WORKING PAPER SERIES

A Firm-level Study of Workforce Challenges at U.S. Manufacturers

Ben Armstrong
Research Scientist, Industrial Performance Center and Initiative for Knowledge and Innovation in Manufacturing at MIT

MIT Work of the Future Working Paper 12-2021

January 2021

400 Main Street, E19-733, Cambridge, MA 02139

Survivors and Startups:

A Firm-level Study of Workforce Challenges at U.S. Manufacturers

Ben Armstrong
MIT

January 2021

Abstract

As U.S. manufacturing recovers from decades of job losses and factory closures, many manufacturing firms report that they have been unable to hire enough workers to meet their demand. A common explanation for this challenge is that manufacturing firms face a "skills gap" in which factory workers do not have the technical skills to operate the advanced technologies now found on the shop floor. This paper examines manufacturing workforce challenges in the United States with firm-level interviews and industry data. It does not find evidence that SME manufacturers face a skills gap. By contrast, SMEs in the interview sample with more advanced technological capabilities appear to have more success overcoming their workforce challenges. The overwhelming majority of firms in the interview sample reported a shortage of traditional manufacturing skills in the labor market. In response to this shortage, firms typically hire entry-level workers and invest heavily in years of informal, on-the-job training. Interview evidence

suggests that startup firms and firms with training partnerships have found more innovative approaches to their workforce challenges.

Between 1980 and 2010, American manufacturing was an industry in decline. The U.S. manufacturing workforce shrank by 41% during this period, equivalent to a loss of approximately 7.8 million jobs. Although many have highlighted technological advances in manufacturing that promise enhanced automation and increased productivity, there is mounting evidence that U.S. manufacturing has suffered from stagnating productivity and comparatively low innovation for decades. These challenges have been particularly severe for small and medium enterprises (SMEs), defined here as manufacturing firms or plants with 500 employees or fewer. Although less than half of all manufacturing workers are employed at SMEs, 98% of U.S. manufacturing firms fall into the SME category. As U.S. manufacturing employment declined overall, SME manufacturing plants lagged further and further behind large manufacturing plants in their productivity growth and technology acquisition. Between 2000 and 2010, the number of SME manufacturing firms in operation declined by 15%, a net loss of more than 40,000 firms.

These problems for U.S. manufacturers – particularly SMEs – have consequences for the labor market, for national security, and for the country's ability to innovate. The decline of production jobs has been associated with the "hollowing out" of the middle of the labor market.[1] The vitality of U.S. manufacturing also matters for the military, which by law and for strategic reasons must source much of their materiel domestically. The military is especially reliant on

[1] David Autor, "The Polarization of Job Opportunities in the US Labor Market: Implications for Employment and Earnings," *Center for American Progress and The Hamilton Project*, 2010, http://www.frbsf.org/community-development/files/CI_IncomeInequality_Autor.pdf; David Autor and David Dorn, "The Growth of Low-Skill Service Jobs and the Polarization of the US Labor Market," *The American Economic Review* 103, no. 5 (2013): 1553–97; Maarten Goos, Alan Manning, and Anna Salomons, "Explaining Job Polarization: Routine-Biased Technological Change and Offshoring," *The American Economic Review* 104, no. 8 (2014): 2509–26.

SME manufacturers. Approximately half of the plants in the defense supply chain have annual revenues of $25 million or less.[2] Moreover, innovative American firms are more capable of developing innovative new products when they can do so alongside a thriving domestic manufacturing ecosystem. Research on innovation shows how proximity between the design, prototyping, and early production runs of a product can be helpful for the innovation process.[3] It is in this context that scholars, policymakers, and industry leaders have sought to understand what strategies and practices at the firm level could help revitalize U.S. manufacturing competitiveness. More broadly, research on U.S. manufacturing firms can reveal how businesses in vulnerable sectors seek to rebuild their competitive advantage.

Since 2010, there have been signs that the American manufacturing economy has stabilized. The pace of business closure has slowed, and the U.S. manufacturing workforce has begun expanding after decades of layoffs. U.S. manufacturers added than 1 million workers between 2010 and 2020, amounting to a growth in the manufacturing workforce of 12%. As U.S. factories have begun hiring, many have reported challenges finding employees to fill open positions. In 2019, approximately 60% of SMEs listed "employee recruitment / retention" as a top 3 "strategic challenge," up from approximately 20% in 2010. These workforce challenges were the second most common concern after "ongoing continuous improvement / cost reduction strategies."[4] Interviews confirm that SME manufacturers and large manufacturers alike consistently report having difficulty finding production workers who meet their needs.

---

[2] Eugene Gholz, Andrew D. James, and Thomas H. Speller, "The Second Face of Systems Integration: An Empirical Analysis of Supply Chains to Complex Product Systems," *Research Policy* 47, no. 8 (October 1, 2018): 1478–94, https://doi.org/10.1016/j.respol.2018.05.001.

[3] Gary P. Pisano and Willy C. Shih, "Does America Really Need Manufacturing?," *Harvard Business Review*, March 1, 2012, https://hbr.org/2012/03/does-america-really-need-manufacturing; Suzanne Berger and MIT Task Force on Production and the Innovation Economy, *Making in America* (Cambridge: MIT Press, 2014).

[4] NIST Manufacturing Extension Program SME Survey, 2008-2020. These data originate with a survey that Manufacturing Extension Program offices in U.S. states administer to their SME "clients." The same survey questions have been administered across states for more than a decade.

Why do so many SME manufacturers in the U.S. report facing challenges recruiting and retaining workers? Past research has offered three hypotheses that emphasize broader features of the labor market rather than firm-level decisions. The first is that manufacturing firms face a "skills gap" in which factories have acquired new technologies more quickly than workers have acquired skills to operate them. The proposed remedy is to ensure that there is an increased supply of manufacturing workers with such advanced technology skills. A second perspective frames the problem as a "skill shortage" brought about by a wave of retirements. The remedy for the shortage is to increase the supply of experienced manufacturing talent in occupations such as welding, machining, and tool and die making. A third hypothesis is that firms are unable to find workers to fill job openings due to a "wage gap." This perspective suggests that if manufacturing firms sought to attract more skilled workers, they should first increase the wages offered to new recruits. While these perspectives are not mutually exclusive, they suggest alternative directions for strategy and Human Resource Management (HRM) within firms.

Understanding the workforce challenges facing manufacturers matters because there is evidence that when firms are able to build the capabilities of their labor force, they can become more productive and competitive as they adapt to technological change. There is a long legacy of research examining how innovative HRM practices can influence firm-level performance.[5] Scholars have given such innovative HRM practices associated with positive firm-level outcomes a variety of labels, including "high-involvement work practices," "high performance

[5] Brian E. Becker and Mark A. Huselid, "High Performance Work Systems and Firm Performance: A Synthesis of Research and Managerial Implications," *Research in Personnel and Human Resource Management* 16 (1998): 53–102; Mark Huselid, "The Impact of Human Resource Management Practices on Turnover, Productivity, and Corporate Financial Performance," *The Academy of Management Journal*, no. 3 (1995): 635; John Paul MacDuffie and John F. Krafcik, "Integrating Technology and Human Resources for High-Performance Manufacturing: Evidence from the International Auto Industry," in *Transforming Organizations*, ed. Thomas A. Kochan and Michael Useem (Oxford University Press, 1992), 209–25.

work systems," and "high-road strategies."[6] Studies show that firms providing complementary "bundles" of training, incentives, and organizational structures for their workers have experienced better performance as they adapt to technological change than firms that adopt individual HR strategies or none at all.[7] The implication of this research is that firm-level strategies that enable firms to overcome these workforce challenges could also improve the competitiveness of SME manufacturers in the United States.

This paper evaluates the three hypotheses about manufacturing workforce challenges ("skills gap," "skill shortage," "wage gap") with firm-level data from interviews with leaders of more than 25 U.S. manufacturing firms. It does not find any evidence of a "skills gap" in which workers cannot keep up with the "advanced manufacturing" capabilities of hiring firms. The majority of the firms interviewed have not adopted such advanced technological capabilities. Among the firms that have invested in advanced production technologies, incumbent workers have trained themselves – or received training from a third party – to learn how to operate the new technologies. In contrast to the "skills gap" hypothesis, SMEs with more technological capabilities were less likely to report workforce challenges and more likely to discuss innovative HRM strategies.

SME manufacturers reported in interviews that they are frequently unable to find workers with traditional manufacturing skills and experience (e.g. welding, machining, and tool and die making), consistent with the "skill shortage" hypothesis. As a response to this problem, many of the manufacturing firms in the sample have hired entry-level workers without experience

[6] Becker and Huselid, "High Performance Work Systems and Firm Performance"; Fritz Pil and John Paul Macduffie, "The Adoption of High-Involvement Work Practices," *Industrial Relations* 35, no. 3 (July 1996); Paul Osterman, "In Search of the High Road: Meaning and Evidence," *ILR Review* 71, no. 1 (January 2018): 3–34.
[7] John Paul Macduffie, "Human Resource Bundles and Manufacturing Performance: Organizational Logic and Flexible Production Systems in the World Auto Industry," *Industrial and Labor Relations Review* 48, no. 2 (January 1995): 197–221.

(consistent with findings from "wage gap" research), providing them with years of on-the-job training to develop the skills that they have been unable to recruit.

Interviews with SMEs reveal heterogeneity in how firms have addressed workforce challenges. Whereas the majority of firms interviewed report persistent difficulty recruiting and retaining workers, a subset of SME manufacturers has adopted innovative HRM practices – such as formalized on-the-job skill training and worker involvement in technology acquisition – that actively address their workforce challenges. In contrast to widespread frustration with the level of skilled manufacturing talent available, some SME manufacturers in the subset report high levels of satisfaction with their workforce and their capabilities. It is not surprising that some SME manufacturers have invested more actively in workforce training than others. Given the small number of firms avoiding workforce challenges in the sample, this paper is better suited to generate hypotheses about innovative HRM practices than test them.

It proposes based on the sample of SMEs interviewed that young "startup firms" are more equipped to adopt innovative HRM practices and address workforce challenges than older firms that have survived the decades-long decline of U.S. manufacturing. Interview research has identified several cases of "survivor firms" adopting innovative HRM practices. In these instances, survivor firms rely on a network of connections with peer firms and educational institutions to defray their risk of investing in training and workforce development. In all cases of SMEs adopting innovative HRM practices, the firms appear to have more technological capabilities than their peers. It appears that those technological capabilities preceded investments in innovative HRM practices. The mechanism by which technology adoption might contribute to different HRM practices is not immediately clear. Additional research can evaluate how a firm's new technological capabilities could change managers' *expectations* of its workers, as well as

examine how the presence of new technologies and a more automated work environment could serve as a *recruitment tool* for a more creative and motivated workforce, for which innovative HRM practices are easier to introduce.

I. THREE PERSPECTIVES ON THE MANUFACTURING WORKFORCE

Although firms widely report that recruiting and retaining workers to fill open jobs is among their top priorities, industry analysts, policymakers, and scholars have come to different conclusions about what exactly the problems with the manufacturing labor force are – and how they might be overcome. There are three primary models of understanding the forces behind U.S. manufacturing workforce challenges. The "skills gap" model emphasizes the importance of workers adapting to technological change. The "skill shortage" model emphasizes how the decline in interest in manufacturing careers has combined with an impending wave of retirements to create an acute demand for tradespeople in more traditional occupations such as machining and welding. The "wage gap" model indicates that stagnant wages – not a lack of skill in the potential pool of manufacturing workers – can explain why American manufacturers have had such difficulty hiring since the Great Recession. These three perspectives are not mutually exclusive, although they do point to different public policy approaches.

The first model identifies the problem with the manufacturing workforce as a "skills gap." The premise of the "skills gap" model is that while the U.S. manufacturing workforce has shrunk dramatically since 1980, manufacturing firms have continued to compete globally by adopting more sophisticated technologies. A suite of technological advances in robotics, additive manufacturing, and multi-axis CNC machining have contributed to the digitization of the factory. These technological advances, the "skills gap" perspective suggests – have changed the types of

skills that U.S. manufacturing firms require to do their work.[8] Whereas manufacturers of the past might have asked a machinist to set up and operate a manual Bridgeport machine, the new requirements for a machinist might emphasize programming a machine or operating a flexible robot. This perspective is consistent with models in labor economics that indicate how technological changes that automate particular tasks reduce the demand for some skills and increase the demand for others.[9] One potential explanation for this mismatch between firm technology and worker training is that there is insufficient employer involvement in setting the curriculum at vocational schools and community colleges.

The "skills gap" perspective suggests that the training apparatuses that support skill development have lagged behind the technological advances of manufacturing firms. As a result, the remedy for the workforce challenges facing U.S. manufacturing must include reforms to the system of community colleges and vocational schools that train American workers. Policy initiatives reflecting the "skills gap" perspective include new educational programs and certifications associated with advanced manufacturing technologies. At Manufacturing USA Institutes, which are federally-funded initiatives to promote the development of new manufacturing technologies, workforce development programs are paired with technology development programs to support a growing population of workers with skills that match the technological sophistication of the modern factory. The assumption is that the American workforce has not adapted to acquire these skills that firms demand.

[8] Deloitte Insights and Manufacturing Institute, "2018 Deloitte and The Manufacturing Institute Skills Gap and Future of Work Study," 2018, https://documents.deloitte.com/insights/2018DeloitteSkillsGapFoWManufacturing; Kristin Majcher, "The Hunt for Qualified Workers," *MIT Technology Review*, September 16, 2014, https://www.technologyreview.com/2014/09/16/171364/the-hunt-for-qualified-workers/.
[9] Daron Acemoglu and David Autor, "Skills, Tasks and Technologies: Implications for Employment and Earnings," *Handbook of Labor Economics* 4 (2011): 1043–1171.

The second approach to U.S. manufacturing workforce emphasizes a "skill shortage." According to this perspective, the workforce needs of manufacturing firms are not novel. Firms need to hire workers in more traditional roles on the factory floor as welders, machinists, and toolmakers. Firms' inability to find skilled individuals in these positions reflects a combination of inadequate interest in manufacturing among younger Americans entering the workforce, along with the ongoing retirement of a generation of older workers who currently hold these positions. The core challenge from the "skill shortage" perspective is recruiting a new generation of workers to become interested in manufacturing trades – not necessarily to adapt vocational curricula to become more technologically advanced. It is important to note that industry reports have discussed the skills gap and skill shortages interchangeably at times, conflating the types of skills that manufacturers are struggling to acquire. I follow other studies of the labor market in separating these perspectives as distinct diagnoses of workforce challenges in manufacturing.[10]

A third model of the manufacturing workforce suggests that firms' difficulties recruiting talent reflects a "wage gap." This perspective claims that firms are unable to fill job openings because the wages they are offering are too low – not because workers do not have the skills to fill those positions. Scholars and analysts point to two sets of evidence to support the "wage gap" idea. The first is that despite persistent claims about the inability of firms to recruit workers, wages in manufacturing have largely stagnated.[11] If there were indeed a skills gap requiring more sophisticated skills or a skill shortage – suggesting labor demand exceeds supply – then the

[10] Peter H. Cappelli, "Skill Gaps, Skill Shortages, and Skill Mismatches: Evidence and Arguments for the United States," *ILR Review* 68, no. 2 (March 1, 2015): 251–90, https://doi.org/10.1177/0019793914564961; Seamus McGuinness, Konstantinos Pouliakas, and Paul Redmond, "Skills Mismatch: Concepts, Measurement and Policy Approaches," *Journal of Economic Surveys* 32, no. 4 (n.d.).
[11] Andrew Weaver, "The Myth of the Skills Gap," *MIT Technology Review*, August 25, 2017, https://www.technologyreview.com/2017/08/25/149485/the-myth-of-the-skills-gap/; Adam Davidson, "Skills Don't Pay the Bills," *The New York Times*, November 20, 2012, sec. Magazine, https://www.nytimes.com/2012/11/25/magazine/skills-dont-pay-the-bills.html.

market expectation would be for wages to go up. The second set of evidence comes from firms themselves. In response to surveys asking what skills they are looking for in prospective workers, firms do not emphasize sophisticated skills like advanced mathematics or programming proficiency.[12] Instead, the majority of firms report that job openings at their firms require more basic levels of proficiency in mathematics, for example. Instead of recruiting for advanced technical skills, these surveys indicate, firms are frequently interested in workers who can communicate effectively and show consistent motivation on the job – what are sometimes referred to as "soft skills." The implication of the "wage gap" perspective is that firms could resolve at least some of their recruiting challenges by increasing wages. Research on efficiency wages, for example, links wage increases at firms to a more motivated and productive workforce.[13]

These three perspectives reflect industry-wide data on job openings and retirements, as well as the specific reporting of individual U.S. manufacturers. They are not competing explanations of a single phenomenon. By contrast, some companies face a skills gap that challenges their recruiting practices, while others grapple with a skill shortage or a wage gap. Individual firms might face more than one of these challenges, perhaps seeking to hire in advanced technology positions as well as longstanding trade and entry-level occupations. Since each of these models has some empirical support, the question for this research becomes: under what conditions do firms grapple with these workforce issues – and under what conditions do

[12] Andrew Weaver and Paul Osterman, "Skill Demands and Mismatch in U.S. Manufacturing," *ILR Review* 70, no. 2 (March 1, 2017): 275–307, https://doi.org/10.1177/0019793916660067.
[13] Lawrence H. Summers, "Did Henry Ford Pay Efficiency Wages?," *Journal of Labor Economics* 5, no. 4, Part 2 (October 1, 1987): S57–86, https://doi.org/10.1086/298165; Zeynep Ton, "The Case for Good Jobs," *Harvard Business Review*, November 2017, https://hbr.org/cover-story/2017/11/the-case-for-good-jobs.

firms avoid or overcome them? This question invites a comparison of how some manufacturing firms approach human resource management differently than others.

II. Re-examining the Three Perspectives with Interview Data

This paper draws on more than 25 interviews with executives of U.S. manufacturing firms with fewer than 500 employees in Ohio, Massachusetts, Connecticut, and New Hampshire. The general aim of these interviews was to understand how individual American manufacturers have adapted to competitive pressures and competed in their industry. The interviews begin by asking the company representative to explain their firm's market niche and place in the supply chain. They proceed by asking the interviewee to describe a specific example of when they won a new contract or developed a new product. What new technologies did they invest in? What new skills were required to do this work? What new hires were made? The purpose of these questions is to understand how workforce and recruiting challenges fit into the broader strategic challenges of an individual firm.

The lines of questioning in these interviews help categorize a firm's set of technological and workforce challenges. They identify what new technologies the firms have acquired, what types of new employees – if any – the firms have sought to hire, as well as how firms have responded to any recruiting challenges that have arisen. Firms' responses to these questions allow for variation according to firms' technological sophistication, their level of difficulty in recruiting, and their responses to workforce challenges.

This paper has two primary objectives. The first is to analyze interview data through the lens of the three perspectives on manufacturing workforce challenges. It sets out to understand the workforce challenges that SME manufacturers face, as well as how they have responded to

those challenges. Whereas survey data and macroscopic labor market analyses can identify mismatches between labor supply and labor demand, interviews with individual business leaders can help pinpoint why those mismatches exist. The second objective is to generate new hypotheses about why some firms have been more successful at addressing and overcoming workforce challenges than others. What might differentiate firms grappling with skills gaps from firms facing a skill shortage – from firms reporting no workforce challenges at all? Interview data is well suited to address this puzzle, pinpointing specific ways in which firms have overcome their strategic workforce challenges. The limitation of using interview data is that the number of firms with "high-involvement work practices" is relatively small, so any conclusions about what differentiates these firms from others should be treated as hypotheses to test in future research.

The companies interviewed were drawn primarily from a sample of U.S. manufacturers in Ohio and New England (Massachusetts, New Hampshire, Connecticut) with profiles in the SBA database (which includes businesses with fewer than 500 employees) that also had at least one defense contract since 2008 valued at over $1,000,000. During the course of the research, several companies were interviewed based on introductions independent of the main sampling procedure.

The research samples firms with fewer than 500 employees for several reasons. First, C-level executives of small and medium manufacturers are generally more accessible to discuss their strategy and operations as compared to executives in similar positions at larger companies. The SBA database of manufacturers with fewer than 500 employees lists the email addresses of a point of contact at each firm; for a substantial number of cases, the listed contact is a C-level executive at the firm, which makes interview outreach more efficient. Second, small and medium

manufacturers in the United States have reported workforce challenges more systematically than large firms. Although executives at large firms have given public statements identifying workforce challenges, survey data from SMEs indicates that workforce issues are a growing priority, as described in the previous section. Third, SMEs represent the vast majority of all manufacturing firms. Moreover, since SME manufacturers' productivity has lagged behind the productivity (measured as value added per employee or revenues per employee) of large manufacturing firms, understanding the challenges that smaller firms face could be important to improving the competitiveness of U.S. manufacturing overall.

Nonetheless, it is important to recognize that interviews with small and medium firms with defense contracts have the potential to overrepresent some phenomena within manufacturing and underrepresent other phenomena. Three potential sources of sampling bias are of particular concern. First, small and medium manufacturers report lower capital expenditures per employee than large firms, which suggests that the firms sampled for interviewing could be less technologically advanced. While it is important to examine the technological sophistication of small and medium firms on their own, it will be important not to suggest that the technological sophistication of the sampled firms applies to U.S. manufacturers as a whole. Second, sampling defense contractors risks oversampling firms from select industries like aerospace from which the military sources a disproportionate share of goods. Focusing on manufacturers in Ohio and New England also risks bias toward oversampling manufacturers in some industries, but not in others. Third, the emphasis on defense contractors could bias the sample toward particular production volumes and mixes. Whereas manufacturers of commodities with small margins produce high volumes of a small mix of products, defense contractors are

more likely to produce a higher mix of goods and low- and medium-volume with an emphasis on precision and quality rather than cost.

Despite these potential biases of the interview sample, there are reasons to believe that interviews with these types of firms are instructive. First, a large share of the population of small and medium manufacturers in the United States has some relationship with the Department of Defense. Over 40% of the small and medium manufacturers in the SBA database in the select regions qualify for the interview sample by having at least one Department of Defense *prime* contract since 2008. This is most likely an underestimate of the real share of manufacturers in the Defense Industrial Base since it does not capture manufacturing firms at lower tiers of defense supply chains. Second, lower-volume, higher-mix production has become more common across U.S. manufacturing since the 1980s.[14] Firms report that their aim is to develop capabilities to produce smaller runs of various goods, often competing on quality more than price. In this way, the sample of defense-related firms is consistent with broader trends in the industry.

III. Findings from SME Manufacturer Interviews

Interviews with manufacturing executives suggest that while U.S. manufacturers in the sample have frequently had difficulty recruiting and retaining workers, manufacturers report that their difficulties originate with a shortage of traditional skills – as well as a shortage of motivated entry-level workers – not a lag in workers learning about advanced technologies. Many of the firms in the sample produce precise goods that require technical expertise, but they have not adopted advanced technologies for manufacturing. The firms interviewed match what one

[14] Paul Hirst and Jonathan Zeitlin, "Flexible Specialization versus Post-Fordism: Theory, Evidence and Policy Implications," *Economy & Society* 20, no. 1 (February 1991): 1; Michael Piore and Charles Sabel, *The Second Industrial Divide* (New York: Basic Books, 1984).

manufacturing executive quoted elsewhere describes as "the cutting edge of low tech."[15] Firms that have invested in robotics or more advanced CNC machines report training their existing personnel to take over these new procedures – not hiring new employees with these specific skills. The majority of the firms interviewed (approximately three out of four) reported that they had difficulty finding skilled tradespeople such as machinists, welders, and tool-makers. Many of these firms recount looking for entry-level workers who are trainable and can grow into one of these roles. Firm executives consistently say that they invest in years of training for new hires, even when those new hires came from manufacturing programs at vocational schools or community colleges.

A small share of the interviewed firms – six in the sample – have avoided or overcome the workforce challenges that were common among their peer companies. In two cases, the executives of these firms praised the skill of their employees, which they were able to recruit from well-established companies where the employees had honed their skills. The employees in these cases appeared to contribute creatively to the production process. In at least three cases, companies relied on external partnerships and networks to acquire reliable talent. The remainder of this section analyzes the interview data as it relates to the "skills gap," "skill shortage," and the "wage gap" – as well as to organizations to which none of these labels apply.

i. The Skills Gap

In stark contrast with the fear that workers' technical knowledge is lagging behind firms' technological proficiency, none of the firms interviewed reported difficulty recruiting workers with advanced technological capabilities. There are several potential explanations for this

[15] Berger, Suzanne. "Manufacturing in America: A View from the Field." *MIT Work of the Future Research Brief.* 24 November 2020.

pattern. The first is that small and medium firms have been slow to adopt advanced technologies. One firm fabricating specialized metal parts – springs and stamped pieces – indicates that it relies on 50 year-old machines to do its work. There are advanced CNC machines that are available to do the work, but the firm's CEO says that they are not necessary. The process that this firm uses to improve production efficiency is technically advanced; they have a tool-maker who modifies the production line to improve speed and safety. However, the machines in that production line – or the skills to operate them – have not changed. Another company supplying sophisticated testing instrumentation for research and aerospace applications says that only about 20% of its machines are numerically controlled. The rest remain manual machines. As I will discuss further below, there were exceptions to this general pattern. A small number of firms interviewed – in similar business circumstances – did report automating parts of their process, even for low-volume production, through investments in robotics and other technologies.

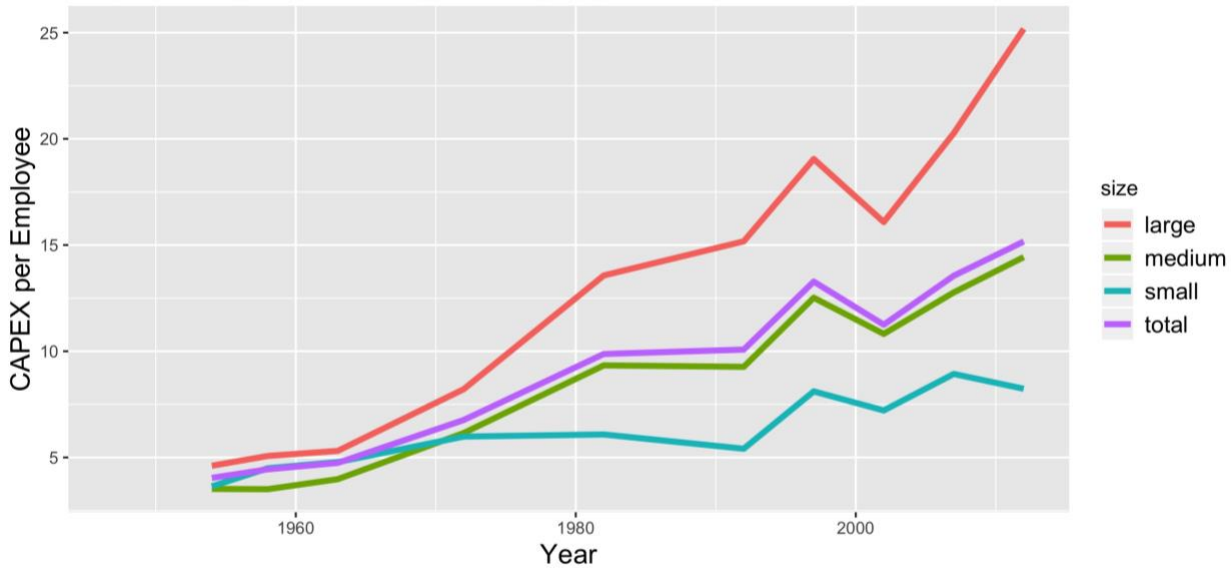
Firms explained their slow adoption of advanced technology in two ways. The first was that given the nature of their business – many of these companies manufacture a high variety of low-volume goods – new technologies might not be worth acquiring unless they can be applied to diverse product applications. An executive at a supplier of electronic modules for the military said that they perform such a variety of tasks for their customers that they don't have very sophisticated equipment. As a result, their added value is mostly in engineering solutions to particular manufacturing problems. The owner of an aerospace supplier said that they make so many different parts each year that nothing in their process is fully automated. The owner of a firm specializing in precision machining said that while they could try to automate their machining process to high tolerances, they do not do work at high enough volumes for it to make sense.

A second explanation was that firms did wish to adopt some new technologies, but they did not have orders in hand that would allow them to defray the risk of such a large investment. The same CEO who said that it would not be cost-effective to fully automate precision machining said that there is some new technology coming on the market that they would like to acquire. The CEO who said that they cannot fully automate their process due to the variety of their parts said that – given the labor shortage – they would like to try co-bots (robots that work in tandem with an operator on the shop floor), but they don't have the resources. If the firm had a lot of cash, they would do it, the CEO said, but they are not early adopters because they cannot take that kind of risk. Her company had previously invested in an advanced Swiss machine, which she says was a mistake. The only way for their firm to make a Swiss machine work would be to move toward a fully "lights-out" production process, and that wasn't practical for them. This was not the only instance of a company reporting a failed investment in new technology.

A supplier of a high mix of low-volume components to the military said that the company had tried to compete in the commercial market with competitors from Mexico and China. They invested in a robotic loading process to manufacture a valve. They were making 1,000 units per day in a fully automated, lights-out process. The CEO of the company said that the material cost was a dollar, and they were able to produce the piece for $2 / unit. However, even with what the CEO described as a very high-quality, low-waste process, the company could not compete with China on price. He attributed the price differential to the subsidies for raw materials that Chinese manufacturers receive. Unable to compete on price for these medium- to high-volume parts, the company shifted to focus on high-margin parts for the military. The CEO described producing a rubber gasket for $30 and selling it to the military for $600 because it was a critical need. The CEO said he cut the gasket with scissors you could buy from Staples, and it took him 20 minutes.

He says that this is an extreme case, but that the high-margin opportunities he found were not dependent on advanced technology.

Figure 1. Capital Expenditures per Employee by Manufacturing Firm Size[16]



These cases of slow technology adoption at small and medium manufacturing firms do not appear to be unique to this sample of firms. In interview research for the Production in the Innovation Economy (PIE) initiative, as well as follow-up interviews for the Work of the Future Initiative at MIT, Suzanne Berger and colleagues similarly found that small and medium

[16] U.S. Department of Commerce, Census Bureau, "2012 Economic Census," Subject Series, Manufacturing (NAICS Sector 31-33) (Washington, DC, 2012), https://www.census.gov/data/datasets/2012/econ/census/2012-manufacturing.html; United States Bureau of the Census, "2002 Economic Census," Subject Series, Manufacturing (Washington, DC, 2002), https://www.census.gov/data/tables/2002/econ/census/manufacturing-reports.html; United States Department of Commerce, Bureau of the Census, "1997 Economic Census," Manufacturing Subject Series (Washington, DC, June 2001), https://babel.hathitrust.org/cgi/pt?id=coo.31924091720049&view=1up&seq=3; United States Bureau of the Census, "1963 Census of Manufactures, Volume I" (Washington, DC, 1966), https://catalog.hathitrust.org/Record/000964090; United States Department of Commerce, Bureau of the Census, "1972 Census of Manufactures, Volume I" (Washington, DC, 1977), https://babel.hathitrust.org/cgi/pt?id=mdp.39015084924565&view=1up&seq=4; United States Department of Commerce, Bureau of the Census, "1982 Census of Manufactures, Part 1," Subject Series General Summary, Part 1. Industry, Product Class, and Geographic Area Statistics (Washington, DC, March 1986), https://babel.hathitrust.org/cgi/pt?id=umn.31951d02881554v&view=1up&seq=1; United States Department of Commerce, Bureau of the Census, "1992 Census of Manufactures," Subject Series General Summary (Washington, DC, 1997), https://babel.hathitrust.org/cgi/pt?id=umn.31951d01536001y&view=1up&seq=3.

manufacturers did not have the advanced technological capabilities in robotics or 3-D printing that had been touted as part of Industry 4.0. Instead, what Berger and colleagues found was that small and medium manufacturers layered some new technologies onto their existing processes.[17] This is consistent with the interviews in this research, where firms largely made incremental decisions about acquiring new technologies; they could not afford to overhaul their whole production processes. These results are consistent with national data on capital expenditures by firm size (Figure 1), which indicate that while capital expenditures per employee at large firms have increased steadily, capital expenditures at small firms have stalled by comparison.

These data of course do not indicate that there is no "skills gap" based on technology. Instead, they suggest that technology acquisition among manufacturing firms might be more concentrated among large manufacturers. It is plausible that large firms that have invested more intensively in technology might face challenges in recruiting workers who can operate those technologies with skill. At the small and medium companies in the sample with the most technological sophistication, however, this was not the case. Those companies – as will be discussed in further detail below – appeared to report fewer workforce issues than companies with less advanced technology. It is important to note that these firms with more advanced machinery were not always recruiting new technicians to operate them. The more technologically advanced companies either relied on highly-trained engineers to manage the advanced equipment or re-trained leading operators to use the new technology. The CEO of one firm developing an advanced technology product said that it decided only to hire engineers – rather than have a combination of engineers and technicians – because they were more confident that their engineers would not make mistakes. A medium-size machine shop with sizable

[17] Berger, Suzanne. "Manufacturing in America: A View from the Field." *MIT Work of the Future Research Brief.* 24 November 2020.

investments in multi-axis CNC machinery said that whenever they bought a new machine, they made sure to invest in training along with it. This was consistent across firms that discussed new technology purchases. These companies would be sure that at least one employee with experience at the firm would learn how to use it, then train others.

It is possible that as these firms acquire new technologies and grow, they might begin to recruit new technicians to take on advanced technology tasks. However, even then, it's unclear whether there will be a significant "skills gap." In discussing the skills required to operate newer or more advanced machines, these companies frequently emphasize that they are not necessarily more complicated than past machines – and in some cases, companies report that they might even be simpler. In one firm, for example, all the new machines they purchase have the same interface, so programming different machines does not require additional training. Nonetheless, several companies implied that they would not want to hire someone who only knew how to operate the latest generation of manufacturing technology. Companies looking for machinists, for example, were searching for operators who could do more than "push the button" on a CNC, but who could also spot problems as they arose.

ii. Skill Shortage

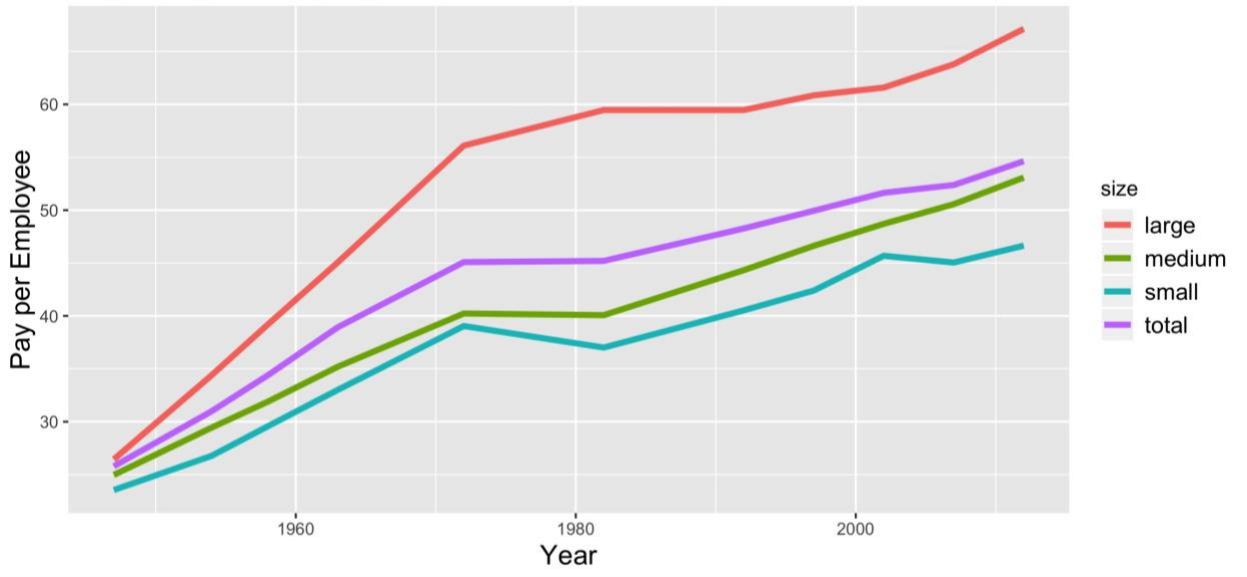
The overwhelming majority of firms in the sample made clear that they were seeking workers with more traditional manufacturing skills, such as the ability to build tools and fixtures that improve the production process, operate various milling and welding machines, and perform other problem-solving tasks on the factory floor. Firms indicate that the workers they have with these skills are aging, and the challenge is training and hiring new skilled workers to replace them. For example, an executive of a company specializing in precision metalwork sought to hire

a toolmaker. Two of his current toolmakers are nearing retirement – they are 63 and 73 years old – and the executive says that he recently interviewed a 69 year-old toolmaker who was asking for an annual salary of $113,000, which he described as reasonable. He estimated that toolmaker salaries were increasing by 10% annually due to increased demand. The one younger toolmaker at his firm was trained on the job. An executive at a family-owned manufacturer of small vehicles reported a similar experience. She lamented that they relied on individual suppliers with specialized skills who were aging. They have a welder, for example, who had a stroke last year and lost visibility in one eye. The vehicle manufacturer sent an engineer to the welder's shop to work on the welds until he recovered. The manufacturer has urged this welder to take on an apprentice to replace him since they depend on his work.

The narrative from manufacturing executives was that while they were looking to recruit individuals with manufacturing skills and experience, they settled for training entry-level workers on the job when they could not find experienced ones. The owner of a machine shop supplying the aerospace industry said that when they were looking to fill or replace a position, they looked for experience first. They would give that a month. Then they would look for entry-level workers coming out of technical schools. An executive of an electronic components manufacturer offered a similar analysis. He began by saying that when they recruited, they were looking for the basics. When I asked why they were not looking for more skills, he said of course they would like to hire people with skills if they were available. But the implication was that even the basics – e.g. showing up to work on time – were difficult to find for certain companies. One owner emphasized that the competition for talent among manufacturing firms was intense. "We don't compete for business. We compete for talent," she said.

The small and medium manufacturers in the sample appear to face a skill shortage that has driven them to focus hiring on entry-level workers and invest in training new hires internally. These experiences, however, do not mean that a skill shortage is manifest across the manufacturers. It could be that large firms do not face the same skill shortage as small firms since they pay manufacturing workers higher wages on average. Figure 2 compares average wages by manufacturer firm size, showing that there is a persistent gap between the average wages at large and small firms.

Figure 2. Average Wages by Manufacturer Firm Size[18]



[18] United States Bureau of the Census, "1963 Census of Manufactures, Volume I" (Washington, DC, 1966), https://catalog.hathitrust.org/Record/000964090; United States Department of Commerce, Bureau of the Census, "1972 Census of Manufactures, Volume I" (Washington, DC, 1977), https://babel.hathitrust.org/cgi/pt?id=mdp.39015084924565&view=1up&seq=4; United States Department of Commerce, Bureau of the Census, "1982 Census of Manufactures, Part 1," Subject Series General Summary, Part 1. Industry, Product Class, and Geographic Area Statistics (Washington, DC, March 1986), https://babel.hathitrust.org/cgi/pt?id=umn.31951d02881554v&view=1up&seq=1; United States Department of Commerce, Bureau of the Census, "1992 Census of Manufactures," Subject Series General Summary (Washington, DC, 1997), https://babel.hathitrust.org/cgi/pt?id=umn.31951d01536001y&view=1up&seq=3; United States Department of Commerce, Bureau of the Census, "1997 Economic Census," Manufacturing Subject Series (Washington, DC, June 2001), https://babel.hathitrust.org/cgi/pt?id=coo.31924091720049&view=1up&seq=3; U.S. Department of Commerce, Census Bureau, "2012 Economic Census," Subject Series, Manufacturing (NAICS Sector 31-33) (Washington, DC, 2012), https://www.census.gov/data/datasets/2012/econ/census/2012-manufacturing.html; United States Bureau of the Census, "2002 Economic Census," Subject Series, Manufacturing (Washington, DC, 2002), https://www.census.gov/data/tables/2002/econ/census/manufacturing-reports.html.

Multiple interviews in the sample suggest that this is not just a function of high wages for senior executive positions at large firms. According to one machine shop executive, large firms can also offer higher wages to skilled craftspeople that were trained at smaller firms. He described how his firm had previously administered a rigorous on-the-job training program, but that a nearby GE factory would poach their employees once they were trained. One plausible hypothesis is that workers with in-demand "traditional" manufacturing skills have concentrated at larger firms that can offer individuals with these skills higher wages and more impact, whereas the "skill shortage" is concentrated among smaller firms like those in the sample. Again, evidence from exceptional firms in the sample – firms that do not report such a skill shortage – suggest that size is not the only determinant of attracting workers with these skills.

iii. Wage Gap

Consistent with the interview data supporting the "wage gap" perspective, the firms interviewed frequently focused on their difficulty recruiting and retaining entry-level workers with basic skills. A sampling of the skills that firm executives emphasized include someone who is trainable, shows up on time, has a memory, who has ambition, who can put down their cell phone, can pass a drug test, can comply with OSHA requirements, and who has an interest in manufacturing. The common refrain among the interviewees was that they wanted to hire for will and train for skill. But, the interviewees frequently lamented, they were having difficulty recruiting these types of workers.

Companies recounted using a variety of techniques to recruit entry-level hires, ranging from online job postings, posting a banner outside the factory, and using temp services. Many of the firms reported hiring from community colleges and vocational schools, although their

reviews of community college programs were largely negative. Multiple executives suggested that what the students learned in their community college was not necessarily relevant to the work that they would do at the firm. At one firm, even community college graduates start at ground zero in terms of on-the-job training. The pattern across firms that "hired for will, trained for skill" was that even community college graduates in programs related to manufacturing would need to undergo years of on-the-job training. One executive hiring machinists said that graduates from community colleges could recognize the parts of a CNC, but they did not really have much practical experience machining, nor did they know how to measure parts. In other cases, firm executives recognized that some community colleges graduated skilled students, but lamented that these students were funneled to larger firms with more opportunities for those students to get started right away. One firm executive said that as a small company, they are only able to recruit from the lowest tier of graduating community college students, whom they need to continue training.

Nearly every firm in the sample reports some form of on-the-job training for its new recruits. Firms report that it takes recruits multiple years – several firms estimated 3-5 years, some fewer – to be fully self-sufficient on the job. The on-the-job training programs range from informal shadowing where a new recruit looks over the shoulder of a more seasoned technician – to more systematic. At one firm, every new employee starts out inspecting parts before being assigned to a particular machine. Before they move onto the next machine, they need to have a more senior technician approve their work before they can go on to the next machine. Another firm manages a spreadsheet where all the employees' skills – what tasks they can do at the company – are tracked so managers can target training goals for particular employees. Other

firms have written standards and best practices, but many firms report that their on-the-job training is informal.

Firms' focus on recruiting entry-level workers appears at first to be consistent with the wage gap perspective, but interview data offer a more complex picture. Firms seem to be focused on entry-level workers as a way of addressing an impending skill shortage – not solely as a way of filling a need for low-skilled labor. This rationale for manufacturers' recruiting practices casts doubt on the idea that wage increases would necessarily solve the workforce challenges of small and medium manufacturers. Indeed, offering higher wages to entry-level workers could improve motivation and productivity of these workers at the entry-level, consistent with efficiency wage theory and evidence from other industries. However, it is unclear whether this increased motivation and efficiency would speed up the process of training entry-level manufacturing workers to be self-sufficient on the job.

Interview responses from manufacturers indicate that a key obstacle facing small and medium manufacturers is the challenge of training inexperienced workers. In particular, firms identify two key difficulties of on-the-job training. The first is that training junior workers, often in an informal way, can be a burden to experienced technicians who are under pressure to be productive at their core jobs, as well as oversee and teach more junior colleagues. One training organization refers to this as the "clash of the titans." Firms have competing, titanic priorities: improving the skill of their workforce and getting product out the door.

The second challenge of on-the-job training is that the better firms train their workers, the more vulnerable they are to poaching from firms that can pay higher wages (and have avoided the years of investment in internal training). As mentioned above, a medium-sized machine shop reported having a very successful training program for new recruits, but they stopped the

program after their trainees kept leaving the company for higher wages at larger firms. Several companies mentioned a fear of other firms poaching their best workers after they had been trained internally. These concerns reflect a long-standing model in economics where the prospect of poaching leads to the underinvestment in training in competitive markets.[19] These issues have been associated with the rise of industry-wide or universal training institutions.[20]

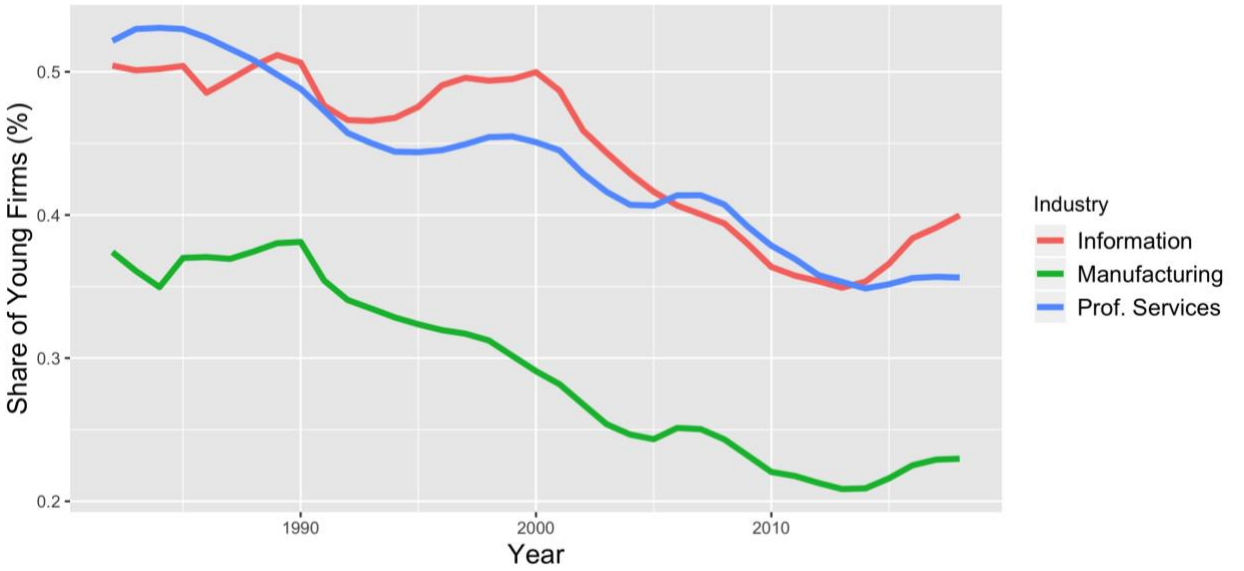
IV. Exploring Variation in Workforce Challenges: Survivors and Startups

There is a clear pattern to the workforce challenges that SMEs in the interview sample face. The typical SME manufacturer in the sample has been in operation for decades, evolving and adapting in response to the series of challenges facing U.S. manufacturing. These "survivor firms" frequently have personnel who have worked for the firm for decades. When these senior personnel retire (or they need to hire another new production worker for another reason) SMEs in the sample *recruit broadly and train informally*. These practices have been associated with poor worker retention and years-long training cycles. There were also exceptions to this paradigm in the interview sample. Understanding these exceptions – firms that have either avoided or overcome the challenges of the *recruit broadly and train informally* model – has the potential to inform firm-level HRM strategies designed to overcome skill shortages.

[19] Gary S. Becker, *Human Capital: A Theoretical and Empirical Analysis, with Special Reference to Education*, National Bureau of Economic Research. General Series, no. 80 (New York: National Bureau of Economic Research; distributed by Columbia University Press, 1964); Daron Acemoglu and Jorn-Steffen Pischke, "Beyond Becker: Training in Imperfect Labor Markets" (National Bureau of Economic Research, September 1, 1998), https://doi.org/10.3386/w6740.

[20] Kathleen Ann Thelen, *How Institutions Evolve: The Political Economy of Skills in Germany, Britain, the United States, and Japan*, Cambridge Studies in Comparative Politics (Cambridge ; New York: Cambridge University Press, 2004).

Figure 3. U.S. Startup Manufacturers Over Time[21]



These exceptions fall into two categories. The first is young "startup" firms that were founded after the most severe period of decline in U.S. manufacturing. Although these firms are fewer in number among manufacturers today than in previous decades (see Figure 3, which measures firms less than 5 years old), the three startup firms in the interview sample all express very different work practices than the typical firms in the interview sample. They have been able to recruit workers with skills developed elsewhere and have empowered those workers with more autonomy on the job. The second category of exceptional firm includes companies that have survived the long decline of U.S. manufacturing and face some of the same workforce challenges as other paradigmatic SMEs, but have addressed challenges like worker retention and long training cycles by developing partnerships with peer firms and training institutions. In addition to making exceptional investments in workforce development, these firms are also

[21] U.S. Census Bureau, "Business Dynamics Statistics: Firm Age by Firm Size by Sector," Dataset, n.d., https://www.census.gov/ces/dataproducts/bds/data_firm.html.

distinguished from the typical SME in the sample by their high level of technology investment. This section illustrates both categories of firms with two examples each from the interviews, then presents a hypothesis about risk tolerance that helps explain why these exceptional firms have adopted more innovative HRM strategies.

i. Startup Manufacturers

The first startup is in the shipbuilding industry. It was established in 2008. Its founders started the company with an innovative boat design using a different technique for producing the hull of smaller vessels. Unlike peer firms that have faced challenges recruiting workers with trade skills, this startup's CEO highlights how they have found excellent craftspeople to work in its factory. The CEO reports that the boat-builders in its shop had not been given the opportunity to be creative and think for themselves in other companies, where they were a cog in a larger machine. At the startup, he says, they have had the freedom to be creative, and the skilled craftspeople the firm has hired have recruited like-minded workers to join the firm. He says this has allowed the firm to recruit workers from larger companies – including companies in entirely different regions of the United States. When the firm, which currently has 20 employees and is growing to 25, hires employees who are less experienced, the company pairs them with a more experienced workers as a "sponsor." It takes an estimated 9 months to 1 year for a new entrant at the boat-building to start taking on projects by themselves.

The company's founders were military veterans with technical expertise and experience on the water. In addition to developing a design innovation for small boats, they developed a significantly more advanced manufacturing process than other companies of their size. In its first phase of production, the company partnered with a variety of high-capacity suppliers, which

manufactured the components of each boat just in time for the firm to integrate and assemble the final product. One key partner was a supplier that had invested in advanced machinery for forming steel, which was critical for the firm's innovative hull. The firm's CEO said they learned from its suppliers so it could bring the production of vessel hulls in house during a second phase of production. The firm designed its factory with the goal of optimizing each square foot of production space. Forty-foot I-Beams cut across their factory floor; production teams can weld different fixtures to the I-Beams for a particular project, then remove them when they are no longer relevant. The firm's CEO emphasized that their workers have significant autonomy to be creative in building their boats.

A second startup firm spun out its core technology from a national laboratory. An executive at the company, which was founded in 2017, reported that the typical route for technologies from national labs was to license them to large prime defense contractors like Lockheed Martin. However, some of the engineers at the lab responsible for the company were interested in entrepreneurship, and the Defense Department supported their continued involvement in the technology, providing initial orders to help launch the venture. The new venture recruited engineering as well as technical talent from the national lab. These workers had already acquired the skills that the company needs in order to assemble its product. This pattern of hiring employees with pre-existing skills from elsewhere and empowering them to take a leadership role in the production process is consistent across multiple startups in the sample. While the company has been able to develop new technologies, they still face limitations in their supplier base. The company's defense contracts require them to source components for their electronic device domestically. The executive said that American semiconductor manufacturers

are less advanced than their Asian competitors, which means his firm is forced to limit the sophistication of their designs.

ii. Survivor Firms with Partnerships

One firm that has overcome workforce challenges with partnerships supplies the aerospace industry with precision machined parts. The company started as a machine shop in the early 1990s and became a defense supplier in the 2000s. After a large contract of theirs was shut down around 2010, the firm shifted its business to aerospace, combining a mix of commercial and military customers. The goal was to have more flexibility and longer-term relationships with their customers. Part of their strategic shift was to focus on hard-to-machine parts with difficult materials. This required them to invest in a series of advanced machines. They not only have high-speed 4-axis Haas CNC machines; they have also invested in a Universal Robot with the goal of having a lights-out cell.

In the three years since acquiring the robot, the firm has implemented a multi-phase roll-out of the machine on the factory floor. Currently, the firm is working on putting the robot into a high-production workstation to increase output by 15% per shift. The eventual goal is to make the robot flexible enough that it can handle a high mix of low-volume parts. The robot's job would be to eliminate set up times. These investments are part of the firm's goal of becoming a 24/7 operation where a technician is responsible for managing a cell of robots. With their current robot acquisition, the CEO estimates that the amortized cost of the robot is $1 / hour, which he says could make them competitive if they get the automated system working.

On workforce issues, the CEO of the aerospace supplier reports many of the same challenges as firms facing a skill shortage report. He says that he has been trying to recruit

machinists to sit operating a machine for 10 hours a day, which is challenging. He had focused on recruiting entry-level machinists and working his way up. In contrast to other firms' complaints about talent from trade schools, he reports that he found trade schools to produce good talent, but not enough of it. This challenge led him to begin participating in an alliance of companies with similar workforce challenges on a collaborative apprenticeship program. The company pays for several of its employees to participate in classroom training once per week along with apprentices from other companies in the region. The classroom training – paired with an on-the-job training program – is part of an effort to refine the skills of their employees more systematically.

A second manufacturer supplies precision components primarily for aerospace and naval applications. The current CEO took over the business from her father, who founded it. She recognizes some of the same challenges in recruiting as the typical SME manufacturers in the sample. She is the CEO who described some of her recruiting process as looking to recruit workers with experience for a month, then turning to entry-level workers. However, her firm also has a co-op program in partnership with the local vocational school. She said that when she needs someone, she has two teachers at the local vocational school whom she can call who will send her a student as a co-op. She said that she has hired at least one co-op per year for the last 7 years (in a company of 28 people), and her foreman was a co-op at the company 20 years ago when he came to the company.

Although she says it still can be 3-5 years before a new recruit is contributing on the shop floor, she emphasizes that her existing employees have flexibility to experiment with new technologies and find ways to promote ownership of the production process from the bottom up. She says that she tells her production team that if they want a new piece of equipment to play

around with, the employees can bring it in and show the firm what it can do. She says that she sends some of her team to machine trade shows just to look around so they can be aware of the things happening in the industry. Recently, when the company purchased a laser welder and a 5-axis CNC, incumbent workers received training on the machines, and the company gave them liberty to figure out how they could best integrate them onto the shop floor. The CEO has also emphasized the data the firm has collected on their manufacturing process, which they plan to use to manage run-times on machines. The firm is working toward a real-time analysis of their production speed with monitors on the shop floor.

iii. Hypotheses about Exceptional Firms

Given the small number of exceptional firms in the sample, the evidence from these interviews is too sparse to build a comprehensive theory explaining the differences between outlier cases and the more typical firms' experiences with the manufacturing workforce. However, there appear to be several factors that differentiate the exceptional firms in the sample from more typical firms that continue to face workforce challenges. These factors are worth considering in future research, as well as in developing HR strategies that could help firms overcome the workforce challenges that they face.

The first factor is technology. Exceptional firms in the sample were far more likely to be technologically advanced than their peers. This evidence suggests – but does not confirm – that more engaged HR practices such as systematic on-the-job training and worker autonomy is associated with the adoption of new technologies. This is surprising given the widespread "skills gap hypothesis," which suggests that U.S. manufacturing has invested in new technology without investing in skill development. Investments in advanced technology might seem obvious for startup firms, which do not have legacy technology to replace. Survivor firms with workforce

partnerships are also more technologically advanced than their peer firms. As the examples suggest, some of the innovative HR strategies at these firms have been linked to – or at least coincided with – the acquisition of new capital equipment.

The interviews suggest two hypotheses about how technology could change how these firms approach their workforce. One possibility is that new technologies lead these firms to expect more creativity and flexibility from their workers because they have to figure out how to use new tools on the factory floor. Firms acquiring new technologies are expecting their workers to become more productive – and perhaps, although we don't have the data from the interview firms – could pay them more as a result. The second hypothesis is that more technologically sophisticated companies could be more attractive to motivated workers with good problem-solving skills. These workers might be more likely to select into firms like the outliers than firms that lag behind the technology curve.

The second factor is risk. One potential explanation for the difference in HR behaviors between typical and exceptional firms is that executives at exceptional firms are more tolerant of risk. This hypothesis would explain the association between technology acquisition and HR strategies. It would also explain why startup manufacturers in the sample – which took an outsized risk merely by opening their doors after the dramatic decline of U.S. manufacturing – have almost universally adopted innovative HR strategies. An alternative explanation is that exceptional firms have adopted different strategies of managing risk – they are not inherently more risk tolerant. Startup firms, for example, can adopt innovative HR strategies at a lower cost than typical firms because they do not have established practices that they must change in order to experiment with more worker autonomy or a modular factory. Given evidence that organizations are loss averse, startup firms are better positioned to adopt strategies that might

appear risky to an established firm. When survivor firms build workforce partnerships, they are adopting strategies that share the risk and cost across organizations. In the case of the cooperative apprenticeship program, peer companies of sharing the cost and the risk of investing in incumbent workers. In the case of companies building a reliable recruiting pipeline with a local vocational school, they are offloading some of the cost and risk to a third party.

V. Concluding Remarks

Future research can test these hypotheses in several ways. One direction would be to compare the workforce practices of SME manufacturers with similar technology profiles. This research would build on studies from the 1990s, which examine the variation in how firms changed their HRM strategies, conditional on adopting new technologies or operational processes. Comparative studies of individual plants or larger surveys could isolate how new technologies changed firms' expectations of their workforces, as well as the tasks that they were expected to perform. Such research should be careful to measure and account for how these firms evaluate risk. A company with advanced technology, but low risk tolerance could adopt more conservative HRM practices.

A second direction for future research would be to study individual companies over time, tracing how their behaviors change as they adopt new technologies, win new business, and hire new workers. This research would require building a longitudinal dataset of firm behaviors, which is time and resource intensive, but the benefit would be a broader perspective on how firms adopt and deploy HRM strategies in response to different conditions, such as a new machine purchase or a large new order. In each of these cases, a longitudinal dataset could test

the expectations of the hypotheses above, evaluating when firms react to new business environments as expected – and when they make surprising decisions.