advertising. Ecommerce didn't take off until Amazon realized that free two-day delivery was a big deal for consumers. When Steve Jobs and Apple created the first smartphone, no one knew that mobile applications and the App Store were going to be so important.²⁹

Keeping in mind the essential unpredictability of innovative business models, what might the future of manufacturing look like? One key is customization. U.S. consumers are more ethnically and culturally diverse than in the past, and they have high expectations for quality, low prices, and variety.

Some consumer products—such as clothing, shoes, and furniture—are substantially more comfortable if fitted to the individual. One can imagine a subscription plan where you are measured once, and then when you need a new piece of apparel, you order it online, and it's delivered the next day from a local manufacturing facility.

Ideally, the design software would have the capability of mapping the original set of measurements onto any style of footwear. This tight integration of software and hardware would be a difficult task but would create a durable competitive advantage.

The same principle applies to industrial components. Parts can potentially be precisely tailored to the particular application and situation—say, a piece of HVAC equipment in a tight space—rather than constrained by the demands of mass production. Embracing this business model would require a substantial rethink of design, sourcing, and production, but the gains could be enormous.

Another key might be accelerated innovation and introduction. A company designing a new product can source the needed parts simultaneously from nearby local production facilities. Once the design is approved, then the new product can quickly go into production around the country with critical parts being sourced from one location and distributed through the ecommerce fulfillment network.

Another potential business model might be built around environmental sustainability. Mass production from a central location inherently imposes an extra burden on the environment due to added pollution from transportation. By some calculations, just one container ship can produce as much pollution as 50 million cars.³⁰ Digitized local production could substantially reduce that environment burden.

Finally, one logical business model might be the franchising of local production facilities, similar to the franchising of restaurants or other businesses. The franchising company supplies the technical knowledge and materials through the manufacturing platform, while the franchiser makes the sales and operates the equipment.

OBSTACLES

Several issues may impede the shift to the Internet of Goods. Cost is one potential obstacle. A survey by McKinsey suggested that companies expect about 40-50 percent of the existing installed base of manufacturing equipment will need to be replaced to achieve digital readiness. McKinsey Global Institute then calculates about \$115 billion annual capital expenditures will be required over the next decade to deploy these new technologies.³¹

These amounts are well within the capabilities of the largest firms. But given the funding constraints for small and medium-sized companies, making the business case for state-of-the-art equipment is often not easy.

Another big obstacle is the availability of the necessary engineers, technicians, and software developers. “We don’t have enough people to program robots,” worries the CEO of a multi-billion dollar company that makes products for both the consumer and business markets. Adds another CEO of a multi-billion dollar industrial company: “There’s a fear of giving up control. The programming is coming from India, not within your four walls.”

Finally, there is the continuing downward pressure on prices coming from imports from China, as noted earlier in this report. However, business models that are built on the digitized Internet of Goods are much less susceptible to competitors at the other end of long supply lines.

Just as the internet would not be possible without fast connections, the Internet of Goods would not be possible without digital distribution.

Public Policy to Encourage the Internet of Goods

It is suggested in this report that a new vision for digitizing manufacturing requires the combination of digitized distribution, digitized production, and new types of manufacturing platforms. The result will be a new geography of manufacturing. Many factories will make customized or small batches and serve regional rather than national or global markets. Production facilities will cluster with ecommerce fulfillment centers to make manufacturing/distribution hubs.

As the Internet of Goods takes hold, three factors will play a powerful role in determining the geography of production:

1. Is the local workforce prepared for the new model of digitized manufacturing and distribution?
2. Is there support available for local entrepreneurs to start new digitized manufacturing businesses, or digitize and expand existing ones?
3. Is the local regulatory environment conducive to new manufacturing facilities?

Each of these three factors can be affected by state and local policy. Let's examine each of these in turn.



WORKFORCE POLICY

The Industrial Revolution of the early 20th century saw a rapid shift to assembly lines rather than craftwork. More engineers were necessary, but the new mode of production did not require most workers to be trained in engineering. Rather, they had to be comfortable working with machines. This new skill led to higher wages since workers became more productive.

In the same way, the new wave of digitized manufacturing will require more coders, but most workers will not need to have coding skills. Instead, workers in digital factories will have to be tech-enabled, in the sense that they have to be comfortable working with technology and robots.

To develop a workforce to support local digitized manufacturing, states, and localities should prepare to shift their training and community college programs to help workers become tech-enabled. In some cases, it may be appropriate to give training incentives directly to companies that adopt digitized manufacturing techniques.

SUPPORT FOR LOCAL ENTREPRENEURS

The rise of local manufacturing will be driven by collaboration, in effect, between entrepreneurs who start up local digitized factories making new products and global manufacturing platforms anchored by larger companies. That

means there will be a role for states and localities to support manufacturing entrepreneurship.

This support can come in two forms. First, capital in the form of loans or grants should be made available to local manufacturing startups. Second, and perhaps equally important, potential entrepreneurs need a chance to experiment with the capabilities of the new technology. States that want to encourage manufacturing entrepreneurs should set up centers with the latest 3D printing and robotics equipment. That will give everyone an opportunity to get in on the ground floor of wealth creation.

REGULATORY IMPROVEMENT

Over the years, manufacturing has been the subject of many state and local laws and regulations dealing with zoning, occupational health and safety, pollution, and noise. Such laws and regulations are addressing important issues.

Still, the new wave of digitized manufacturing may not pose the same environmental and siting issues as the factories of the past. State and localities that want to be leaders in digitized manufacturing should embark on a serious program of regulatory improvement—systematic examination of existing regulations to see which ones are obsolete, and which ones can be improved for the new era.³²

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With experience spanning policy, academics, and business, Dr. Mandel has helped lead the public conversation about the economic and business impact of technology over the past two decades. Mandel's seminal analysis shows how e-commerce creates jobs and reduces inequality was featured by the *Wall Street Journal*, *New York Times*, *Washington Post*, *Boston Globe*, and *Financial Times*, among others. Dr. Mandel regularly engages with policymakers in Europe, Latin America, and Asia-Pacific on key issues such as privacy, tax, regulation, and competition policy.

Dr. Mandel started two businesses: South Mountain Economics LLC, a consulting firm focusing on emerging occupations and emerging industries; and Visible Economy LLC, which produced news and educational videos for the college market. Dr. Mandel is the author of four books, including *The High-Risk Society* and *Rational Exuberance: Silencing the Enemies of Growth and Why the Future Is Better Than You Think*. His essentials level economics textbook from McGraw-Hill, *Economics: The Basics*, is in its third edition and widely used across the country. Dr. Mandel received a doctorate in economics from Harvard University and taught at New York University's Stern School of Business.

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