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The Puzzle of the Missing Robots

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ABSTRACT

There is a popular narrative that the rise of automation threatens to displace a large segment of the American workforce. Robots in particular are the object of public concerns about employment. But in most American manufacturing plants—particularly small and medium firms—robots are scarce. Fewer than 10 percent of American manufacturers have any industrial robots. This case study argues that the technology challenge facing American industry is not too many robots, but too few. Multiple factors contribute to low robot adoption, including high integration costs, flexibility and design limitations, and workforce challenges. When firms do adopt robots—whether to fulfill a new contract or attract a new customer—there may be benefits for the workforce as well as the economy as a whole.

Keywords: robots, automation, manufacturing, workforce

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Learning Objectives

- Understand how predictions and perceptions of industrial automation compare to technology on the factory floor.
- Understand the difference between “bottom up” and “extrapolation” studies on the impact of new technologies.
- Identify what motivates some manufacturing firms to adopt robots, while others do not.
- Consider policy directions for encouraging the benefits of robot automation while also improving workplace conditions and wages for (human) workers.

Automation has been a longstanding source of concern for the public and the government in the United States. In 1955 and again in 1960, the US Congress held hearings on the progress of automation and its consequences. The hearings were supposed to keep Congress “currently informed lest the increasing productivity to be obtained through automation and which is sought and welcomed by all segments of American life carry with it excessive personal hardships or set up adverse forces which will hamper future economic stability and growth.”¹ Walter Reuther, the head of one of America’s largest labor unions—the Congress of Industrial Organizations (CIO)—was invited to speak. He said of automation, “we are faced with mighty forces whose impact on our economy can be vastly beneficial or vastly harmful, depending on whether we succeed or fail in achieving economic and social progress that will keep pace with changing technology.”² Reuther and fellow labor leader George Meaney described technological change as a force for increasing the country’s economic well-being, while also urging government to play a more active role in insuring that gains from automation were fairly distributed.

Public hopes and anxieties about the impact of automation and technological change have coexisted since at least the start of the Industrial Revolution. Economists and journalists writing about robots and jobs nowadays often reach back to the introduction of new machines in factories in the 19th century and to the “Luddities”—farm and factory workers who protested by smashing machines at the workplace. Even before large-scale mechanization of work, governments worried about whether new technologies might lead to unemployment and to political unrest. References to the Luddites have become ways of warning about the political dangers of hostility to machines.³ Today, as in the past, public sentiments continue to be mixed. In polls from 1970 and 2017, respondents generally approved of new technologies and their benefits for the economy and society.⁴ A Pew Research Center survey in 2017 found that more people reported that technology made their work more interesting and increased their opportunities for career advancement. When it came to specific automation technologies like scheduling software and even industrial robots, workers were more likely to say that new technologies have had a positive impact on their jobs. However, in the same poll, 72 percent of US adults reported that they were worried about a “future where robots and computers can do many human jobs.” And 85 percent of respondents said they would favor a policy that limited machines to doing dangerous or unhealthy jobs.⁵

In 2017, these anxieties about a robotic future coincided with waves of headlines about robots eating jobs and self-driving cars and trucks becoming ubiquitous on the road

within one to five years. Research contributed to this panic with widely cited academic articles predicting massive job losses.⁶ Two Oxford researchers, Carl Benedikt Frey and Michael A. Osborne, published work suggesting that 47 percent of US jobs were at risk within “a decade or two.”⁷ But the Frey-Osborne predictions were basically extrapolations, as were others made at the time. Frey and Osborne used 702 occupation classifications from a database maintained by the US Department of Labor (known as the “Occupational Information Network,” or O*NET) and identified tasks within the occupations. They then asked technology experts to judge whether they thought machines could do those tasks now, or would soon be able to do them. Other studies followed in the same methodological vein, including studies by the Organisation for Economic Co-Operation and Development (OECD), which, however, focused on tasks rather than occupations and estimated that far fewer jobs were in jeopardy. McKinsey Research Institute used similar methodologies and estimated about four hundred million jobs worldwide would be lost. These were all basically exercises that extrapolated from an expert’s view of which tasks could now or “soon” be automated to calculations about job loss.

What followed were empirical studies of job losses in factories that already had robotic automation in France, Germany, Netherlands, Canada, and the United States. And here the picture became a lot more complicated. Some large firms with international markets in France employed more workers after robots were introduced while their domestic competitors seemed to lose workers.⁸ In Canada, the introduction of robots led to the reduction in the numbers of middle-level managers and an increase in production workers.⁹ Large-scale studies in Germany and the Netherlands of changes in the workforce after the introduction of robots also showed increases in some categories of workers, with decreases in other categories. Among firms in the United States, those adopting robots seemed to offer higher wages to production workers, but the addition of robots was associated with fewer jobs overall.¹⁰ Context seems to matter when it comes to the effects of robot adoption—but how it matters we do not yet understand.

Too Many Robots or Too Few?

Amid growing concerns about automation, Americans also worried about declining manufacturing competitiveness and the stagnation of wages in manufacturing jobs. As researchers, we have been concerned by the puzzle of slow productivity growth in the US economy and that has led us to be especially interested in technology and skills in small and mid-sized manufacturing enterprises (SMEs). (See [Figure 1](#).)¹¹

Figure 1
Manufacturing productivity in advanced industrial economies.

The gap between the productive performance of these SMEs and that of large manufacturing firms has widened at the same time that economists have shown a concentration of economic activity in the most productive “superstar firms” in a sector.¹² The widening gap between the most productive performers and the rest raise questions about why diffusion of best practices from the most productive firms has been slow, and what public policies might do to accelerate it.

Over the past fifty years, this performance gap between large manufacturing firms and small and mid-sized manufacturing plants has widened. In the early 1970s, the output per worker of large manufacturing establishments—plants with over five hundred workers—was only about 25 percent higher than in plants with fewer than five hundred workers. By 2012, output per employee at plants with more than five hundred workers was 93 percent higher than that at smaller plants. (See [Figure 2.](#))¹³ A growing wage gap between large and small plants has mirrored the growing gap in output per worker. (See [Figure 3.](#))¹⁴

Figure 2
Output gap by plant size.

Figure 3
Wage gap by plant size.

Trying to explain slow productivity growth in SMEs and what appears to be their worsening relative performance seems a critical step in understanding the future prospects of US manufacturing. Whereas automation anxieties emphasize the risks of too much technology, slow productivity growth suggests that there may not be enough

technology for small and medium firms to become more competitive. When, why, and how manufacturing firms acquire new technology, and how they find or train workers with new skills—these issues are central to figuring out why productivity lags in smaller companies.

Looking for Robots

In seeking to understand the impact of the introduction of robots and other new forms of automation on the number and quality of manufacturing jobs, as well as the performance of manufacturing firms, we turned to a different research approach from one that seeks to match up tasks with the capabilities of machines.¹⁵ It is an approach that starts from the “bottom up”—from the people and the machines already in the plant and from the factory manager’s conception of possible options. In order to carry out these “bottom up” studies over the past thirty years, MIT researchers have walked through factories with managers in the United States, Germany, France, Japan, Hong Kong, and China.¹⁶ They have listened to managers explain how they organize production, when and how they decide to buy new equipment, how they hire and train workers, and what they see as promising strategies for their business in the future. In the most recent of these studies, the 2018–2020 MIT Taskforce on Work of the Future, a group of faculty and graduate students again focused on analyzing changes in production from the factory floor up.¹⁷ The methodology aimed at identifying the mechanisms that link the key variables: hiring and training, technology adoption, and productivity.

Our interviews and observations examined the adoption of new production technologies in general and industrial robots in particular. The definition of an industrial robot we used was that of the International Federation of Robotics: an “automatically controlled reprogrammable multipurpose manipulator programmable in 3 or more axes.” If a 5-axis CNC (computer numerical control) machine were to be counted as a robot, we would have counted more robots in the plants, since several companies had recently acquired advanced CNC machines. There are good reasons to distinguish CNC machines from robots, our colleagues from an MIT robotics laboratory suggested. Even though a CNC machine can do the same milling as a robot does, a robot can *also* be repurposed for functions like pick-and-place by changing out the end effector.¹⁸ Roboticists think of robots as taking inputs from sensors and making decisions based on those inputs, as well as being flexible enough to perform a variety of tasks that the CNC machine does not do. So in this study we decided to distinguish between purchases of robots and purchases of advanced CNC machines. We also ruled

out including automated guided vehicles (AGVs), which are small mobile robots that are used to move parts from station to station across factory floors.¹⁹

Based on the experts' predictions of the past few years we expected to find many robots on the factory floors. But the majority of the firms that our group visited had none. Many still had manual machines that their grandparents had purchased in the 1940s and 1950s. We observed that the plants with old technology also had low-skill and low-wage workers and high turnover of the workforce. But is it the low skills of the workers that keep the firm from adopting robots, or is it the old technology in the plants and low productivity that make it likely that managers will continue to hire low-skilled workers at low wages? How could we tell? We started to consider what forces were keeping American manufacturers in this low-tech—low-skill—low-wage equilibrium, and how they might break out of it.

We interviewed owners and senior managers in forty-four manufacturing companies in Ohio, Massachusetts, and Arizona, and leaders in twenty-one industrial ecosystem institutions, such as trade associations, community colleges, unions, and Manufacturing Extension Partnership offices. In Germany, we visited eleven companies identified as having world-class advanced manufacturing systems. The US companies ranged from a metal stamping firm whose owner frankly described it as on “the cutting edge of low tech” to a photonics company on the far frontier of new technology. Of the forty-four U.S. companies we visited between 2018 and the outbreak of COVID-19 in 2020, ten are US divisions of large multinational corporations, and thirty-four are small and mid-sized enterprises (SMEs) that employ fewer than five hundred workers. Manufacturers in the latter size category represent 98.4 percent of all manufacturing establishments in the United States, and they employ 43 percent of all manufacturing workers.

The firms we interviewed in 2018–2020 were mainly ones that MIT researchers had interviewed once before, in 2009–2012, in the MIT Production in the Innovation Economy study.²⁰ The original sample of firms had been drawn from a list of all US manufacturers that had doubled their revenues and increased employment between 2004 and 2008, that is, firms that were reasonably “healthy” on the eve of the 2008–2010 economic and financial crisis.²¹ By returning to firms we had visited previously, we hoped to be able to track changes in their technology and workforce profiles. To firms we had visited in 2009–2012, we then added eighteen other companies in the same codes from the North American Industry Classification System (NAICS), namely,

metalworking, automotive, and electronics.²² These new added firms were chosen in close geographic proximity to the original sample.

The key questions we asked in all of our 2018–2020 factory visits were simple ones that we posed in the formal interviews and pursued as we walked with the managers across the plant floor. “Which technologies did you buy over the past five years? Why did you buy them? What new skills did you need to work the new equipment? Where did you find people with those skills? What happened to the people who used to work with the old machine?” We had read the 2017–2018 articles predicting a massive wave of robots replacing workers over a five- to ten-year horizon, so we were surprised to find very few robots anywhere. Surely, if the process of robots replacing workers were to take place over the short period that Frey and Osborne or the publications of the World Economic Forum (“Davos”) predicted in 2017, by 2018–2020 we should already have been seeing robots moving into the factories. But they were few and far between.

In the Ohio small and medium-sized manufacturing firms we studied, one mid-sized auto supplier that we had first visited in 2010 had subsequently been purchased by Japanese suppliers, incorporated into Japanese auto supply networks, and then experienced a major growth spurt. That company in 2018 had 105 robots in plants it now managed—and its Ohio workforce had grown from 120 to 260. But in all the other Ohio SMEs we visited, there had been only one robot purchase over the previous five years: a 6-axis welding robot to work on large tubular sections for a naval defense contract. In the Arizona SMEs, there had been three robot acquisitions; in Massachusetts, one.

Indeed, even in the large firms (with over five hundred workers) we visited, robots were scarce.²³ In one large division of a multinational company in Pennsylvania, we learned that there had been robots in the plant in the past. But when demand for the parts they were making with the robots fell off sharply, the job along with the robots was transferred to another division of the company. At the time of our visit, the plant had no robots. They were experimenting with a robot that they hoped to use for vision and quality control. The onslaught of rapidly advancing robots that we had expected to find in the heartland of American manufacturing was nowhere in sight.

Preliminary results of the 2018 first-ever US survey “on the presence of robots” in US manufacturing establishments confirms that the absence of robots in the SMEs we visited is no sampling error, but in fact representative of the overall situation. The Census of Manufacturing survey of robots shows that only 9.5 percent of US

manufacturing establishments have at least one robot. Even among plants with more than five hundred employees, fewer than half have robots.²⁴

What did we learn about when firms do decide to buy robots or other advanced manufacturing technologies? We had often read that companies buy robots and other new equipment to reduce their workforce. But on the ground we did not find such cases. In fact, in the firms we were visiting for a second time after eight years, all of them (with the exception of one going out of business and a second in fragile shape) were hiring more workers. We interviewed a company that manufactures welding robots and asked what changes they saw in their customers' businesses after the purchase of the robot. They told us that customers buy robots thinking to become more productive, but then discover that the biggest change is greater quality and reliability in their operations. In our own interviews, the most frequent factor driving a purchase was the prospect of a new contract that would require new equipment. A third-generation family firm that started its business making industrial boilers today does about two-thirds of its business on defense contracts. When the navy urged them to use robotic welding, the company bought a 6-axis welding robot. Another firm we visited purchased a new bed mill when they realized the laser mill they had could not produce the volume they needed for a customer with a big project coming up. An Arizona firm that makes analogue load cells that measure force acquired robots for their high-volume products and for automated visual inspection. But the small-volume cells are still made by hand. There's a lot of tacit knowledge involved in making load cells, and as we walked the factory floor, we saw people assembling tiny parts under magnification.

In a few factories, robots were introduced to reduce stressful and boring human labor. Artaic, a small Boston firm that makes customized mosaics, mainly for hotels and restaurants, realized that its competitive advantage was sending out samples rapidly.²⁵ Owner Ted Acworth had already figured out how to program robots to do the otherwise tedious task of picking and placing individual tiles. But to make samples, workers needed to place tiles in sample squares manually. To make the task easier, Acworth invented a device he calls Whack-a-Tile, basically a monitor with light signals to assist workers in putting the sample together quickly. Each Whack-a-Tile is set up to take best advantage of the individual work styles and hand positions of each employee. Ackworth's company is a modern design firm. But we saw similar reasoning in a very traditional Arizona metalworking job shop. The owner told us that before buying the shop twenty years ago, he had worked on a Boeing assembly line, which he experienced as "boring, brain-dead work that no human being should do."²⁶ He's

planning to retire soon and leave the business to his sons. In the past few years, he has replaced old manual machines with new lathes that can be programmed so that one person can deal with three to five machines. He now plans to buy a robot to feed the machines. With the new machines and a few trained workers, the sons' principal tasks would be to program the machines.

The Puzzle of the Missing Robots

Why are there so few robots in the small and mid-sized companies that constitute the majority of American manufacturers? Virtually all of the businesses we visited were suppliers, companies that make a diversity of parts for customers who make the final products. The suppliers are high-mix, low-volume manufacturers. Robots today are still relatively inflexible. They are invaluable in auto assembly plants, in which the robots operate consistently on large product runs. These are industrial robots: too powerful and hence too dangerous to work alongside humans. They are located in fenced-in areas that workers do not enter. Collaborative robots (cobots), which are robots that are safe to work alongside humans, still have limited use on factory floors. They are still very difficult to reprogram, so for a business that makes a very diverse product mix involving quite different production phases, it's not economically rational to buy a robot that can do only one operation.

What makes the robot expensive is not just its initial cost, but all the costs of integrating the robot into the factory. Equipment needs to be installed to move the part up to the robot and away from the robot. It's estimated that the purchase price of the robot is only 25 percent of the total cost of integrating it into the production line. Sometimes firms use integrators to help them get the robot working. But many companies worry that the integrators pick up too much of the firm's proprietary knowledge along the way. An Arizona firm told us of the years it spent trying to install a robot by itself. "How long was it until you were able to get real value out of it?" we asked. "Seven years." We asked what the problem was. The answer was short: "It took seven years because there was a lot of hubris on our part. We tried to do way too much."²⁷ Much progress is being made in research labs and robot manufacturers in designing more user-friendly interfaces, and success in that line should eventually make robots more accessible to smaller manufacturers. But even in factories that do have robots and advanced CNC machines and other new technology, we observed that the new machines are simply working alongside old ones. It's common to find equipment purchased in the 1940s by the owner's grandfather still in service. This

layering of the new on top of the old makes it difficult to reap the full productivity benefits out of advanced equipment.

The barriers to the introduction of advanced manufacturing equipment are not just technological. A high-mix/low-volume supplier is dependent on customers whose orders vary unpredictably, so heavy investment in equipment for making any particular product is unwise. The owner of Gent Machine Co. in Cleveland, Ohio, repeated to a journalist what he had explained to MIT researchers previously: that even on a large contract he hesitated to buy automation equipment because the contract could disappear overnight. That's exactly what happened to an eight-year-long Tesla contract with Gent for making fasteners that attach battery parts. About Tesla's decision to terminate the contract, Gent's owner said: "That's just how it works."²⁸ It is how it works in US manufacturing, at least. In Germany and Japan, MIT researchers have observed more collaborative relationships between large firms and their suppliers. Large firms make longer-term commitments to suppliers and share their plans and technical know-how in order to help the smaller firms adjust and advance.

Finally, we needed to consider a frequently heard explanation of the slowness of adoption of advanced manufacturing technologies: that the problem lies in the lack of skills of the manufacturing workforce. In this view, manufacturers are reluctant to invest in new equipment because they cannot find workers with the right skills to work on it. International comparisons highlight the weaknesses of US workforce education relative to the institutions in countries like Germany and Denmark that provide apprenticeships and extensive advanced training and retraining to workers. People blame culture change for the unwillingness of young people to seek out manufacturing jobs. But low entry-level wages and job insecurity can explain much of that reluctance. When parents have watched more than five million manufacturing jobs disappear in their lifetimes, it can be difficult to convince them of a good future in manufacturing for their children. And low-tech jobs are not challenging and attractive to new generations of workers.

Breaking Out of the Low-Tech—Low-Wage Trap

The scarcity of robots and other automation equipment in most US manufacturing plants shows that robots are not taking over the jobs of most humans. But this is hardly good news for the US economy or for American workers. Without higher rates of investment in advanced manufacturing technology, the country's sluggish productivity growth is not likely to accelerate. Without new technology in manufacturing plants, the wages of workers are not likely to rise. Wages are

determined by multiple factors, including labor supply, unionization, and public policies. We observed that firms that invested little in advanced equipment were also unwilling to invest in their employees' skill development. They asked little of their workers beyond coming to work on time. They offered low entry wages and little training beyond shadowing a worker already doing the job for which the new entrant was hired. These firms typically have high turnover rates, since workers have little incentive to stick with such a company.

There are companies that have followed a different track. We encountered them in our research and discovered that they had typically made substantial investments in new equipment—either to improve the quality, speed, and safety of their production process, or to satisfy a big customer, such as the US Department of Defense. When they make investments in technology, manufacturers also frequently invest in training. After all, now they need their workforce to know how to make the best use of new tools. The acquisition of new technology and new skills often goes hand in hand. These observations suggest that in order to break out of a stalemate in which outdated equipment and low-level skills are mutually reinforcing, we need public policies to support both higher levels of capital investment and investment in worker education.²⁹ There is a road out of our current dilemma. We need to move onto it.

Discussion Questions

1. What factors might influence manufacturing firms to adopt new technologies like robots? Could government play any role here?
2. How could engineers design new technologies and take into consideration factors that would make for good jobs: more interesting ones, ones with less physical and mental stress, ones that encourage workers to contribute to process improvement?
3. How should a company decide who should be trained to use new technology? Workers? Technicians? Engineers?
4. There have been proposals to tax robots or in some other way limit their use. What do you see as the pros and cons of such restrictions?
5. The authors of the article suggest at the end that government should play an active role in supporting the introduction of robots and other advanced manufacturing technologies into the workplace. Do you agree? On what grounds could one critique the authors' position?

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14. [1963 Census of Manufactures](#); [1972 Census of Manufactures](#); [1982 Census of Manufactures](#); [1992 Census of Manufactures](#); [1997 Economic Census](#); [2002 Economic Census](#); [2012 Economic Census](#). ↵
15. This report draws on the work presented in “Manufacturing in America: A View from the Field,” in <https://workofthefuture.mit.edu/wp-content/uploads/2021/01/2020-Final-Report4.pdf>. ↵

16. Michael Dertouzos, Robert Solow, and Richard K. Lester, *Made in America* (Cambridge, MA: MIT Press, 1989); Suzanne Berger and Richard K. Lester, *Made By Hong Kong* (Hong Kong: Oxford University Press, 1997); Suzanne Berger and the MIT Industrial Performance Center, *How We Compete* (New York: Doubleday, 2005); Suzanne Berger and the MIT Taskforce on Production in the Innovation Economy, *Making in America* (Cambridge, MA: MIT Press, 2013). [↵](#)
17. <https://workofthefuture.mit.edu/wp-content/uploads/2020/11/2020-Research-Brief-Berger.pdf>. [↵](#)
18. Alex Owen-Hill, “What’s the Difference between Robots and CNC Machines?” May 29, 2019, <https://robodk.com/blog/difference-robots-cnc-machines/>. [↵](#)
19. We had seen AGVs in German plants with wide enough aisles to allow them to move safely. There were none in any of the US plants we visited. [↵](#)
20. See Berger and the MIT Taskforce on Production in the Innovation Economy, *Making in America*. [↵](#)
21. The list of the US manufacturers meeting those criteria had been purchased from a data contractor who had identified them for a contract with the Small Business Administration. Spencer L. Tracy, Jr., “Accelerating Job Creation in America: The Promise of High Impact Companies,” Corporate Research Board, LLC for SBA Contract Number SBAHQ-10-M-0144, www.sba.gov/sites/default/files/files/HighImpactReport.pdf. [↵](#)
22. NAICS codes identify businesses by six-digit numbers based on the kind of work carried out in the company. [↵](#)
23. We did not visit auto assembly plants where since the 1980s robots are omnipresent. About a third of all robots worldwide are in the automotive sector. [↵](#)
24. US Census Bureau, “Annual Survey of Manufactures Industrial Robotic Equipment,” Share of Plants with Robots and Share of Employees Exposed to Robots by Industry, March 11, 2021, <https://www.census.gov/library/publications/2019/econ/2018-asm-robotic-equipment.html>. [↵](#)
25. Before each interview, the researchers promised confidentiality. So in this article, the only cases in which firms are identified are those in which a newspaper

article has already identified the owner or manager making the same points they made to us. [↵](#)

26. Interview with owner of a small machine shop in Phoenix, Arizona, January 16, 2020. [↵](#)

27. Interview with manager of a 600-person firm in Phoenix, Arizona, January 13, 2020. [↵](#)

28. Timothy Aeppel, “The Robot Apocalypse Is Hard to Find in America’s Small and Mid-sized Factories,” Reuters, August 2, 2021, <https://www.reuters.com/technology/robot-apocalypse-is-hard-find-americas-small-mid-sized-factories-2021-08-02/> [↵](#)

29. For further discussion of public policies, see Armstrong, Berger, and Bonvillian, “Advanced Technology, Advanced Training.” [↵](#)