



The Work of the Future:

Shaping Technology and Institutions

FALL 2019 REPORT





MIT TASK FORCE ON THE WORK OF THE FUTURE

MIT President Rafael Reif convened the MIT Task Force on the Work of the Future in the spring of 2018. Its goals are to understand the relationships between emerging technologies and work, and to explore strategies to enable a future of shared prosperity. The Task Force is co-chaired by Professors David Autor and David Mindell, with Dr. Elisabeth Reynolds as Executive Director; its members include more than twenty faculty drawn from twelve departments, as well as a dozen graduate students. The Task Force has also been advised by boards of key stakeholders from industry, academia, education, labor and philanthropy. For the past year, the Task Force has been working to bring grounded, empirical understanding and insight into the ongoing debate about what is occurring today and what we can expect in the next decade.

Alarmist rhetoric animates today's public conversation about technology and work: *Robots are taking our jobs. AI will mean the end of work. Three-fourths of all jobs will be automated. Prepare for mass unemployment. Robots can't take your job if you're retired.*

These forecasts may be unduly grim, but they reflect valid underlying concerns. Technological and economic shifts have created social pain in wide swaths of industrialized economies. The last four decades of U.S. history showed that even if technological advances deliver rising productivity, there is no guarantee that the fruits of this bounty will reach the typical worker—and the uncertainty is greater still for women and minorities. These discouraging facts may help to explain why, despite the tightest U.S. labor market in decades, a substantial majority of people believe that emerging technologies will magnify inequality and make high-paying jobs harder to find.

With these uncomfortable truths in mind, MIT's Task Force on the Work of the Future aims to identify a constructive path forward—grounded in evidence of what is happening today, deploying deep expertise in technology and the social sciences, and applying reasonable assumptions and extrapolations to anticipate what might happen tomorrow.

This report will not provide definitive answers, but instead aims to enable decision-makers to ask the right questions. Due to the urgency of the topic, we offer preliminary insights that may help to frame public debate and public policy as Task Force members conduct deeper analyses and deliver a final report.

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INTRODUCTION

Technological change has been reshaping human life and work for centuries. The mechanization that began with the Industrial Revolution enabled dramatic improvements in human health, well-being, and quality of life—not only in the developed countries of the West, but increasingly throughout the world. At the same time, economic and social disruptions often accompanied those changes, with painful and lasting results for workers, their families, and communities. Along the way, valuable skills, industries, and ways of life were lost. Ultimately new and unforeseen occupations, industries, and amenities took their place. But the benefits of these upheavals often took decades to arrive. And the eventual beneficiaries were not necessarily those who bore the initial costs.

The world now stands on the cusp of a technological revolution in artificial intelligence and robotics that may prove as transformative for economic growth and human potential as were electrification, mass production, and electronic telecommunications in their eras. New and emerging technologies will raise aggregate economic output and boost the wealth of nations. Will these developments enable people to attain higher living standards, better working conditions, greater economic security, and improved health and longevity? The answers to these questions are not predetermined. They depend upon the institutions, investments, and policies that we deploy to harness the opportunities and confront the challenges posed by this new era.

How can we move beyond unhelpful prognostications about the supposed end of work and toward insights that will enable policymakers, businesses, and people to better navigate the disruptions that are coming and underway? What lessons should we take from previous epochs of rapid technological change? How is it different this time? And how can we strengthen institutions, make investments, and forge policies to ensure that the labor market of the 21st century enables workers to contribute and succeed?

To help answer these questions, and to provide a framework for the Task Force's efforts over the next year, this report examines several aspects of the interaction between work and technology. We begin in Section 1 by stating an underlying premise of our project: work is intrinsically valuable to individuals and to society as a whole, and we should seek to improve rather than eliminate it. The second section introduces the broader concerns that motivated the Task Force's formation. Here we address a paradox: despite a decade of low unemployment and generally rising prosperity in the United States and industrialized countries, public discourse around the subject of technology and work is deeply pessimistic. We argue that this pessimism is neither misguided nor uninformed, but rather a reflection of a decades-long disconnect between rising productivity and stagnant incomes for the majority of workers.

In Section 3, we provide some historical perspective on the relationship between technological change and work. This enables us in Section 4 to address what we believe is distinctive about the current era.

Section 5 presents our framing of how the current digital age—specifically, automation, robotics, and artificial intelligence—are affecting the modern workplace and altering skill demands and job opportunities for current and future workers. Armed with this perspective, Section 6 turns to the subject of potential policy responses, identifying four broad areas, in addition to education and training, where we believe forward-looking investments, institutions, and incentives could help shape the future of work to generate greater economic security for workers, higher productivity for firms, and broader opportunity for all members of society. Developing these ideas in more detail will be the major focus of the Task Force’s next efforts that will culminate in a final report.

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1. WHY WE SHOULD CARE ABOUT THE WORK OF THE FUTURE

Work has meaning and importance, for individuals and for society as a whole, that transcend the merely economic or financial. Work is a central human activity, critical to self-realization and social cohesion.

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Countries that productively employ the great majority of their people are better off for it.¹

Work enables people to achieve self-sufficiency, support families, contribute to broader communities, and raise children prepared to do the same.² Through work, people apply their capacities to public and private endeavors, provide for others through their own generosity, and save for an uncertain future. Workers fund public goods through their tax payments and contribute toward the claims they will make during infirmity or retirement. A society is unhealthy when all material needs are met by the state with no reciprocal contribution, or when most people live off the surplus provided by a sliver of ultra-wealthy workers and capital owners.

Of course, not all work is good work: witness the horrendous legacies of slavery, indentured servitude, and child labor, enduring race and gender discrimination, and dangerous, exploitive, and demeaning work today. Nevertheless, the economic history of the 20th century shows that a healthy labor market can serve as the foundation, if not the entire basis, for shared prosperity.

Because work provides, in the best case, purpose, community, and esteem to those who engage in it, we must address not only the number of jobs available to future workers, but also the quality of those jobs. How can we strengthen and build institutions, make investments, and forge policies that ensure that work remains a rewarding and economically viable avenue for most adults to prosper?

2. THE PARADOX OF THE PRESENT

The industrialized world is undergoing rapid employment growth. A May 2019 cover story in the *Economist* magazine declared that “most of the rich world is enjoying a jobs boom of unprecedented scope.” Nonetheless people throughout the industrialized world are pessimistic about the future of work. In 2018, the Pew Research Center found that between 65 and 90 percent of those surveyed in advanced economies believe that robots and computers will probably or definitely take over many jobs now done by humans.³

The possibility that machines may eliminate jobs is not bad news if these technologies deliver higher living standards.⁴ But the Pew survey makes clear that people do not expect to benefit: most people believe that automation will greatly exacerbate inequality between rich and poor while making jobs harder to find. Less than one third of those surveyed believe that new, better-paying jobs will emerge.⁵

Why, after a decade of rising employment, are people pessimistic about job prospects? One possibility is that the avalanche of alarmist “end of work” newspaper articles, books, and expert reports have overwhelmed the facts. Perhaps, in the words of the *Economist*, “the zeitgeist has lost touch with the data.”

Alternatively, public pessimism may reflect the hard-learned lessons of recent history. People may worry that the introduction of new technologies with human-like capabilities will generate enormous wealth for a minority while diminishing opportunity, upward mobility, and shared prosperity for the rest of us.

Economic history confirms that this sentiment is neither ill-informed nor misguided. There *is* ample reason for concern about whether technological advances will improve or erode employment and earnings prospects for the bulk of the workforce.⁶

New and emerging technologies *will* raise aggregate economic output and boost the wealth of nations. Accordingly, they offer the *potential* for people to realize higher living standards, better working conditions, greater economic security, and improved health and longevity.

But whether nations and their populations realize this potential depends on the institutions of governance, societal investment, education, law, and public and private leadership to transform aggregate wealth into greater shared prosperity instead of rising inequality. By taking bold actions to invest in its people, lead in innovation, and protect and augment workers, the United States can cultivate this historic opportunity to generate broadly shared prosperity.

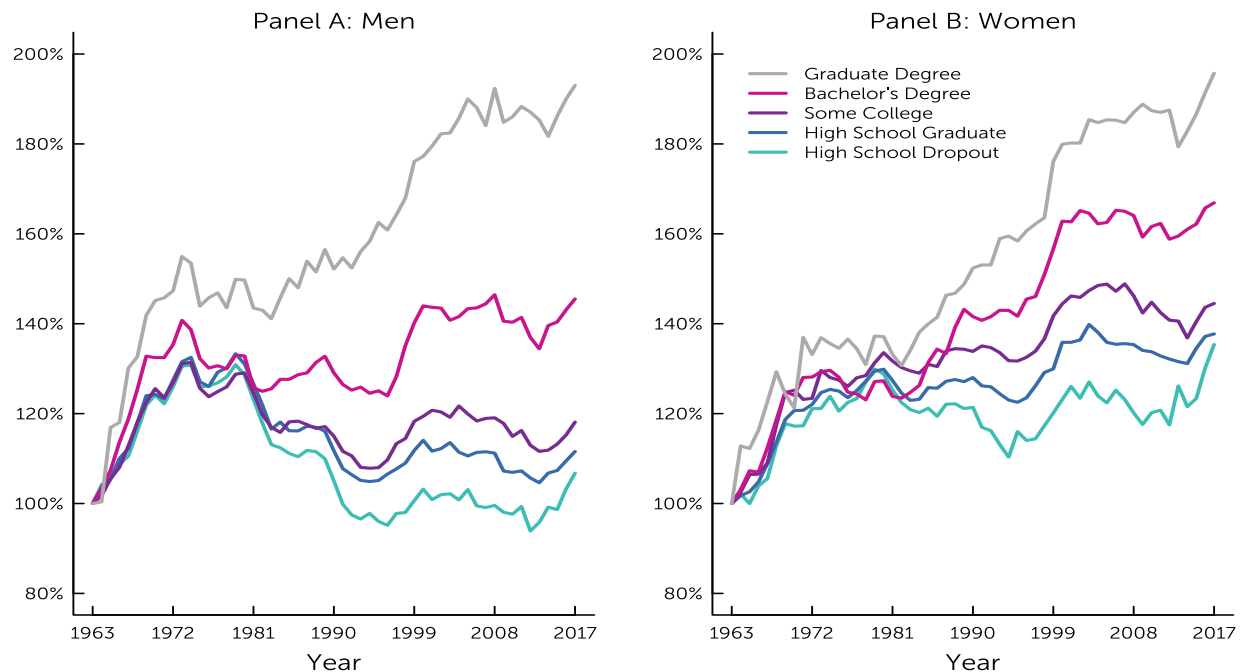
The basis for our argument rests on four empirical pillars evidenced below:

1. *A firm foundation:* In the postwar decades between 1940 and 1980, rapid technological advances and well-functioning institutions in the United States delivered rising productivity and rapid, relatively evenly distributed wage gains to the vast majority of workers. This history provides a case for optimism.
2. *The case for concern:* This virtuous dynamic broke down in the decades from 1980 to the present. During this period, even though wage growth tracked productivity growth *on average*, the distribution of gains was so highly skewed that earnings for the typical (median) worker stagnated. Only those workers with four-year college and graduate degrees saw sustained earnings growth.
3. *The case against fatalism:* The failure of the U.S. labor market to deliver broadly shared earnings gains despite rising productivity was not an inevitable byproduct of current technologies or free markets. Countries shape their trajectories of productivity growth and income distribution through their educational systems, labor market regulations, collective bargaining regimes, financial markets, public investments, and tax and transfer policies. Industrialized countries with access to comparable technologies, skills, and trading opportunities as the United States—including Germany, Canada, Japan, Korea, and the U.K.—distributed the gains from rising productivity far more equally than the United States without sacrificing economic growth or reducing the odds that children rise from “rags to riches.”⁷
4. *The case for investing in job **quality** not job **quantity**:* Contrary to the conventional narrative in which automation renders jobs increasingly scarce, we anticipate that, due to slowing labor force growth rates, rising ratios of retirees to workers, and increasingly restrictive immigration policies, over the next two decades industrialized countries will be grappling with more job openings than able-bodied adults to fill them. While these demographic changes herald many fiscal, social, and generational challenges, they also offer opportunities: countries that make well-targeted, forward-looking investments in education and skills training should be able to deliver jobs with favorable earnings and employment security to the vast majority of their workers—and not exclusively to those with elite educations.

2.1 A Firm Foundation

Starting in the 1960s and continuing through the early 1980s, earnings grew for U.S. workers of both sexes, regardless of education, as shown in Figure 1. In fact, the U.S. economy delivered stellar and broadly shared growth in the preceding two decades as well, from the end of World War II through 1963. This growth in earnings was both rapid and evenly distributed: a remarkable 92 percent of children born in 1940 earned more than their parents in adulthood.⁸

Figure 1: Cumulative Change in Real Weekly Earnings of Working-Age Adults Ages 18-64



Source: Autor (2019, Figure 1). Series are calculated from March Current Population Survey Annual Social and Economic Supplement data for earnings years 1963 to 2018. Each series depicts the percentage change in real hourly earnings relative to its value in 1963 for the indicated education and sex group.

This progress would not have been possible, however, without sustained, rapid growth in productivity.⁹ Between 1940 and 1980, productivity growth in the U.S. economy averaged almost 2 percent annually, the steepest rate of growth for any sustained period in U.S. history.¹⁰

Where did this productivity come from? MIT Economist and Nobel Laureate Robert Solow showed that it was almost entirely due to technological progress: improvements in tools, techniques, and organizational practices allowed businesses, households, and government to accomplish more and better work.¹¹

Productivity growth, however, is a necessary but not sufficient force for broadly shared economic gains. The parallel movement of productivity and compensation in this period reflected, in part, the success of collective bargaining in tying wage increases to rising economic fortunes.¹²

Those four decades of U.S. economic history tell an encouraging story: technological progress feeds a rising tide of productivity, a tide that can lift all economic boats. That history also raises an urgent question: if productivity growth yields rising living standards, and if automation abets productivity, shouldn't we welcome new technologies that fuel this virtuous cycle?

2.2 The Case for Concern

Contemporary concerns originate in the decades starting in 1980. As compared to the earlier period, earnings growth in the past forty years has been slow, sporadic, and unequal. Figure 1 shows that real earnings rose robustly between 1980 and 2017 among the most-educated adults, those with college and post-college degrees. But during the same period, earnings fell steeply among adults without college degrees. Even worse, among men without college degrees working full time, real weekly earnings in 2018 were actually 10 to 20 percent *below* their levels in 1980, nearly four decades earlier.¹³

This stagnation of earnings hit minority workers particularly hard. Between 1980 and 2015, the gap between black and white workers' earnings (27 percent in 1980), failed to close by even one percent. Meanwhile, the gap between Hispanic and white earnings *expanded*, from 29 percent in 1980 to 31 percent in 1990. Earnings of women of all races and ethnicities grew closer to that of white men during these years, but the gains were much greater for white women than for either black or Hispanic women.¹⁴

Rising inequality also played out across *places*. The United States has seen steeply rising income levels and bustling prosperity over the past three decades in superstar cities such as New York, San Francisco, and Los Angeles. Highly educated workers are attracted to such knowledge centers because of job opportunities as well as higher wages. Indeed, in contrast to predictions about the “death of distance” due to the Internet and telecommunications technology, urban areas have become more, not less attractive, leading to increasing divergence in the economic fortunes of urban vs. rural and younger vs. older areas. Some mid-size cities such as Kansas City, Columbus, Charlotte, and Nashville have also benefited from the knowledge economy while leveraging their relative affordability.¹⁵

Even as these and similar cities have boomed, the robust urban wage premium that non-college-educated workers enjoyed in these locations has sharply diminished. U.S. cities used to offer an economic escalator to workers of all backgrounds. For less-educated workers, it is no longer clear that this escalator still works.

Even in the wealthiest U.S. cities, the workforce is increasingly bifurcated. On one hand, high-wage professionals enjoy the amenities that thriving urban areas can offer. On the other hand, an underclass of less educated service workers gets by with diminishing purchasing power while attending to the care, comfort, and convenience of the more affluent.¹⁶ These problems plague the best-off places in America.

Elsewhere, in many once-thriving metropolitan areas in states from Mississippi to Michigan, the situation is even more distressing. We see economic stagnation, declining employment of adults in their prime working years, and high rates of physical disability. In these places, opioid abuse and declining life expectancy are but two indicators of communities in acute economic and social distress.¹⁷

Despite these problems, the U.S. is currently in its longest sustained economic expansion in its history—approaching a full decade. Nonetheless, the persistent growth in the *quantity* of jobs has not correlated to an equivalent growth in the *quality* of jobs for the majority of workers.¹⁸

In the U.S. and throughout the industrialized world, employment is *polarizing*. At the top end, high-education, high-wage occupations offer strong career prospects and rising lifetime earnings. At the other end, low-education, low-wage occupations provide little economic security and limited career earnings growth.¹⁹ As a result, the pathways to economically stable and secure careers for workers without college degrees are becoming narrower and more precarious. Simply put: we see no shortage of good *careers* for highly educated workers. And we see no shortage of *jobs* for less educated workers. But we do find a paucity of good careers for workers without significant post-secondary training—strong technical or vocational training, associates degree level certification in a credentialed field, or attainment of a traditional four-year college or graduate degree.

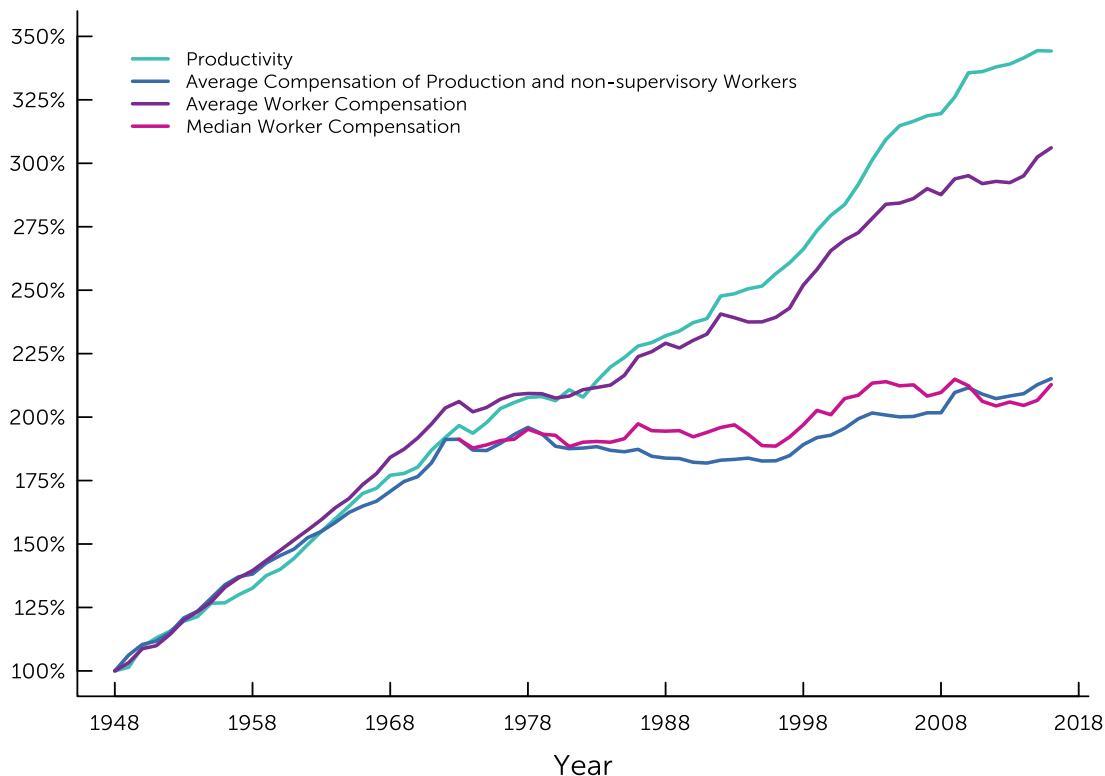
Why, for the vast majority of workers, have the most recent four decades of economic history failed to deliver on the promise of the prior four?

One possible explanation is that recent productivity growth simply fell short of earlier decades, leaving little room for sustained increases in living standards. Figure 2 shows that labor productivity growth did decelerate after the mid-1970s (a point that we return to below).²⁰ But more dramatic is the growing disconnect between the earnings growth of the typical worker and the growth in productivity.

From the end of the Second World War to 1973, the earnings of the typical worker rose in lockstep with productivity, both of which nearly doubled over the course of three decades. After that time, they diverged. Between 1973 and 2016, labor productivity rose by a healthy 75 percent, yet the compensation of workers rose by only 12 percent, and the compensation of the median worker rose by only 11 percent.²¹

We see no shortage of good careers for highly educated workers. And we see no shortage of jobs for less educated workers. But we find a paucity of good careers for workers without significant post-secondary training.

Figure 2: Changes in Labor Productivity and Compensation, 1948–2016



Source: Stansbury and Summers (2018, Figures 1 and 2). Note: Data from BLS, BEA, and Economic Policy Institute. Labor productivity is total economy real output per hour, average compensation is total economy real compensation per hour, deflated by CPI-U-RS, median compensation is median economy real compensation per hour, deflated by CPI-U-RS, and Productivity is real compensation per hour for production and nonsupervisory workers, deflated by CPI-U-RS. The chart depicts the percent change in each series from its value in 1948 for all series except median compensation. The median compensation series starts in 1973 and is normalized to equal the average compensation of production and non-supervisory workers in that year.

Why didn't this productivity growth translate into wage growth for the typical worker? In fact, workers did *on average* share in the productivity gains. But the distribution of gains around the average was so unequal—so skewed towards the top—that the median worker saw almost none of the bounty.

Several forces contributed to this skew. Computers and the Internet enabled a digitalization of work that made highly-educated workers more productive and made less-educated workers easier to replace with machinery.²² Trade also played a key role: spurred by surging U.S. imports from China and rapid outsourcing of U.S. production work to China, blue-collar manufacturing

employment rapidly declined in the United States, falling by one third between 1999 and 2010.²³ Weakened by plummeting labor union membership and falling real federal minimum wage levels, rank and file workers were less able to bargain for wage growth to match productivity growth.²⁴

We noted above that more than nine out of ten children born in 1940 surpassed their parents' earnings in adulthood. Among children born in 1980, four decades later, this rate was a mere five out of ten.

Had economic growth been as evenly distributed among households between 1980 and 2010 as it was in the three post-War decades (even at the slower post-1980 rate of economic growth) much of this stagnation of intergenerational mobility would have been reversed.²⁵ Thus, technological advances did deliver productivity growth over the last four decades. But productivity growth did not translate into shared prosperity, but rather into employment polarization and rising inequality.

The failure of the U.S. labor market over the last four decades to deliver broadly shared prosperity despite rising productivity is not an inevitable byproduct of current technologies nor of free markets.

Public concern about the future of work is neither ill-informed nor misguided. The last four decades of economic history show that technological progress will likely deliver rising productivity, but there is no certainty that the fruits of this bounty will reach the typical worker. The uncertainty is greater still for women and minorities.

2.3 The Case Against Fatalism

The failure of the U.S. labor market over the last four decades to deliver broadly shared prosperity despite rising productivity is not an inevitable byproduct of current technologies nor of free markets. Technologies and markets alone do not determine inequality or economic mobility. Public and private institutions all play critical roles: these include educational systems, labor market regulations, collective bargaining regimes, financial markets, public investments, and tax and transfer policies.

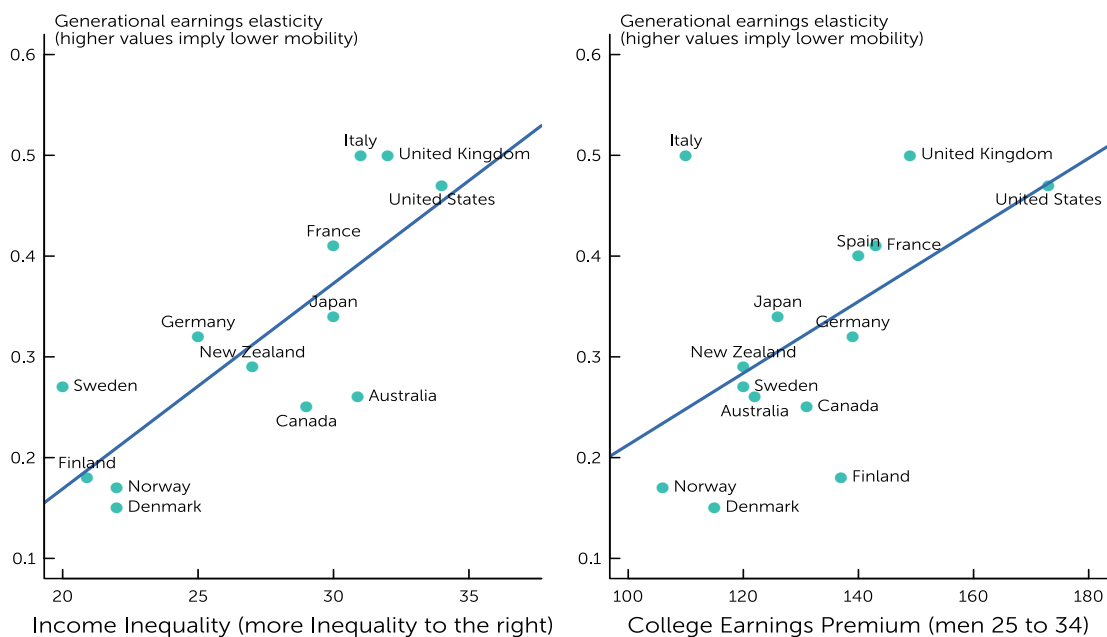
In fact, other economies with access to the same technologies—Germany, Switzerland, Japan, Canada, Korea, Sweden, and the U.K.—have realized comparable productivity growth per worker without suffering the same stagnation of incomes or increase in inequality.²⁶ Almost all developed countries have experienced job polarization, widening income distributions, and contraction of traditional manufacturing. But most have done more than the United States to

counter these undercurrents by investing in worker skills, strengthening social safety nets where needed, and incentivizing private-sector firms to augment labor rather than simply displace it.²⁷

To illustrate, Figure 3 compares inequality among developed market economies along two dimensions: overall inequality of earnings among workers (the so-called Gini coefficient) and the ratio of hourly earnings for college-educated workers to earnings for non-college workers. Among its peers, the United States stands out for its extremes of rich and poor. Indeed, to locate another large country with greater inequality, one must expand the set to include less-developed nations such as Brazil.

One might counter that high inequality and accompanying economic dynamism mean that U.S. children face better odds of ascending the economic ladder over their lifetime. Figure 3 dispels this notion by comparing rates of intergenerational mobility—that is, the odds that a child will rise from “rags to riches” over the course of a generation—across countries. It shows that the United States now has one of the *lowest* rates of intergenerational mobility among wealthy democratic countries. The likelihood that a child born to parents in the bottom fifth of the income distribution reaches the top fifth in adulthood is actually about twice as high in Canada (13.5 percent) as in the United States (7.5 percent).²⁸

Figure 3: Earnings in Inequality and Economic Mobility: Cross-National Relationships



Source: Autor (2014, Figure 5) reproduced from Corak (2013) with permission of the American Economic Association. Note: In both panels, the mobility measure is equal to the intergenerational earnings 'elasticity,' meaning the average proportional increase in a son's adult earnings predicted by his father's adult earnings measured approximately three decades earlier. A higher intergenerational earnings elasticity therefore implies lower intergenerational mobility. In the left panel, cross-sectional income inequality is measured using a 'Gini' index that ranges from 0 to 100, where 0 indicates complete equality of household incomes and 100 indicates maximal inequality (all income to one household). In the right panel, the college earnings premium refers to the ratio of average earnings of men 25 to 34 years of age with a college degree to the average earnings of those with a high school diploma, computed by the OECD using 2009 data.

This has not always been the case.²⁹ In fact, America's cherished view of itself as the preeminent "land of opportunity" is rooted in a longer history of responding to new technologies by increasing investments in people and education. By the late 19th century, for example, Americans recognized that farm employment was declining, industry was rising, and children would need different skills to earn a living. In 1900, the typical young, native-born American had only a common school education, about the equivalent of six to eight grades.³⁰ Over the first four decades of the 20th century the United States became the first nation in the world to deliver universal high school education to its people. This movement was led by the farm states, which were experiencing both the economic bounty and the occupational disruption that accompanied agricultural mechanization.³¹

2.4 Investing in Job Quality not Job Quantity

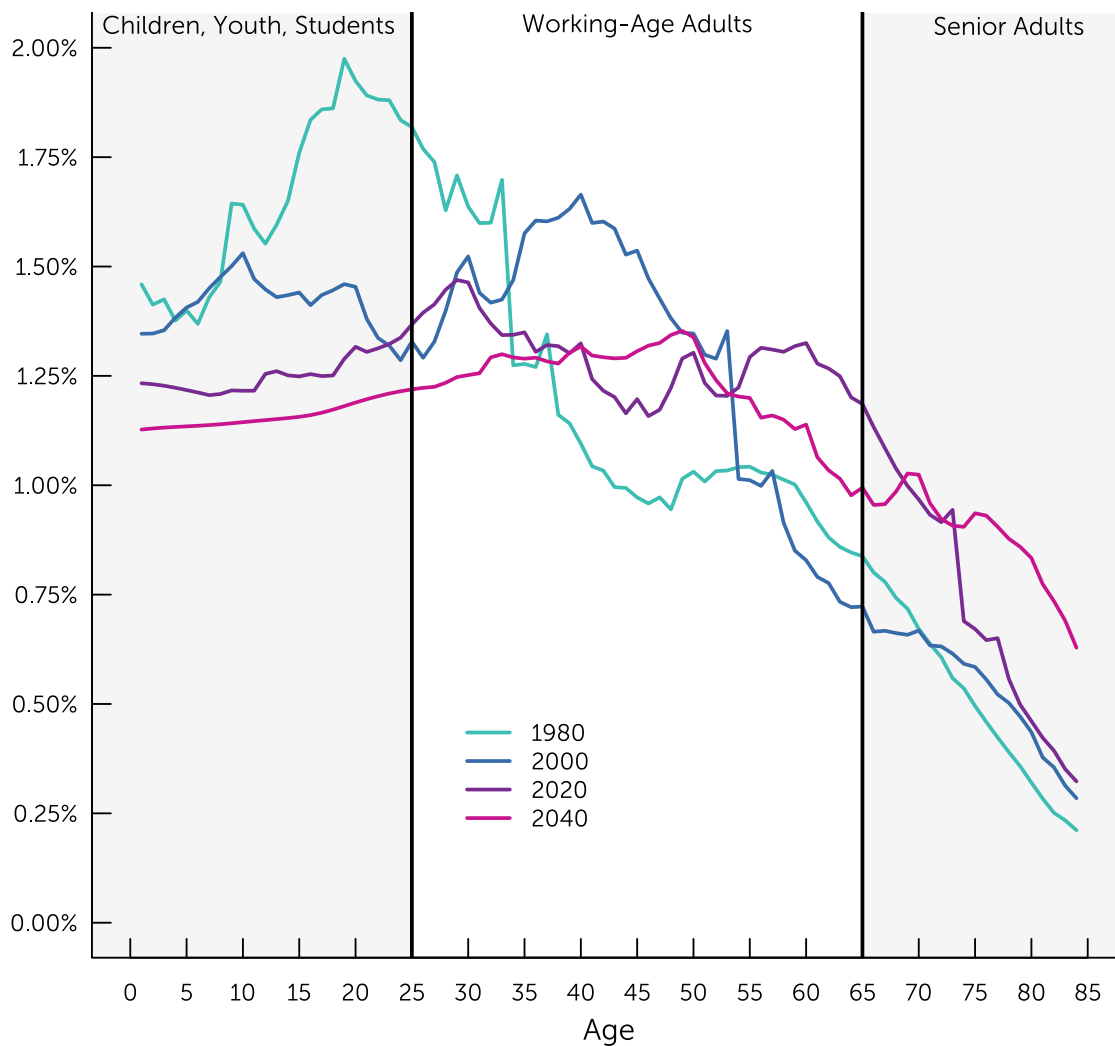
We noted above that we are less concerned about the *quantity* of jobs than their *quality*. Given popular discussion of the end of work, this may seem cavalier. But demographic trends point towards rising labor scarcity in the decades ahead.³²

In the United States and most other industrialized countries, the growth of the labor force has slowed over the past two decades due to declining fertility and increasingly restrictive immigration policies.³³ Between 1996 and 2006, the growth rate of the U.S. labor force averaged 1.2 percent per year. In the following decade, it fell to 0.5 percent per year and is projected to continue at essentially the same rate between 2016 and 2026.³⁴

Since labor force growth primarily stems from young people reaching working age, this slowdown implies an aging labor force. The Bureau of Labor Statistics projects that the share of U.S. workers age 55 and over will rise from 16.8 to 24.8 percent between 2006 and 2026, while the share considered prime age (ages 25 to 54) and young (ages 16 to 24) will fall by 5 and 3 percentage points respectively. Figure 4 illustrates the dramatic and still unfolding shift in the age distribution of the U.S. population between 1980 and 2040 (projected).³⁵

We anticipate that in the next two decades industrialized countries will have more job openings than workers to fill them, and that robotics and automation will play an increasingly crucial role in closing these gaps

Figure 4: The Working-Age Share of the U.S. Population is Contracting



Note: Figure reports the percent of U.S. residents in each age group in the indicated years. Individuals above 85 are included in the total but not pictured in the chart. Series for 2020 and 2040 are based on population projections.
Source: U.S. Census Bureau | International Programs | International Data Base Revised: September 18, 2018
Version: Data:18.0822 Code:12.0321

As labor force growth has slowed, the educational attainment of entering cohorts of workers has rapidly risen.³⁶ In the decade between 2007 and 2017, for example, the share of U.S. adults ages 25 to 29 with a high school diploma rose from 87.0 to 92.5 percent, while the share with at least a four-year college degree grew from 29.6 to 35.7 percent. These are dramatic changes in a short time interval, and they augur positive news for future productivity and earnings growth. But they also mean that a shrinking fraction of labor market entrants is likely to seek work in traditional non-college occupations, while a rising fraction will enter professional, technical, and managerial positions.

Slow labor force growth, increasing scarcity of young workers, and rapidly rising educational attainment will coincide with an expanding senior population with attendant health and personal care needs. This combination will strain employers' ability to recruit able-bodied young adults to replace retirees in manual, blue-collar, personal care, and other in-person service occupations.³⁷ In the conventional narrative, automation renders jobs increasingly scarce. By contrast, we anticipate that in the next two decades industrialized countries will have more job openings than workers to fill them, and that robotics and automation will play an increasingly crucial role in closing these gaps.³⁸ While this scenario may seem speculative, one need look no further than contemporary Japan to see that rapid population aging generates severe labor scarcity and intense pressure for automation.³⁹

These demographic shifts will impose steep burdens on national budgets as the ratio of retirees to workers rises and as the growth rate of working-age taxpayers slows. But these shifts also offer an opportunity: countries that make well-targeted, forward-looking investments in education and skills training should be able to deliver middle-skill jobs with favorable earnings and employment security to the vast majority of their workers—and not exclusively to those with elite educations.

3. TECHNOLOGY AND WORK: A FRAUGHT HISTORY

Over the past two centuries, transformative innovations such as the internal combustion engine, electricity, and telecommunications, among many others, improved quality of life, raised productivity and earnings; made work less dirty, dangerous, physically punishing, and dull; and increased the value of thinking, creativity, and expertise. Productivity gains enabled by new technology generated wealth that eventually reduced the hours that people worked per day, per week, and per year; spared young people the burden of laboring during childhood so they could develop skills in the schoolhouse; and made it possible for adults to retire while still in good health.

But even the most beneficial technological advances also spurred painful labor market adjustments: devaluing specific skill sets (e.g., artisanal skills in sewing, weaving, typesetting), eclipsing certain occupations (blacksmiths, switchboard operators), and largely eliminating entire industries (e.g., chemical photography, candle-making). In the 19th century, machine tools displaced skilled craftsmen, mechanized farming displaced masses of agricultural workers, and typewriters displaced scribes. In the 20th century, “talking” motion pictures displaced musicians in movie theaters, electric relays displaced elevator operators, and software displaced flight engineers in airplane cockpits.

For workers who were displaced, these disruptions inflicted personal and social as well as economic pain—sometimes with repercussions that lasted generations. They also prompted ongoing debates about the risks and benefits of new technology.⁴⁰ Ultimately new and unforeseen occupations, industries, and amenities emerged. But the benefits of these upheavals often took decades to arrive. And the eventual beneficiaries were not necessarily those who bore the initial costs.

In today’s conversation, innumerable expert reports and news articles offer alarming forecasts about what share of current jobs may be “affected” by new technologies such as AI and robotics.⁴¹ While such forecasts grab headlines, they provide limited actionable information. All jobs will be affected, directly or indirectly, by these technologies.

The question that concerns us is: What do these job changes imply for employment prospects, earnings, and career trajectories of workers with different skills and resources? And: How do we manage this process to improve work opportunities broadly?

To move beyond a simplistic focus on counting potentially affected jobs, a useful starting point is to look closely at the distinct mechanisms through which automation changes human work. This process operates through three distinct but related channels: substitution, complementarity, and new task creation. Of these three, only the first (substitution) is generally recognized in popular discussions—which we believe leads to undue pessimism.

Automation at its most basic level serves to *substitute* for workers in performing a subset of work tasks, often those that involve physically demanding, repetitive, and rote activities, e.g., equipping ditch diggers with mechanical excavators. This process raises productivity and generally leaves workers with safer and more interesting jobs. But displacement is not innocuous. When industrial textile machinery displaced rural spinners, lace workers, and handloom weavers in 19th century England, the shift was a boon to productivity and consumers but a serious and enduring hardship for rural textile workers.⁴²

Substitution is less than half the story, however (and indeed machines rarely substitute for human workers one-for-one).⁴³ Frequently, automation *complements* the cognitive and creative capabilities of workers. Architects using Computer Aided Design (CAD) software, for instance, can design more complex buildings faster than they can with paper drawing. Machinery raises the value of human expertise in developing and guiding complex production processes and provides tools that enable people to turn their ideas into products and services.⁴⁴ Automation magnifies the power of ideas by shortening the distance from conception to realization. Over time, automation has profoundly shifted the comparative advantage of human labor from the physical to the cognitive domain, and this has gradually but inexorably raised the formal reasoning demands and educational requirements of most jobs.⁴⁵

If work were static, this would be the end of the story. But new technologies often enable or require new tasks that demand human expertise, judgment, and creativity.⁴⁶ In the 19th century, for example, advances in metalworking and the spread of electrification created new demand for telegraph workers, managers, and electrical engineers.⁴⁷ In the 20th century, even as agricultural machinery was displacing farm workers, changes wrought by mechanization and rising incomes generated new employment in factories, offices, medicine, and finance.⁴⁸ In the 21st century, as computers and software have displaced workers performing repetitive tasks, they have simultaneously created new opportunities in novel, cognitively intensive work such as designing, programming, and maintaining sophisticated machines, analyzing data, and many others.⁴⁹

How recent, rapid progress in robotics, artificial intelligence, and machine learning might be shaping the path of complementarity, substitution, and new task creation in the digital age is the subject of the Section 5. Before that exploration, we consider what has made the last four decades so different from the four that preceded them.

New technologies often enable or require new tasks that demand human expertise, judgment, and creativity.

4. IS THIS TIME DIFFERENT?

In prior eras, mechanization and automation eliminated much undesirable work, while creating substantial new and more desirable work, and simultaneously raising productivity and enabling higher living standards.⁵⁰ Does the current era of digital technologies possess these same virtues—or is it different this time?⁵¹ In our assessment, the current era is different in two respects: employment polarization and ‘so-so’ technologies.⁵²

4.1 Employment Polarization

A first distinction between past and present is in how digital technologies reshape the division of labor between people and machines.

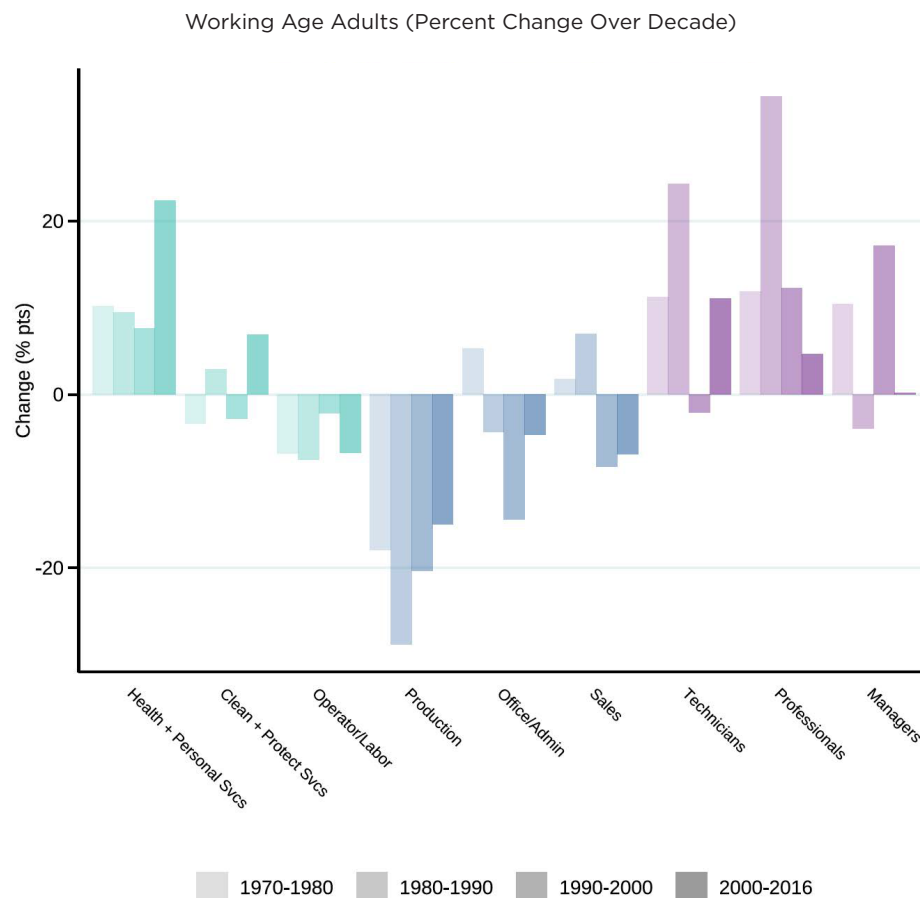
The era of mass production created vast new earnings opportunities for blue-collar workers in factories and businesses, while simultaneously opening new vistas for skilled workers in white-collar work and the professions. As did earlier waves of automation, the current era of digitalization also complements highly-educated workers possessing expertise, judgment, and creativity.

But in contrast to earlier eras, digital automation tends to displace *middle-skill* workers performing routine codifiable tasks, such as sales, office and administrative support, and production, craft and repair occupations. Figure 5 shows that in 1970, these middle-skill occupations accounted for more than a third (38 percent) of employment. By 2016, this share had fallen to less than one-quarter (23 percent) of employment. To be clear, this decline is not due solely to digitalization, as international trade added substantially to the displacement of middle-skill production and operative jobs during the 2000s.⁵³

Ironically, digitalization has had the smallest impact on the tasks of workers in low-paid manual and service jobs. Those positions demand physical dexterity, visual recognition, face-to-face communications, and situational adaptability. Such abilities remain largely out of reach of current hardware and software but are readily accomplished by adults with moderate levels of education.⁵⁴ As middle-skill occupations have declined, manual and service occupations have become an increasingly central job category for those with high school or lower education.

Thus, unlike the era of equitable growth that preceded it, the digital era has catalyzed labor market polarization—that is the simultaneous growth of high-education, high-wage and low-education, low-wage jobs at the expense of middle-skill jobs. (Figure 3).⁵⁵ This lopsided growth has concentrated labor market rewards among the most skilled and highly-educated workers while devaluing much of the non-specialized work that remains. This imbalance contributes to the vast divergence of earnings between college- and non-college-educated workers in recent decades (Figure 1).⁵⁶

Figure 5: Changes in Occupational Employment Shares, 1970–2016



Source: Autor (2019, Figure 3). Note: Series are calculated from March Current Population Survey Annual Social and Economic Supplement data for earnings years 1970 to 2016. The sample consists of civilians age 16–64 who reported working at least one week in the earnings year. Occupational share for a given occupation is hours worked in that occupation divided by total hours worked in that earnings year, where hours for each individual consists of the number of weeks worked last year times the usual hours worked per week. Each bar corresponds to the decadal average change in the share of hours worked in each occupational category over the indicated time interval.

The digital era has catalyzed labor market polarization—that is the simultaneous growth of high-education high-wage and low-education/low-wage jobs at the expense of middle-skill jobs.

4.2 ‘So-So’ Technologies

A second key difference between the era of digitalization and earlier eras is that digitalization has *not* delivered the same gains in productivity. While productivity growth was not as rapid between 1975 and 2005 as during the first three decades after World War II, it was consistent with the prevailing prewar trend. By contrast, it has been remarkably sluggish since the mid-2000s, both in the United States and the European Union.⁵⁷

How do we reconcile this lackluster growth with the dazzling new technologies we see around us?⁵⁸ And how can we square these sluggish productivity numbers with the disruptive labor impacts of these same innovations? It feels counterintuitive that so many kinds of workers—cashiers, fast food cooks, machine operators, legal secretaries, and administrative assistants among them—should be losing their jobs to disruptive technologies, without those same job cuts spurring measurable gains in productivity.⁵⁹

To understand this paradox, we return to our discussion of the mechanisms by which automation changes human work—specifically, to the effects of substitution and complementarity. When a new technology automates a set of tasks previously done by workers, it *substitutes* machinery for people. This process raises aggregate productivity to the extent that the machinery is cheaper, faster, or better at the tasks than the workers who previously performed them. Examples abound: automated turnpike tolls substitute for toll collectors, thereby speeding traffic and reducing pollution; computerized typesetting software substitutes for physical typesetters, enabling faster, cheaper print layout; tax preparation software substitutes for trained tax accountants, enabling consumers to cheaply file taxes from their personal computers.

Substitution of machines for workers creates winners and losers. The gains typically flow to firms via higher profits and to customers via lower prices. The costs, however, are typically borne by displaced workers, their families, and their communities, as well as by the public, through the social benefit programs that workers rely upon when they lose jobs.⁶⁰

But automation may also complement workers. New technologies often *augment* workers’ productivity in their current job tasks rather than displace workers from those tasks. Examples include power tools that equip construction workers to accomplish more in less time; computer aided design (CAD) software that allows architects to rapidly explore design options without painstaking drafting; and medical imaging tools that boost the speed and accuracy with which medical experts diagnose patients.

As with labor-substituting technologies, these labor-complementary technologies also raise productivity. In contrast to labor-substituting technologies, however, complementary technologies tend to increase earnings because they render workers more effective in their existing job tasks. They also frequently change the nature of the work and enable new capabilities. Because productivity gains often spur lower prices, improved quality, or greater convenience, employment of workers performing these tasks may rise. For example, following the introduction of Uber and Lyft, the fraction of U.S. adults who work as chauffeurs or taxi drivers nearly tripled.⁶¹

Most workplace technologies do both: substitute for one set of tasks while simultaneously complementing others.⁶² Power tools displace manual laborers but complement workers who can skillfully wield them; CAD software substitutes for draftspersons but complements architects; imaging tools substitute for technicians but complement experts.

While most new technologies offer a mix of substitution and complementarity, the mix differs greatly across technologies and across organizations, as do the productivity impacts. And herein lies a little acknowledged economic reality: *not all innovations that raise productivity displace workers, and not all innovations that displace workers substantially raise productivity.*

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raise productivity.

Consider the introduction of electric lighting in the late nineteenth century. Electric lighting allowed industrial plants to operate in shifts around-the-clock, reduced employee exposure to oil smoke and fire risk, and allowed workers to perform precision tasks with greater speed and fidelity.⁶³ Electric lighting was accordingly strongly labor-complementing, raising worker productivity and spurring new job creation (e.g., night shifts).⁶⁴ While some workers in the gas lighting sector were adversely affected, the ratio of broadly distributed productivity benefits to modest labor displacement was favorable.

Now consider two other recent, commonplace digital technologies: computerized telephone agents deployed by airlines and hotels, and self-checkout kiosks offered by large retailers. Both technologies perform tasks previously done by workers. Yet neither improves the quality of the product or service: computerized telephone agents stumble over all but the most rudimentary queries; self-service kiosks merely shift checkout tasks from practiced cashiers to amateur customers. Firms deploy these technologies because they deliver sufficient labor cost savings to justify the attendant increases in customer frustration, not because they make their services better.⁶⁵

Economists Daron Acemoglu and Pascual Restrepo label these latter cases ‘so-so’ technologies.⁶⁶ They disrupt employment and displace workers without generating much of a boost in productivity. Computerized telephone agents and self-checkout kiosks likely do raise productivity by some amount, or firms would presumably stick with human workers. But the ratio of worker displacement to productivity growth for these so-so technologies is arguably less favorable than for labor-complementing innovations such as electric lighting.⁶⁷

The ‘so-so’ nature of some digital innovations may help explain the paradox of sluggish productivity growth accompanied by considerable labor displacement.⁶⁸ Of course, not all digital innovations are so-so, and some have extraordinary productivity benefits such as the CAD software and medical diagnostic tools mentioned above. But these innovations tend to complement the labor of highly-educated professionals. Conversely, digital technologies affecting workers outside these elite ranks may displace non-college workers from clerical, sales, production, and operations occupations—shunting them toward in-person services that typically require generic skill sets and offer low wages.⁶⁹

4.3 Different but not Altogether Better

The problems of sluggish productivity growth, steep occupational polarization, and rising wage inequality may share common origins.⁷⁰ Labor-complementing digital innovations that have strongly concentrated earnings and employment growth among the most skilled and highly-educated workers; “so-so” labor-substituting digital innovations that have displaced non-college workers from traditional office and production jobs without yielding an equivalent set of opportunities elsewhere;⁷¹ and the failure of policies and institutions to blunt these impacts.

So the era of digitalization *does differ* from prior waves of automation: it has spurred growth of high- and low-wage jobs at the expense of the middle (labor market polarization); it has concentrated earnings growth among the most educated and highest-ranked workers, while earnings growth for the majority of workers has lagged (rising inequality); and it has delivered only modest productivity growth in the recent decade, even while displacing many categories of work, particularly those done by workers with high school or lower education (so-so technologies).

Americans are right to be worried. Current pessimism about what the next wave of technology-enabled workplace changes might mean for them, far from showing a failure to understand economic history, suggests that we grasp the uncomfortable lessons of the last four decades. If the advent of ubiquitous robotics and artificial intelligence heralds another era like the recent past, popular concerns will be amply justified.

The obvious next question, and the question that animates the work of the Task Force, is, what can be done about it? Despite the sobering record of the last forty years, our research argues against fatalism and in favor of tempered optimism. Better work and broadly shared prosperity are not assured, but both are feasible, and technological advances make them more, and not less attainable.

Before asking what investments and policies might begin to set us on such a course (Section 6) the next section lays out the Task Force’s developing understanding of the technological terrain that is emerging and changes we see on the horizon.

5. WORKPLACES OF THE FUTURE: AUTOMATION, ROBOTICS, AND ARTIFICIAL INTELLIGENCE

How are widely-reported advances in AI, machine learning (ML), robotics, and autonomous vehicles currently being applied and what are the implications for the future of work? How much substitution, how much complementarity, and how much new task creation do we expect to see? To answer these and related questions, the Task Force is conducting a series of studies on the development and application of AI, ML, and robotics in industry.

This section summarizes our preliminary insights, observations, and conclusions, based on research into three industries that are experiencing high levels of new technology adoption today: supply chains, manufacturing, and vehicles. This work is ongoing and will be further developed in the year ahead.

5.1 The Robots are Coming, but Slowly

As cultural icons, robots tap into long-standing fears and mythologies of artificial life, from Mary Shelley's *Frankenstein* to modern science fiction villains. Robots in practice are more prosaic: computer-enabled variants of mechanical sequencers, manipulators, and mobile platforms, enabled by increasingly powerful perception and software systems. While robots have been employed for decades in extreme environments (such as warfare and spaceflight), large-scale industrial applications have made the greatest impact in manufacturing (where the automotive and electronics industries were early adopters) and, increasingly, automation of the supply chain (distribution, warehousing, logistics) across multiple industries. Today, robots are finding their way into a host of new environments, from food service to surgery, as the promise of AI-enabled software broadens their reach and flexibility.

Industrial Robots

Industries such as automobile manufacturing and electronics incorporated robotics in the late 20th century. Recent evidence indicates that industrial robots have displaced production workers and had negative impacts on earnings and overall employment in the local labor markets where large manufacturing plants are based.⁷² These effects are economically, socially, and politically consequential, but their economy-wide impacts are modest so far since most industrial robotics is concentrated in a few industry sectors. We anticipate additional displacement of skilled production workers by robotics as these technologies advance. Still, our researchers around the country (particularly the Midwest and Northeast) have observed that *firms are struggling to find and retain workers at current wages—indeed that struggle is often cited as a driver for investments in automation*. As discussed above, an aging workforce as well as the loss of manufacturing capacity over several decades have left the country short of specialized production workers for the foreseeable future.

Robots integrate cognition, perception, and actuation, and hence are inherently more complex to deploy than conventional software systems. Accordingly, they do not proliferate at the same rapid rates we are used to seeing for software-only products like apps or web-based services. Robots remain expensive, relatively inflexible, and challenging to integrate into work environments.

Firms are struggling to find and retain workers at current wages—indeed that struggle is often cited as a driver for investments in automation.

These hurdles are falling, but gradually. Precise manipulation has been making great strides, but human-like flexibility remains out of reach. Similarly, autonomous navigation for mobile robots works well in structured environments but has trouble in dynamic or unstructured areas. Larger robots, or those operating as vehicles or heavy machinery, are dangerous to people, so safety requirements further moderate the pace of change.

Collaborative Robots and Augmented Intelligence

Not all robots displace workers, and major efforts are underway, particularly with collaborative robots, to enhance their complementarity with people. Compared to traditional robots, collaborative robots are less expensive, easier to program, and safer to work alongside. While collaborative robots are a small fraction of the total robotics industry, they do represent the vanguard of a new wave of “*augmented intelligence*,” wherein AI and related technologies assist human workers to make them more productive—enhancing the complementary nature of new forms of automation.

Most companies we speak to now have adopted the language of augmentation: “Our robots complement human workers rather than replace them.” We are currently studying how well actual implementations match that rhetoric, though we do see potential here for technology to greatly augment human work and productivity. We imagine factories of the future that have achieved the safe, harmonious coordination of large numbers of people and robots, and indeed innovation is occurring in this area already.

Beyond the Factory Floor

Commercial robots, as they gain flexibility, will assume a larger set of tasks in warehouses, hospitals, and retail stores. Robots will perform more tasks outside of factories that will substitute for mundane human tasks such as stocking, transporting, and cleaning, as well as awkward physical tasks that require picking, harvesting, stooping, or crouching (as in arenas like agriculture). As we heard from several companies, advances in robotics can displace relatively low-paid human tasks and may boost the productivity of workers by freeing their attention to focus on higher value-added work.⁷³ While the pace at which these tasks are delegated to

machines today varies across firms and industries, it will likely be hastened in the future by tight labor markets and the rapid aging of workforces.⁷⁴

Recent history shows that key advances in workplace robotics—those that radically increase productivity—depend on breakthroughs in work design that often take years or even decades to achieve. Using robots effectively will require redesigning how work is accomplished to harness the strengths of the new technologies while circumventing their current limitations. For example, the well-known Amazon/Kiva robotic system, used for order fulfillment at Amazon warehouses, is effective precisely because engineers redesigned the warehouse to segregate the robot-feasible and human-touch-required tasks into distinct stages of the workflow. They assigned to robots the simple transport tasks that people were doing (by walking). The new workflow concentrated and transformed the manual “pick and pack” tasks still done by human workers. The key innovation was not the individual robots, but fleets of robots working with people in a software-connected system.

This case highlights how the tremendous growth of e-commerce means that supply chains are both automating and creating thousands of new jobs. While robotics lower labor input per shipment, internet commerce has significantly increased the number of shipments. Without this automation, Amazon might have hired more workers, but it also might have hired the same number of workers at a slower rate of growth. The automation engineers kept humans in the process but transformed their jobs. Dozens of startups have emerged to similarly automate other logistics and warehouse operations alongside human workers. Still, one large e-commerce supplier told us they could never fully automate their supply chain because the spike in consumer demand over the Christmas season is so great that the company cannot afford to keep robots idle during the rest of the year. By contrast, the supply of human labor is more flexible and can better accommodate surges and contractions in demand. Over the longer run, improvements in robotics and supply chain technologies, such as standardized packaging, may prove scalable and flexible enough to meet these demands. Still, we draw only modest comfort from the observation that it is easier to hire humans as seasonal workers than to deploy robots.

The Importance of Scale

Automation still succeeds best at large scale. Because of high set up costs, such systems need to pay for themselves over a large number of operations. Advances in technology promise to enable robotics to be deployed more flexibly and productively at smaller scales, but it is still early in that cycle. The Task Force’s field research in manufacturing reinforces the importance of scale in adoption. Interviews (particularly in the Midwest and Northeast) suggest that small and mid-sized firms are slowly and incrementally adopting new automation technology into existing production systems (evidence indicates that automotive firms are still the most advanced in terms of adoption⁷⁵). None of them report replacing workers with new technology. “When we bring in new technologies, our business grows and we add new jobs,” said one small firm owner, “we’ve never laid anyone off because of productivity.” Of course, what is true during a prolonged economic expansion such as the U.S. is currently experiencing may not remain so under more typical economic conditions.

Small and medium-sized manufacturing firms in the United States and other industrialized countries are typically engaged in low-volume/high-mix production. Hence their return on investment for adopting new robotics must include any required reconfiguration of existing equipment, as well as the cost of the robots, which presents a high bar. Robots also must be cost-competitive with respect to the workers engaged in manual tasks.

New technological advances such as AI, augmented sensing, and additive manufacturing hold great promise for enabling innovations in design, measurement, and materials—creating new products and new methods of production. Still, our interviews find many companies consider themselves at the early stages of adoption of these techniques, figuring out how to collect and structure data such that they can apply greater insights to their existing operations. Doing so requires integrating multiple data sources, often for hundreds to thousands of machines in larger companies. It requires merging expertise from both operations and information technology, while ensuring continuous improvement in the production system. *“If I connect the chaos in my plant,”* said one “Industry 4.0” expert, *“I have only connected chaos.”* Many firms interviewed to date are focusing on specific pain points and automating activities such as materials transport or inspection, to enable workers to spend more time in high-value activities.

“Lights out” factories, with no human input, have long been a utopian/dystopian vision for the future. The vision may make sense for some situations where the product or process is mature and highly stable. But even the most automated electronics or assembly plants still require a large number of workers to set up, maintain, and repair production equipment. A typical mobile phone—a stable and uniform product made in very high volumes—is touched by dozens of human hands during production. As one CEO said to us, “You can’t innovate in a lights out factory.”

AI-based systems offer the promise of one day achieving such learning. But supply and demand, political relationships, and innovation are dynamic forces, affecting even the most stable and uniform products. Production systems must constantly adapt to rapidly changing conditions. With current technology, human presence often exceeds machinery in providing that flexibility.

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We are a long way from AI systems that can read the news, re-plan supply chains in response to anticipated events like Brexit or trade disputes, and adapt production tasks to new sources of parts and materials.

5.2 Artificial Intelligence and Machine Learning: Deep Strengths, Narrow Capabilities

While AI is a component of robotics, it has broader reach in its software-only forms. The current state of AI is similar to, though more uncertain than, the current state of robotics. Artificial general intelligence, the idea of a truly artificial human-like brain, remains a topic of deep research interest but an aspirational goal that experts agree is far in the future. Some, including Task Force advisor Professor Rodney Brooks, argue that the traditional “Turing test” for artificial intelligence should be updated. The new standard for artificial general intelligence should be work tasks such as those required of a home health aide—including physical aid of a fragile human, observations of their behavior, and communications with family and doctors.⁷⁶ New understandings of work may even drive us to redefine the quest for artificial general intelligence.

With forms of AI that are here today, firms are experimenting with new technologies and with ways to redesign their workflows, task allocation, and job design to best adopt new technologies to increase productivity. But the pace of adoption appears uneven across industries as well as firm sizes.

Most contemporary AI successes involve forms of machine learning (ML) systems, in applications where large data sets are available. These basic techniques have been around for a long time, but in the past decade new computing hardware, software, and large-scale data have made ML notably more powerful.

ML applications include image classification, face recognition, and machine translation. They are familiar to consumers in applications like Amazon Alexa, real-time sports analytics, face recognition on social media, and customer recommendation engines. An equivalent array of applications is finding its footing in business, including document analysis, customer service, and data forecasting. The barriers to deploying these technologies are rapidly coming down, as cloud-based AI services make algorithms once available only to highly skilled, well-resourced companies available to small and even individual enterprises.

These applications are already replacing tasks and aspects of existing jobs: for example, workers labeling data, paralegals doing document discovery in law firms, or production workers performing quality inspection on factory lines.⁷⁷ We also see cases where AI and ML tools are deployed to make existing employees more effective, by aiding call center responses, for example, or speeding document retrieval and summary. Some applications in engineering involve using AI to search physical models and design spaces to propose alternatives to human designers—enabling people to come up with entirely novel designs. In short, AI and ML systems have deep implications for the workplace, as the tools on which we have come to rely become more intelligent and widespread.

New understandings of work may even drive us to redefine the quest for artificial general intelligence.

ML differs from previous waves of automation in that it applies to high- as well as low-education jobs, and has the promise of learning as it works. Still, ML applies at the task level (ideally to tasks with easily measurable results) and does not fully automate particular occupations in any case of which we are aware, though all occupations have some exposure. As one example, ML interpretation of x-ray images, while an important part of a radiologist's work, affects but one of dozens of tasks performed by a professional radiologist. That effect may in turn complement other tasks that radiologists perform such as conducting physical examinations and developing treatment plans.

ML differs from previous waves of automation in that it applies to high- as well as low-education jobs and has the promise of learning as it works.

Learning to Use Machine Learning

To make use of the strengths and limitations of ML, organization will need to redesign workflow and rethink the division of tasks between workers and machines, akin to what occurred as Amazon deployed robotics in its warehouses. The resulting changes in work design will alter the nature of many jobs, in some cases profoundly. But the implications for specific skill groups are as yet uncertain and will in part depend on managerial and organizational choices, not on technologies alone. We should nevertheless expect to see declining demand for some broad occupational task categories that are most suitable for ML applications. These include back office and phone support operations, transcription and translation services, customer service, credit monitoring activities, and many financial management activities.⁷⁸

ML systems still face challenges with respect to robustness and explicability. The industries that use ML are slowly learning that the data used to train ML systems must be as unbiased and trusted as the systems themselves need to be—crucial challenges in an era of hacking and cyber-warfare. Additionally, ML systems tend to be “black boxes” that offer no insight into how they make their decisions. Explainability, however, is essential for systems that must be robust to failure, interact with humans, and aid in significant decisions with legal or life-critical implications.

While it seems unlikely that AI has greatly impacted the labor market so far—beyond spurring increased demand for computer and data scientists—we have no definitive evidence on this topic to date. AI is being applied to a range of tasks in white collar work and is predicted to have greater displacement effects on higher skill professional and technical workers than earlier waves of automation.⁷⁹ Proven measures of those effects, however, are still in development.

5.3 Autonomous Vehicles: A Leading Use Case

Perhaps no arena of technological innovation has provoked more investment, excitement, and anxiety than mobility, where robotics and AI could have especially profound effects on human lives and work. Autonomous vehicles (AVs), whether cars, trucks, or buses, are basically ML-enabled industrial robots on wheels, operating at high speeds in human environments. They combine the industrial heritage of Detroit and the millennial optimism/disruption of Silicon Valley. AVs exemplify the challenges of robotic systems as well, including the uncertainties around their labor implications. Truck drivers, bus drivers, taxi drivers, auto mechanics, and insurance adjusters are but a few of the types of workers expected to be displaced or complemented.

Coming decades will see greater numbers of cars and trucks with some degree of autonomy. Since more than three million commercial vehicle drivers currently work in the United States, a rapid emergence of AVs would be highly disruptive for workers. A slower transition will greatly ease the implications for workers, enabling current drivers to retire and younger workers to fill newly created roles.

Planning for the consequences of AV deployment requires educated guesses about the nature and timing of the transition.⁸⁰ Rapid and total transition to vehicle autonomy, however, appears highly unlikely. AV developers have been ratcheting back their aggressive ambitions for deploying driverless cars and trucks. Some will now focus on making cars that augment rather than replace drivers. Others are extending their timelines or limiting autonomy to fixed routes. The variability and complexity of real-world driving conditions require levels of situational adaptability that current technologies have not yet mastered. The recent tragedies and scandals surrounding the Boeing 737 MAX, as well as accidents involving AV testing on public roads, have increased public and regulatory uncertainty over software-based systems in life critical situations. A great deal of testing, verification, and proving still needs to occur before AVs displace traditional automobiles. Automation that complements rather than entirely replaces human drivers will more rapidly overcome these barriers, as evidenced by the numerous computerized systems already built into today's cars.

Rapid and total transition to vehicle autonomy appears highly unlikely. Automation that complements rather than fully replaces human drivers will more rapidly overcome these barriers.

AI systems potentially enable human drivers to take on additional tasks, drive more safely, and provide a greater range of services than currently possible. Such improvements will take place within novel landscapes that are likely to feature more congestion, increased ride-sharing, new urban transit, and growing electrification (and even potentially aerial taxis). Which pathways different companies pursue will respond to a host of factors: technological capabilities, costs, consumer preference, regulation and market potential. Implications for jobs and skills apply not only to driving but also to vehicle manufacture and maintenance, road infrastructure, and even data security. New occupations are already emerging: AV companies, while they are recruiting for software engineers, are also looking for “safety drivers” and “field autonomy technicians”—workers. These workers are of course unlikely to be hired primarily from the ranks of former long-haul truck drivers. As elsewhere, the labor market challenges posed by automation stem from the disruption of existing jobs and careers, not from net reduction in employment.

Autonomous mobility—the form of automation and AI receiving the lion’s share of public attention, private investment, and engineering development—stands as a leading use-case for AI and robotic systems more generally. These systems hold great promise for new applications and services, generating novel products and occupations that may positively impact productivity. They also generate disturbing portents for the displacement of substantial numbers of driving jobs. The productive uses of the technology are still evolving, along with the key supporting technologies. The environment of investments, incentives, and institutions in which these technologies grow will shape the likely outcomes.

6. WORKING FOR THE FUTURE: INVESTMENTS, INCENTIVES AND INSTITUTIONS

Technologies, skills, and markets do not alone determine inequality or economic mobility. Educational institutions, labor market regulations, collective bargaining regimes, financial markets, public investments, and tax and transfer policies all play important roles.

As we have stressed above, the failure of the U.S. labor market, over the last four decades, to deliver broadly shared prosperity despite rising productivity is not an inevitable byproduct of current technologies or free markets, however.

What have other industrialized countries done differently? And how can the United States do better over the *next* several decades to meet the technology and workforce challenges that increasingly confront all the world's industrialized economies? We begin by articulating the need for proactive policies and investments, before offering some preliminary thoughts about specific opportunities in education and training, and other policy areas.

Much of the remainder of this section focuses on how the United States can again be a leader in education, training, and ongoing learning to better equip its workforce for the digitalized economy of the future. But we stress that this supply side response is by itself insufficient: hoping that “if we skill them, jobs will come,” is an inadequate foundation for constructing a more productive and economically secure labor market. Concerted public and private action are essential to shape the work of the future towards greater economic security for workers, higher productivity for firms, and broader opportunity for all.

While the Task Force's work is incomplete, at this stage of our research we see four broad areas, alongside education and training, where public and private action may prove critical to shaping the future of work:

1. Rebalancing fiscal policies away from subsidizing investment in physical capital and toward catalyzing investment in human capital;
2. Restoring the role of workers as stakeholders, alongside owners and stockholders, in corporate decision-making;
3. Fostering technological and organizational innovation to complement workers; and
4. Reinvigorating America's leadership position in technology and innovation.

“Change is overdue, not only for education and training institutions, but also in the areas of tax policy, labor representation, and public investment.”

These responses will require key public and private institutions, many of which were established in the 20th century or before, to adapt and modernize to meet the needs of a 21st century digital economy. Change is overdue, not only for education and training institutions, but also in the areas of tax policy, labor representation, and public investment.

6.1 The Skills of the Future: Attaining Excellence in Education, Training, and Ongoing Learning

Investing and innovating to provide workers with new skills is an urgent and indispensable response to the labor market challenges spurred by ongoing technological change. But what skills will be required, which institutions will provide them, who will pay the costs, and who will have access? Understanding what can be achieved through such investments and which training models are most effective at helping workers boost their long-term employment and earnings prospects is a central topic for rigorous research, some of which is currently underway by Task Force members. We expect to report in more detail on this research in our final report.⁸¹

Our work to date in this topic area is informed by two tenets. First, current and impending waves of automation will disproportionately burden workers without a four-year college degree, increasing their exposure to skills obsolescence and job displacement, and diminishing their prospects for reemployment.⁸² Our research on skills development focuses on non-elite postsecondary education and training venues, including community colleges, apprenticeship programs, sectoral training programs, and online education offerings because we believe these avenues are likely to be most relevant and accessible to these workers.

Second, while ongoing occupational polarization is reducing employment in middle-skill production, operative, technical, and administrative positions, we should not forgo further investments in these types of jobs for three reasons.⁸³ One is replacement hiring. In every occupation, firms regularly hire new workers to replace incumbents who retire, leave the labor force for personal or health reasons, or change careers.⁸⁴ Production workers provide a case in point: The Bureau of Labor Statistics projects that employment in production will fall by 406,000 workers between 2016 and 2026 due to pressure from automation and trade.⁸⁵ In the same interval, 1.97 million currently employed U.S. production workers will attain or exceed retirement age. Accordingly, U.S. firms will need to *hire* 1.52 million *new* production workers net of the projected decline of 406,000 production jobs simply to compensate for these retirements.⁸⁶

A second important force in middle-skill employment for at least the next decade or more is the expansion of the healthcare sector. Due to the nation's aging population, employment in healthcare occupations is predicted to grow by 18 percent from 2016 to 2026—more than seven times more rapidly than overall employment—and add 2.4 million jobs.⁸⁷ Many healthcare occupations are closed to workers without a college degree, however, and not all healthcare occupations that employ non-college workers offer good career prospects.⁸⁸ But current and projected job growth in medical technical occupations is substantial, and jobs such as respiratory therapist, dental hygienist, and clinical laboratory technician offer middle-income salaries to workers with an associates degree in the relevant field. These fields are strong candidates for targeted training investments.⁸⁹

Finally, as highlighted above, the declining size and rising educational attainment of new cohorts of labor market entrants mean that a shortage of jobs is unlikely. The appropriate focus of policy should instead be to improve worker skills and augment overall productivity to meet the challenge of an older, less abundant workforce.

The Role of Community Colleges

America's more than 1,200 community colleges are currently the country's largest provider of training, serving approximately six million students enrolled in for-credit courses, and another six million in non-credit programs.⁹⁰ Community colleges are also the most accessible and affordable option for students from lower-income families, a pool in which African American, Hispanic, and first-generation college-goers are overrepresented. While fewer than 40 percent of students who enroll in a U.S. community college complete a certificate or degree from any institution within six years, rigorous evaluations have shown that innovative programs that support students with “wrap-around” services can speed time to degree and substantially boost graduation rates, in the short and long run.⁹¹

Another promising avenue for investment involves connecting community colleges with employers to design skill programs that are directly responsive to market demands (an example is the PowerPathways program in California).⁹² Ongoing engagement between community colleges and private-sector employers is critical to ensure the long-term success of the community college system; here, too, best-practice models are emerging in several states.⁹³

Given their scale, their ability to adapt offerings to local market needs, and their ongoing engagement with non-baccalaureate adults at all career stages, community colleges could play an even more central role in providing skills and training to U.S. workers. To reach that goal, educators will need to identify best practices and carefully study obstacles to the diffusion and scale-up of these practices. Resources are, of course a significant issue, especially in the context of declining federal funding and flat state funding since the Great Recession; recent policy proposals have suggested a significant reinvestment in community colleges (\$20 billion).⁹⁴ Task Force members are engaged in in-depth research on best practices at community colleges through a collaborative study with the Community College Research Center at Columbia University. This work will feature in the Task Force's final report.

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The Role of Work-Based Learning Programs and Sectoral Employment Programs

Work-based learning programs, in the form of co-ops and apprenticeships, have proved valuable for skills development, with German and Swiss programs often cited as models for effectively combining classroom and work-based learning, both for vocational training and four-year-degrees, which are becoming increasingly integrated.⁹⁵ Workers benefit from apprenticeships by receiving a skills-based education that prepares them for good-paying jobs, while employers benefit by recruiting and retaining a skilled workforce.⁹⁶ The current focus on this approach and the expansion of apprenticeships across the country is encouraging, although the scale of the opportunity is not yet matched by the availability of programs; moreover, more work is needed at the state and national level to facilitate the administration of apprenticeships.

Recent evidence from experiments with apprenticeship-like sectoral employment programs is perhaps even more promising. As with apprenticeships, these programs emphasize on-the-job training, but they do not require the creation of formal or registered apprenticeship positions. Typically, sectoral training programs include some upfront screening (e.g., minimum literacy and math skills and showing up on time for intake sessions); soft-skills training; three to eight months of occupational/industry training, often with an industry partner and/or community college or nonprofit intermediary; job placement; and follow-up services. Project Quest in San Antonio is an excellent example of one such program.⁹⁷ Researchers have found short- to medium-run impacts on earnings of around 20 percent or more in eight of eleven recent program evaluations,⁹⁸ providing evidence that sectoral approaches may be more effective than older training models, such as the Job Training Partnership Act (JTPA) and the Comprehensive Employment and Training Act (CETA). These older programs employed a more general, “one size fits all” approach to training that failed to meet market demands for more specialized skills.⁹⁹

The Role of Online Learning

Online education has been heralded as a potentially transformative technology for expanding access to higher education because it lowers the cost of delivery and removes capacity constraints. As of 2011, fully one-third of college students took at least one course online during their college careers, a share that tripled during the preceding decade.¹⁰⁰

Traditionally, the term “online learning” has been associated with distance learning. However, modern online learning includes Massive Open Online Courses (MOOC’s), micro-credentials such as the MicroMasters, fully online masters (such as the one on computer science offered by Georgia Tech), and online material accompanied by “flipped” classroom interaction (where lectures are delivered online and class time is used for activities and discussion). Evidence on the efficacy of these complex learning environment is still emerging. Goodman et. al. (2019) study the Georgia Tech Master’s and present a broad summary. They describe the advantages of access and scale of the Georgia Tech master’s program, and the opportunities online programs might create. Traditional distance education has also been used by for-profit colleges, and Bettinger (2017) describes the less than satisfactory results of from one such college.¹⁰¹ This points to the need for better understanding the mechanisms of learning, and the design of online and classroom tools that support student success. The MIT Integrated Learning Initiative is studying such questions.

We do not read this incomplete evidence to suggest that new education delivery platforms lack great potential. On the contrary, innovation in online education and training tools will ultimately lower the cost, boost the efficiency, and broaden the accessibility (and perhaps even the appeal) of educational offerings directed at all age and skill levels. But history makes clear that new technologies rarely serve as wholesale replacements for their predecessors—thus, for example, online classes have not succeeded in replacing in-person instruction with no loss of quality. Realizing the full potential of a major new technology almost always means reengineering the way work (in this case learning) is done to harness the strengths and circumvent the limitations of the new tool. An important focus for research going forward is to explore how new technologies can augment and potentially transform traditional education models. MIT's Office of Digital Learning is currently field-testing both practical and “moon-shot” efforts in this area, and we look forward to reporting on their work in our final report.

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The Role of Advances in the Science of Learning

If the rapid pace of technological change demands career-long adult learning for workers to gain new skills and retain good jobs, then it will be insufficient to merely develop new offerings and venues for education and training. We also require a *better understanding of how adults learn*, particularly when interfacing with technology. Given the importance of such learning for individuals, companies, and society as a whole, there is a remarkable lack of evidence about what kind of learning is effective.

Although new technology can support novel learning experiences, from personalized instruction to virtual reality displays, it is unclear what practices actually facilitate learning for adults. For example, although technology ought to support individualized or personalized learning that lets learners progress at their own pace, the published literature reports that such personalized learning is as likely to help or harm learning relative to conventional group instruction without personalization. It is highly likely that technology can promote adult learning, but it is not yet known what principles guide the implementation of *effective* adult learning.¹⁰²

In addition, there is not yet a framework for translating results from laboratory studies of optimal skills acquisition into real adult learning. Researchers at MIT have begun to try to build such a framework by bridging the science of learning to actual workplace adult learning. For example, in collaboration with one large company, MIT researchers showed that the simple application of a single science-of-learning principle to employee training improved retention of new material

by 25 percent.¹⁰³ It remains to be seen whether these tools will prove equally (or more) effective for learners at different ages and with different levels of educational attainment and work experience.

The Role of Innovation and Experimentation

One of the core strengths of the U.S. education system is its flexibility: People can move in and out of the system at different points in life or change their course of study to pursue new career paths. The system also allows for the development of new education and training programs and partnerships where there is perceived demand or opportunity. Recent years have seen significant experimentation within higher education. A number of community colleges are offering four-year degrees rather than just two-year degrees, or are working closely with four-year institutions to offer courses and credit that can smooth the transition for transfer students.¹⁰⁴ Likewise, community colleges are connecting with students in high school to provide college credits before students graduate from high school. These are important efforts to address college affordability and build relevant skills for the labor market, and they should be evaluated over time to monitor their efficacy.

At the same time, new systems for delivering skills are emerging about which relatively little is known. A plethora of new bootcamps, badges, and other models for conferring non-degree credentials have been launched in the last few years. Indeed, a recent study estimates the number of different postsecondary credentials in the United States at approximately 500,000.¹⁰⁵ This proliferation of options is fueled in part by a sense that four-year degrees are not a good fit for all learners, may over-educate people for certain jobs, and may impart burdensome student debt.¹⁰⁶ Not all non-college educational venues are well-suited for all learners. For example, many targeted technical training initiatives such as code academies are tailored for non-college adults with comparatively strong pre-existing skill sets and aptitudes. Careful evaluation will be required to determine whether these models can work well for a broader population and deliver long-term returns on investment compared to traditional two-year degrees.

To further such evaluation, and to build our knowledge base about what types of programs and strategies might be most effective in delivering skills and augmenting career prospects, particularly for non-college-educated workers, MIT's Jameel Poverty Action Lab (J-PAL North America) is undertaking a multi-year, multi-million dollar research effort to complement the integrative work of the Task Force. Launched in 2018, this initiative is currently funding and rigorously evaluating innovative programs and supporting randomized field experiments (the gold standard of social science). Our final report will feature early results from some of the experiments fielded by the J-PAL Work of the Future Initiative as well as qualitative work on non-degree credential programs.¹⁰⁷

6.2 Shaping the Work of the Future Towards Innovation, Productivity Growth, and Economic Security

As we have already noted, policy options for addressing the technology and workforce challenges of the future will be the main focus of the Task Force's efforts over the next year. This section offers some early thoughts concerning promising areas for policy action to ensure that the future of work over the next several decades tends towards outcomes that benefit workers as well as the economy.

Rebalancing Fiscal Policies

The U.S. tax code favors capital investment, offering low marginal rates on capital income, rapid rates of depreciation on plant and equipment investments, and, in many cases, directly subsidizing capital expenditure (e.g., the R&D tax credit). Similar subsidies for investments in labor and skills are lacking. As a result, the effective tax rate on human capital investments—in the form of labor income taxes—greatly exceeds the tax rate on capital investments. This imbalance between the taxation of human versus physical capital investments gives firms an incentive to replace workers with tax-subsidized machinery where possible; indeed, one reason that firms may adopt “so-so” technologies is because taxpayers implicitly subsidize labor-replacing capital investments.¹⁰⁸ This bias seems particularly antiquated in light of the growing importance of intangible assets, relative to tangible assets, in firms' market value.

Rebalancing the tax code to reduce these distortions and provide a (closer to) level playing field for labor and capital investment would provide firms with stronger incentives to invest in human capital development, particularly for lower-skilled workers, who typically receive less training. Favorable tax treatment for firms' investments in training should be reserved for those programs that lead to recognized credentials, thus certifying quality and ensuring workers gain portable skills. Efforts are underway to ensure that firms account for human capital investments in the same ways they have traditionally accounted for capital investments. For example, the Security and Exchange Commission's Investor Advisory Committee has recently recommended increasing reporting requirements for companies that are making workforce investments through human capital management disclosures.¹⁰⁹ Without creating undue burdens on firms, incentives to invest in human capital, and greater recognition that such investments are an important part of firms' practices, will create a stronger foundation for developing workforce skills in the future.

Recognizing Workers as Stakeholders

The United States is unique among market economies in venerating pure shareholder capitalism—the notion that the sole legitimate objective of firms is to maximize shareholder value. Shareholder capitalism dictates that employees should be valued like all other intangible assets—that is, compensated at market prices and scrapped if their value to the firm falls below their cost to the firm (i.e., their wage).¹¹⁰ Within this paradigm, the personal, social, and public costs of layoffs and plant closings should not play a critical role in firm decision-making.

This paradigm contrasts with that of most other market economies, which broadly accept (and often enforce) the notion that employees and communities are among the legitimate stakeholders to whom a firm must be responsive.¹¹¹

Shareholder capitalism, taken to its logical extreme (as in the United States), fails to appropriately internalize the external costs that firms impose when they make business decisions or adopt business practices that directly affect their workers and the communities in which they operate. Accordingly, we are encouraged that the Business Roundtable has just announced a revision of its statement about the purposes of the firm that once again recognized the broader responsibilities of corporations.¹¹²

Historically, of course, labor unions played a role in forcing firms to recognize these external costs in the United States. Indeed, there was a period in the post-war era when U.S. labor unions were arguably too strong—limiting flexibility, raising costs, and blunting incentives for productivity improvements.¹¹³ But over the last four decades, the shareholder primacy model has gained intellectual currency while unions have atrophied, at least outside the public sector. This has had significant social costs. One is that rank and file workers have generally not benefited from rising productivity over the last four decades, as discussed at some length earlier in this report. American workers' greater anxiety about the adverse consequences of automation, relative to their counterparts in other advanced economies, is arguably another cost because workers rightly perceive that they are not guaranteed to share in the productivity benefits of robotics, AI, and machine learning.¹¹⁴ This may explain the rise in recent years of new forms of worker advocacy (in the form of on-line petitions, industry-based membership organizations, worker centers), as well as workers' increasing interest in expanding their voice and influence within firms.¹¹⁵

While shareholder capitalism can plausibly be credited with some of the productive dynamism of the U.S. economy, we believe that the uniquely American embrace of pure shareholder capitalism is due for reevaluation. Though there may be no one optimal model of worker representation, two points seem clear. First, simple economic efficiency requires that workers are given some weight as stakeholders in the firms that employ them.

Although we are uncertain precisely what rules should govern worker representation in the United States, we are certain that the nearly 'voiceless' model that the nation has embraced over the last four decades is out of balance.

Otherwise, firm decisions will continue to fail to internalize the real costs that job losses impose, not only on workers but also on society as a whole.¹¹⁶

Second, the U.S. framework for worker representation is unduly restrictive and limits opportunities for cooperative bargaining between worker and employer representatives. In contrast to countries such as Germany that mandate worker representation on some company boards and provide for works councils that represent workers more broadly, the United States' National Labor Relations Act of 1935 makes such activities illegal at nonunion establishments through its ban of company-dominated unions.¹¹⁷ While constructive in its era, this legal constraint now hinders experimentation with new forms of worker representation that might both complement and compete with the traditional trade union model. Simply eliminating this provision would not solve the problem. But reforms that allowed employees to organize by region and industry and collaborate on a range of issues are ideas worth considering. We will elaborate on these ideas in our final report. Although we are uncertain precisely what rules should govern worker representation in the United States, we are certain that the nearly 'voiceless' model that the nation has embraced over the last four decades is out of balance.

Fostering Innovation to Complement Workers

To foster the kinds of innovations that complement workers, it will be important to support private-sector investments in organizational capacities that boost productivity by increasing know-how. Much research demonstrates that firms benefit from using new technologies only after making substantial investments in experimentation, training, and standardizing to integrate these tools into their workflow and build complementary skills in their workforce.¹¹⁸ Evidence from industries as diverse as auto manufacturing, information technology, and health care shows that integrating technology with complementary innovations in work systems and management practices magnifies the productivity benefits.¹¹⁹ Unlike investments in physical capital, investments in organizational capital are *not* generally recognized by the tax code and hence are typically taxed in the same way as labor income (since their main cost is in the form of worker time). As outlined above, we believe the tax code should incentivize investments in organizational capital.

More broadly, improving organizational and managerial practices that boost productivity by complementing workers needs to be a priority for the private sector. Though seldom acknowledged, managing organizations is a skill that profoundly affects what outputs a firm obtains from its inputs of skills, technologies, materials, and effort.¹²⁰ Management practices—measuring inputs and outputs, recording and learning from defects, providing concrete incentives for improvement—differ substantially in quality across firms, across countries, and across different types of organizations (e.g., family-owned firms, founder-led firms, board-governed firms, multinational firms). These practices have measurable impacts on productivity, profitability, market share, and firms' success in deploying new technologies.¹²¹ They also affect worker productivity, earnings, and career advancement.¹²²

While U.S. government agencies have for decades disseminated *technical* know-how through agricultural and manufacturing extension programs, we are unaware of analogous public extension programs for disseminating best *management* practices. Developing and dissem-

inating best practices that speak to how technology can complement workers and lead to greater productivity gains could have a significant impact on U.S. firms. This would be particularly useful for small firms, especially family-led firms, which often follow traditional practices that are ill-suited to contemporary needs. Evidence from randomized field experiments demonstrates that helping managers adopt and apply contemporary information-based and incentive-driven practices can yield large and lasting productivity gains.¹²³

Restoring Technological Leadership

While we are only beginning to understand the implications of AI, machine learning, and robotics, America has an opportunity to lead in their development and application. These advances connect to a range of important enabling technologies and frontier sectors of the economy: next-generation chip design, communications, security, quantum computing, and others. As with other major technological transformations, it will take sustained investment over a decade or more to realize the most significant payoffs, just as earlier instances of focused public and private investment provided the foundation for recent decades of U.S. scientific and economic leadership.

Given that people are profoundly anxious about the disruptions that these technologies may catalyze, why do we recommend that the U.S. renew its investments in those same technologies? There are two reasons: economic growth and beneficial leadership.

Economic Growth

The wealth of industrialized countries depends substantially on their leadership in frontier sectors. If the United States cedes leadership in key sectors for innovation and growth in the 21st century, it will be weaker—economically, intellectually, and militarily.

At present, the United States leads in most, though not all, aspects of AI—but that leadership is being challenged. Numerous countries are investing, often with state support. China, Canada, France, Germany, the Netherlands, South Korea, and Sweden have all launched focused national strategies for developing AI.¹²⁴ In recent decades, the United States has fallen behind in R&D intensity, (measured as the percentage of GDP spent on R&D) compared to Germany, Japan, and Korea. China is catching up rapidly: its R&D expenditures were 88 percent of the U.S. level in 2016, up from 34 percent in 2012.¹²⁵

R&D intensity is an incomplete measure of innovative activity, but these developments bode ill for long-term U.S. prosperity, and for its economic and national security. As a more concrete indicator, Chinese patents and scientific publications have been growing robustly, with China now leading the United States in cited publications in some critical aspects of AI. While China continues to seek scientific and technological information and expertise from the United States, including through illicit means, China has also developed its internal capacity and is no longer primarily dependent on progress elsewhere.

Beneficial Leadership

If the goal of leadership were exclusively to win the race for commercial or military control of key technologies, the Task Force would not take a position on the topic. As we see it, however, the goal is not merely to win, but to nudge innovation in directions that will benefit the nation: among them complementing workers, boosting productivity, and providing a foundation for shared prosperity. The U.S. investment agenda should not solely support universities, national laboratories, and private-sector innovation, rather it should assist public- and private-sector actors in creating and adopting new technologies to improve productivity *and* augment human work.

The goal is not merely to win, but to nudge innovation in directions that will benefit the nation: among them complementing workers, boosting productivity, and providing a foundation for shared prosperity.

The best ideas in frontier technological domains still often originate from U.S. universities, firms, and entrepreneurs. These unrivaled strengths provide a foundation for leadership, but not the entire edifice. History has repeatedly shown that government leadership and public investment are indispensable.

At crucial moments in its history, the U.S. government used its considerable convening power and fiscal resources to tackle challenges and build the institutional capacity to further the country's science and technology agenda. It partnered with academia and the private sector to usher in the atomic age and put people on the moon. It also created national laboratories, the National Science Foundation, NASA, and DARPA—which together with military support laid the foundations for the information age. Similar leadership and investment on the part of the federal government can again lead the promising but fraught transition into a new era of computing intelligence and its applications.¹²⁶

7. CONCLUSION: SHAPING TECHNOLOGY AND INSTITUTIONS FOR THE WORK OF THE FUTURE

We stand on the cusp of a technological revolution in artificial intelligence and robotics that may prove transformative for economic growth and human potential. Of course, other forces besides technology will shape the nature of work, opportunities for workers, and living conditions for the vast majority of people around the world. Other challenges, such as climate and the environment, to name just one salient example, could fundamentally re-order the terms and parameters under which economies, governments, and societies operate in the decades to come.

Nevertheless, new and emerging technologies *will* have a profound effect on the work of the future and will create new opportunities for economic growth. Whether that growth translates to higher living standards, better working conditions, greater economic security, and improved health and longevity in the United States and elsewhere, depends on institutions of governance, public investments, education, law, and public and private leadership.

Developed countries have experienced job polarization, widening income distributions, and contraction of traditional manufacturing in the last 20 years. But most other nations have done more than the United States to counter these undercurrents by investing in worker skills, strengthening social safety nets where needed, and incentivizing private sector firms to augment labor rather than to simply displace it. We repeat: the failure of the U.S. labor market to deliver broadly shared prosperity despite rising productivity is not an inevitable byproduct of current technologies or free markets. We can and should do better.

To begin to do better, however, we must first understand that today's challenge, and likely tomorrow's, is *not* too few jobs. Instead, it is the quality and accessibility of the jobs that will exist and the career trajectories they will offer to workers, particularly to those with less education. Addressing this challenge means channeling technological progress and accompanying productivity growth into a strong labor market that delivers broadly distributed income growth and economic security, as occurred in the decades after World War II.

The economic history of the twentieth century demonstrates that a healthy labor market can serve as the foundation, if not the entire basis, for shared prosperity. The United States must strengthen and build institutions, launch new investments, and forge policies that ensure that work remains a central, rewarded, esteemed, and economically viable avenue for most adults to prosper. We will propose further steps towards advancing those goals in our subsequent report.

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- ¹ See Wilson, William Julius. *When Work Disappears: The World of the New Urban Poor*. New York: Knopf, 1996; and Radcliff, Benjamin. 2001. "Politics, Markets, and Life Satisfaction: The Political Economy of Human Happiness." *American Political Science Review* 95 (4): 939–52. <https://doi.org/10.1017/S0003055400400110>.
- ² Here, we are paraphrasing a recent editorial by policy scholar Oren Cass: Cass, Oren, "The Communal Power of a Real Job." *New York Times*, 8/3/2019, <https://www.nytimes.com/2019/08/03/opinion/sunday/workers-conservatives.html>
- ³ Richard Wike and Bruce Stokes. "In Advanced and Emerging Economies Alike, Worries About Job Automation." Pew Research Center's Global Attitudes Project, September 13, 2018 <https://www.pewresearch.org/global/2018/09/13/in-advanced-and-emerging-economies-alike-worries-about-job-automation/>.
- ⁴ Aristotle predicted in *Politics*: Book I that "If... the shuttle would weave and the plectrum touch the lyre without a hand to guide them, chief workmen would not want servants, nor masters slaves."
- ⁵ Optimism is highest among Canadians, 47 percent of whom believe that these such jobs will emerge. Optimism is second-lowest among Americans at 25 percent, and lowest among Italians at 24 percent.
- ⁶ The consequences of technological change are almost always outside the control of the people most affected by them. New technologies are typically developed by industry, government, and academia. Workers whose skills are variously complemented or substituted by these technologies typically have no hand in their design, no voice in whether they are adopted by their employers, and no ownership stake that would potentially offset their employment losses with capital gains.
- ⁷ We join Robert Samuelson and others in rejecting the thesis of Arthur Okun's influential 1975 book, *Equality and Efficiency: The Big Tradeoff*. Washington, D.C: Brookings Institution Press. See Samuelson, Robert J. 2015. "Poof Goes the Big Tradeoff." *Washington Post*, May 10, 2015, sec. Opinions.
- ⁸ Raj Chetty et al., "The Fading American Dream: Trends in Absolute Income Mobility since 1940," *Science* 356, no. 6336 (April 28, 2017): 398–406.
- ⁹ Formally, we are referring to growth in Total Factor Productivity, equal to the growth of real output net of the growth of real inputs.
- ¹⁰ Data from Figure 16-5 of Robert J. Gordon, *The Rise and Fall of American Growth: The U.S. Standard of Living since the Civil War*, The Princeton Economic History of the Western World (Princeton: Princeton University Press, 2016).
- ¹¹ Robert M. Solow, "Technical Change and the Aggregate Production Function," *The Review of Economics and Statistics* 39, no. 3 (August 1957): 312, <https://doi.org/10.2307/1926047>.
- ¹² Frank Levy and Thomas Kochan, "Addressing the Problem of Stagnant Wages," *Comparative Economic Studies*, 54 (4), October 2012, 739–764.
- ¹³ While the real wage growth was less adverse among non-college women, there was a 15-plus year period between 1981 and 1997 when women with high school or lower education earned less than their counterparts in 1980.
- ¹⁴ Patten, Eileen, 2016. "Racial, Gender Wage Gaps Persist in U.S. Despite Some Progress." Pew Research Center: Fact Tank, July 1.
- ¹⁵ Kotkin, Joel. 2018. "The Midwest Is Booming—Just Not Where You Think." *The Daily Beast*, April 28, 2018, sec. us-news. <https://www.thedailybeast.com/the-midwest-is-boomingjust-not-where-you-think>. All of these cities are experiencing employment and population growth: Kansas City, Minneapolis, Indianapolis, Columbus, Grand Rapids, Des Moines, Charlotte, Raleigh, Austin, Nashville.
- ¹⁶ David H. Autor, "Work of the Past, Work of the Future," *AEA Papers and Proceedings* 109 (May 2019): 1–32, <https://doi.org/10.1257/pandp.20191110>.
- ¹⁷ See Christine J. Walley, *Exit Zero: Family and Class in Postindustrial Chicago* (Chicago; London: University of Chicago Press, 2013), Benjamin Austin, Edward Glaeser, and Lawrence Summers, "Jobs for the Heartland: Place-Based Policies in 21st Century America," *Brookings Papers on Economic Activity*, no. Spring (2018): 151–240, <https://doi.org/10.3386/w24548>, Frank Morgan R. et al., "Small Cities Face Greater Impact from Automation," *Journal of The Royal Society Interface* 15, no. 139 (February 28, 2018): 20170946, <https://doi.org/10.1098/rsif.2017.0946>, Jonathan Gruber and Simon Johnson, *Jumpstarting America: How Breakthrough Science Can Revive Economic Growth and the American*

Dream (New York, NY: Public Affairs, 2019). 2019, Case, Anne, and Angus Deaton. 2017. "Mortality and Morbidity in the 21st Century." *Brookings Papers on Economic Activity*, 397–467, and David H. Autor, "Work of the Past, Work of the Future," *AEA Papers and Proceedings* 109 (May 2019): 1–32, <https://doi.org/10.1257/pandp.20191110>. Austin et al. define the eastern heartland as the set of states extending geographically from Mississippi to Michigan, generally lying east of the Mississippi River, excluding the Atlantic Coast.

¹⁸ <https://www.nber.org/cycles/cyclesmain.html>

¹⁹ David H. Autor, "Work of the Past, Work of the Future," *AEA Papers and Proceedings* 109 (May 2019): 1–32, <https://doi.org/10.1257/pandp.20191110>.

²⁰ Figure source: Anna M Stansbury and Lawrence H Summers, "Productivity and Pay: Is the Link Broken?," *NBER Working Paper #24165*, December 2017. See also Erik Brynjolfsson and Andrew McAfee, *The Second Machine Age: Work, Progress, and Prosperity in a Time of Brilliant Technologies* (New York: W.W. Norton & Company, 2014).

²¹ Meanwhile, *average* worker compensation largely tracked labor productivity until 2000, after which time average compensation grew slower than labor productivity. This disjuncture indicates a fall in labor's share of national income, which poses an important (further) puzzle that is the subject of much recent research. Data are from Stansbury and Summers (2017).

²² Daron Acemoglu and David H. Autor, "Skills, Tasks and Technologies: Implications for Employment and Earnings," *Handbook of Labor Economics* 4B (2011): 1043–1171, [https://doi.org/10.1016/S0169-7218\(11\)02407-5](https://doi.org/10.1016/S0169-7218(11)02407-5).

²³ David H Autor, David Dorn, and Gordon H Hanson, "The China Shock: Learning from Labor Market Adjustment to Large Changes in Trade," *Annual Review of Economics* 8, no. 1 (September 2016): 205–240, <https://doi.org/10.1146/annurev-economics-080315-015041>. U.S. manufacturing employment fell from 17.4 million in January of 1999 to 14.0 million in January 2007 to a trough of 11.5 million in January of 2010. By July of 2019, it had risen to 12.9 million. (U.S. Bureau of Labor Statistics, All Employees: Manufacturing [MANEMP], retrieved from FRED, Federal Reserve Bank of St. Louis; <https://fred.stlouisfed.org/series/MANEMP>, August 22, 2019)

²⁴ Card, David. "The Effect of Unions on the Structure of Wages: A Longitudinal Analysis." *Econometrica* 64, no. 4 (July 1996): 957. <https://doi.org/10.2307/2171852>. Card, Lemieux, and Riddell, "Unions and Wage Inequality." Thomas Kochan and William Kimball, "Unions, Worker Voice, and Management Practices: Implications for a High Productivity-High Wage Economy. Forthcoming, Russell Sage Foundation *Journal of the Social Sciences*.

²⁵ Raj Chetty et al., "The Fading American Dream: Trends in Absolute Income Mobility since 1940," *Science* 356, no. 6336 (April 28, 2017): 398–406.

²⁶ Gilbert Cetté, Yusuf Kocoglu, and Jacques Mairesse, "Productivity Growth and Levels in France, Japan, the United Kingdom and the United States in the Twentieth Century," Working Paper (National Bureau of Economic Research, December 2009), <https://doi.org/10.3386/w15577>.

²⁷ See Facundo Alvaredo et al., "The Top 1 Percent in International and Historical Perspective," *Journal of Economic Perspectives* 27, no. 3 (August 2013): 3–20, <https://doi.org/10.1257/jep.27.3.3>; Stijn Broecke, Glenda Quintini, and Marieke Vandeweyer, "Wage Inequality and Cognitive Skills: Reopening the Debate," *Education, Skills, and Technical Change: Implications for Future U.S. GDP Growth*, January 26, 2018, 251–86. It bears note that there are also other large market economies that have been less successful than the United States in adapting to similar circumstances.

²⁸ The corresponding figures for the UK and Denmark are 9 percent and 11.7 percent. Raj Chetty et al., "Where Is the Land of Opportunity? The Geography of Intergenerational Mobility in the United States," *The Quarterly Journal of Economics* 129, no. 4 (November 1, 2014): 1553–1623, <https://doi.org/10.1093/qje/qju022>.

²⁹ Long, Jason, and Joseph Ferrie. 2013. "Intergenerational Occupational Mobility in Great Britain and the United States Since 1850." *American Economic Review* 103 (4): 1109–37. <https://doi.org/10.1257/aer.103.4.1109>.

³⁰ Claudia Goldin and Lawrence F Katz, *The Race Between Education and Technology* (Cambridge, Mass.: Belknap, 2008).

³¹ As the high school movement reached its conclusion, postsecondary education became increasingly indispensable to the growing occupations of medicine, law, engineering, science, and management. In 1940, only six percent of Americans had completed a four-year college degree. From the end of the Second World War to the early 1980s, the ranks of college-educated workers rose robustly and steadily, with each cohort of workers entering the labor market boasting a proportionately higher rate of college education than the cohort that preceded it. From 1963 through 1982, the fraction of all U.S. hours worked that were supplied by college graduates rose by almost one

percentage point per year, a remarkably rapid increase. A large body of economic research documents that the slowing entry of new college graduates into the U.S. labor market after 1980 contributed to the rapid rise in the college premium and attendant increase in wage inequality over the subsequent decades. David Card and Thomas Lemieux, “Can Falling Supply Explain the Rising Return to College for Younger Men? A Cohort-Based Analysis,” *The Quarterly Journal of Economics* 116, no. 2 (May 1, 2001): 705–46, <https://doi.org/10.1162/00335530151144140>.

- ³² For additional detail, see Hal Varian, “Automation vs. Procreation” https://www.bradford-delong.com/2018/09/hal-varian-_bots-vs-tots_.html, January 2018 and Daron Acemoglu and Pascual Restrepo, “Demographics and Automation,” NBER Working Paper No. 24421, March 2019, <https://doi.org/10.3386/w24421>.
- ³³ In 2019, 40 countries had shrinking working-age populations, defined as 15- to 64-year-olds, up from 9 countries in the late 1980s. Some of the large countries most affected include China, Japan, Germany, Italy, and Russia. While working population growth has slowed in the U.S., it is not currently anticipated to shrink in absolute terms. “Many Countries Suffer from Shrinking Working-Age Populations,” *The Economist*, May 5, 2018, <https://www.economist.com/international/2018/05/05/many-countries-suffer-from-shrinking-working-age-populations>.
- ³⁴ U.S. Bureau of Labor Statistics, Employment Projections. Table 3.1: Civilian labor force, by age, sex, race, and ethnicity, 1996, 2006, 2016, and projected 2026, <https://www.bls.gov/emp/tables/civilian-labor-force-summary.htm>
- ³⁵ These data indicate that the ratio of adults ages 65 and over to working-age adults ages 25 through 64 will rise from 0.24 in 2000 to 0.33 in 2020 to 0.44 in 2040.
- ³⁶ Between 2007 and 2017, the share of U.S. adults ages 25 to 29 with a high school diploma rose from 87.0 to 92.5 percent, the share with an associates degree or higher rose from 38.6 to 46.1 percent, while the share with a four-year college degree or higher rose from 29.6 to 35.7 percent. U.S. National Center for Education Statistics, *Digest of Education Statistics* 2017, Table 104.20: Percentage of persons 25 to 29 years old with selected levels of educational attainment, by race/ethnicity and sex: Selected years, 1920 through 2017, https://nces.ed.gov/programs/digest/d17/tables/dt17_104.20.asp
- ³⁷ A preview of the labor market pressures this will create can be glimpsed by studying the state of Maine, which has the highest median age (44.6) among all U.S. states. US Census Bureau, “The Nation’s Older Population Is Still Growing, Census Bureau Reports,” The United States Census Bureau, accessed August 17, 2019, <https://www.census.gov/newsroom/press-releases/2017/cb17-100.html>. Jeff Stein, “‘This Will Be Catastrophic’: Maine Families Face Elder Boom, Worker Shortage in Preview of Nation’s Future,” *Washington Post*, August 14, 2019, sec. Business, https://www.washingtonpost.com/business/economy/this-will-be-catastrophic-maine-families-face-elder-boom-worker-shortage-in-preview-of-nations-future/2019/08/14/7cecafc6-bec1-11e9-b873-63ace636af08_story.html. These demographic forces will also spur greater automation. See Daron Acemoglu and Pascual Restrepo, “Demographics and Automation,” March 2019, <https://doi.org/10.3386/w24421>.
- ³⁸ See Daron Acemoglu and Pascual Restrepo, “Demographics and Automation,” NBER Working Paper No. 24421, March 2019, <https://doi.org/10.3386/w24421>. These forces are already playing out in Japan.
- ³⁹ “The Challenges of Japan’s Demography - The Economist Explains,” *The Economist*, November 26, 2018. <https://www.economist.com/the-economist-explains/2018/11/26/the-challenges-of-japans-demography>.
- ⁴⁰ Amy Sue Bix, *Inventing Ourselves Out of Jobs?: America’s Debate Over Technological Unemployment, 1929–1981* (Johns Hopkins University Press, 2002).
- ⁴¹ See most prominently Carl Benedikt Frey and Michael A. Osborne, “The Future of Employment: How Susceptible Are Jobs to Computerisation?,” *Technological Forecasting and Social Change* 114 (2016): 254–280, <https://doi.org/10.1016/j.techfore.2016.08.019>.
- ⁴² Mokyr, Joel. “A review essay of Carl Benedikt Frey, *The Technology Trap: Capital Labor, and Power in the Age of Automation*.” September 2019, *Journal Of Economic History*, forthcoming.
- ⁴³ David A. Mindell, *Our Robots, Ourselves: Robotics and the Myths of Autonomy* (Viking Penguin, 2015).
- ⁴⁴ David H Autor, Frank Levy, and Richard J Murnane, “The Skill Content of Recent Technological Change: An Empirical Exploration,” *The Quarterly Journal of Economics* 118, no. 4 (2003): 1279–1333.
- ⁴⁵ Claudia Goldin and Lawrence F Katz, *The Race Between Education and Technology* (Cambridge, Mass.: Belknap, 2008).

- ⁴⁶ Daron Acemoglu and Pascual Restrepo, “Automation and New Tasks: How Technology Displaces and Reinstates Labor,” *Journal of Economic Perspectives* 33, no. 2 (May 2019): 3–30, <https://doi.org/10.1257/jep.33.2.3>. Quoting from their article, “The history of technology is not only about the displacement of human labor by automation technologies. If it were, we would be confined to a shrinking set of old tasks and jobs, with a steadily declining labor share in national income. Instead, the displacement effect of automation has been counterbalanced by technologies that create new tasks in which labor has a comparative advantage. Such new tasks generate not only a positive productivity effect, but also a reinstatement effect—they reinstate labor into a broader range of tasks and thus change the task content of production in favor of labor.”
- ⁴⁷ See Joel Mokyr, *The Lever of Riches: Technological Creativity and Economic Progress* (Oxford University Press, 1992). Jr. Chandler, Alfred D., *The Visible Hand: The Managerial Revolution in American Business* (Harvard University Press, 1977) and Daron Acemoglu and Pascual Restrepo, “Automation and New Tasks: How Technology Displaces and Reinstates Labor,” *Journal of Economic Perspectives* 33, no. 2 (May 2019): 3–30, <https://doi.org/10.1257/jep.33.2.3>. Quoting from their article, “The history of technology is not only about the displacement of human labor by automation technologies. If it were, we would be confined to a shrinking set of old tasks and jobs, with a steadily declining labor share in national income. Instead, the displacement effect of automation has been counterbalanced by technologies that create new tasks in which labor has a comparative advantage. Such new tasks generate not only a positive productivity effect, but also a reinstatement effect—they reinstate labor into a broader range of tasks and thus change the task content of production in favor of labor.”
- ⁴⁸ Guy Michaels, “The Division of Labour, Coordination, and the Demand for Information Processing,” SSRN Scholarly Paper (Rochester, NY: Social Science Research Network, June 1, 2007), <https://papers.ssrn.com/abstract=1136684>. Claudia Goldin and Lawrence F. Katz, *The Race Between Education and Technology* (Cambridge, Mass.: Belknap, 2008).
- ⁴⁹ Mindell, *Our Robots, Ourselves*. Jeffrey Lin, “Technological Adaptation, Cities, and New Work,” *The Review of Economics and Statistics* 93, no. 2 (2011): 554–74.
- ⁵⁰ See especially Robert J. Gordon, *The Rise and Fall of American Growth: The U.S. Standard of Living since the Civil War*, *The Princeton Economic History of the Western World* (Princeton: Princeton University Press, 2016).
- ⁵¹ We use the term digital technologies to denote the vast set of technologies made possible by symbolic processing, including computers, mobile telephony, the Internet, global positioning systems, artificial intelligence, robotics, and many others.
- ⁵² In fact, each time is different, but each differently so.
- ⁵³ David H. Autor, David Dorn, and Gordon H. Hanson, “The China Shock: Learning from Labor Market Adjustment to Large Changes in Trade,” *Annual Review of Economics* 8, no. 1 (September 2016): 205–240, <https://doi.org/10.1146/annurev-economics-080315-015041>.
- ⁵⁴ David H. Autor, “Why Are There Still So Many Jobs? The History and Future of Workplace Automation,” *Journal of Economic Perspectives* 29, no. 3 (August 2015): 3–30, <https://doi.org/10.1257/jep.29.3.3>.
- ⁵⁵ On the demand for blue-collar workers in 20th century industry, see Claudia Goldin and Lawrence F. Katz, “The Origins of Technology-Skill Complementarity,” *The Quarterly Journal of Economics* 113, no. 3 (August 1, 1998): 693–732, <https://doi.org/10.1162/003355398555720>.
- ⁵⁶ David H. Autor, “Skills, Education, and the Rise of Earnings Inequality Among the ‘Other 99 Percent,’” *Science* 344, no. 6186 (May 23, 2014): 99, <https://doi.org/10.1126/science.1251868>.
- ⁵⁷ See Robert J. Gordon, *The Rise and Fall of American Growth: The U.S. Standard of Living since the Civil War*, *The Princeton Economic History of the Western World* (Princeton: Princeton University Press, 2016). and Erik Brynjolfsson, Daniel Rock, and Chad Syverson, “Artificial Intelligence and the Modern Productivity Paradox: A Clash of Expectations and Statistics,” Working Paper (National Bureau of Economic Research, November 2017), <https://doi.org/10.3386/w24001>.
- ⁵⁸ While it is tempting to dismiss this puzzle as a failure of government statistical agencies to capture the technological bounty all around us, careful research rejects this explanation. See David M. Byrne, John G. Fernald, and Marshall B. Reinsdorf, “Does the United States Have a Productivity Slowdown or a Measurement Problem?,” *Brookings Papers on Economic Activity*, no. Spring (2016), <https://www.brookings.edu/bpea-articles/does-the-united-states-have-a-productivity-slowdown-or-a-measurement-problem/> and Chad Syverson, J. Baum, and Harris Professor, “Challenges to Mismeasurement Explanations for the US Productivity Slowdown,” *Journal of Economic Perspectives* 31, no. 2—Spring (2017): 165–186, <https://doi.org/10.1257/jep.31.2.165>.

- ⁵⁹ <https://www.bls.gov/emp/tables/occupations-largest-job-declines.htm>
- ⁶⁰ A large literature documents the substantial burden of displacement for affected workers, prolonged earnings and employment losses, impaired mental health, and premature mortality. L.S. Jacobson, R.J. LaLonde, and D.G. Sullivan, “Earnings Losses of Displaced Workers,” *The American Economic Review*, 1993, 685–709; Daniel Sullivan and Till von Wachter, “Job Displacement and Mortality: An Analysis Using Administrative Data,” *Quarterly Journal of Economics* 124, no. August (2009): 1265–1306, <https://doi.org/10.1162/qjec.2009.124.3.1265>; Steven J. Davis and Till von Wachter, “Recessions and the Costs of Job Loss,” *Brookings Papers on Economic Activity* 2011, no. 2 (2011): 1–72, <https://doi.org/10.1353/eca.2011.0016>.
- ⁶¹ Alison Kopf and Dan Griswold. “The Number of American Taxi Drivers Has Tripled in a Decade.” *Quartz*. Accessed August 28, 2019. <https://qz.com/1647247/more-americans-are-driving-taxis-thanks-to-uber-and-lyft/>.
- ⁶² A classic example is the deployment of Automated Teller Machines (ATMs) starting in the 1970s. ATMs served to reduce the number of bank tellers *per branch* by about a third between 1988 and 2004. By reducing staffing costs, however, ATMs also led banks to open more small urban bank branches, generating a modest net *rise* in teller employment. Finally, ATMs profoundly changed the job tasks of tellers. Instead of serving primarily as checkout clerks for cash, tellers increasingly functioned as salespersons, forging relationships with customers and offering additional bank services such as credit cards, loans, and investment products. James Bessen, “Toil and Technology,” *Finance and Development*, no. March (2015): 16–19.
- ⁶³ See https://en.wikipedia.org/wiki/Productivity_improving_technologies#Lighting_efficiency
- ⁶⁴ Nordhaus (1996) estimates that the real cost of 1,000 lumen-hours of light fell from 52.5¢ to 0.124¢ between 1827 and 1992, a more than four-hundred-fold reduction. William D Nordhaus, “Do Real-Output and Real-Wage Measures Capture Reality? The History of Lighting Suggests Not,” in *The Economics of New Goods* (University of Chicago Press, 1996), 27–70.
- ⁶⁵ To be clear, this is not necessarily bad for customers. Given the choice between using a self-checkout kiosk or paying extra for a human clerk, many customers might choose the kiosk.
- ⁶⁶ Daron Acemoglu and Pascual Restrepo, “Automation and New Tasks: How Technology Displaces and Reinstates Labor,” *Journal of Economic Perspectives* 33, no. 2 (May 2019): 3–30, <https://doi.org/10.1257/jep.33.2.3>.
- ⁶⁷ Note that a technology slightly degrades the quality of a product or service but reduces its price more than proportionately represents a productivity improvement. For example, Walmart greatly improved productivity in retailing by offering lower quality goods with limited customer service at extremely low prices.
- ⁶⁸ We stress that this is not the only possible explanation. Brynjolfsson et al. (2018) hypothesize that the gains from new workplace innovations are temporarily masked by the high fixed costs of deploying and integrating them into workplaces; once firms ascend this steep and costly learning curve, large measured productivity gains will follow. Erik Brynjolfsson, Daniel Rock, and Chad Syverson, “The Productivity J-Curve: How Intangibles Complement General Purpose Technologies,” Working Paper (National Bureau of Economic Research, October 2018), <https://doi.org/10.3386/w25148>.
- ⁶⁹ David H. Autor, “Work of the Past, Work of the Future,” *AEA Papers and Proceedings* 109 (May 2019): 1–32, <https://doi.org/10.1257/pandp.20191110>.
- ⁷⁰ We qualify the phrase “may share” because we cannot measure the root causes of popular sentiment. For a related argument on the role of popular dissatisfaction with the direction of technological change in history, see Carl Benedikt Frey, *The Technology Trap: Capital, Labor, and Power in the Age of Automation*. 2019, Princeton University Press.
- ⁷¹ This scenario has historical precedent. An oft-discussed epoch in the history of automation is the period between 1800 and 1840 known as Engel’s pause, during which British working-class wages stagnated despite rapid technological progress and rising GDP, with a similar phenomenon occurring in the U.S. between 1830 and 1870. (Robert C. Allen, “Engels’ Pause: Technical Change, Capital Accumulation, and Inequality in the British Industrial Revolution,” *Explorations in Economic History* 46, no. 4 (October 1, 2009): 418–35, <https://doi.org/10.1016/j.eeh.2009.04.004>.) Mechanization in this period was highly disruptive. Mechanization of textiles and the rise of mass production devalued the skills of highly-trained artisans and raised demand for relatively unskilled laborers—often children—who toiled for long hours tending machines. Factories in this era were cramped, dirty, disease-ridden, and often dangerous. Output rose but workers did not share in the benefits for decades. Engel’s pause eventually gave way to an era of broadly shared gains, which lasted from approximately the mid-nineteenth century through the mid-1970s. In that time, the acceleration of mass production enabled workers with modest

levels of formal education to be highly productive in factories and, for those with somewhat higher education, offices. Mass production has been central to the economic development of many high- and middle-income countries precisely because it seems to catalyze rapid growth from modest human capital inputs.

- ⁷² Daron Acemoglu and Pascual Restrepo, “Robots and Jobs: Evidence from US Labor Markets,” *Journal of Political Economy*, forthcoming, <https://doi.org/10.3386/w23285>; Asha Bharadwaj and Maximiliano A. Dvorkin, “The Rise of Automation: How Robots May Impact the U.S. Labor Market” Federal Reserve Bank of St. Louis, 2nd quarter, 2019. <https://www.stlouisfed.org/publications/regional-economist/second-quarter-2019/rise-automation-robots>
- ⁷³ Recent research by MIT Professor Julie Shah has shown how robots can help nurses make critical time-sensitive decisions on an obstetrics ward. See Matthew Gombolay, Xi Jessie-Yang, et al, “Robotic Assistance in Coordination of Patient Care,” *International Journal of Robotics Research*, June 22, 2018.
- ⁷⁴ Daron Acemoglu and Pascual Restrepo, “Demographics and Automation,” NBER Working Paper No. 24421, March 2019, <https://doi.org/10.3386/w24421>.
- ⁷⁵ Susan Helper, Robert Seamans, and Raphael Martins, “Complements or Substitutes? Firm Level Management of Labor and Technology”; Presented at NBER Summer Institute, 2019.
- ⁷⁶ Mindell, David. n.d. “Are Home Health Aides The New Turing Test For AI?” *Forbes*. Accessed August 30, 2019. <https://www.forbes.com/sites/davidmindell/2019/01/03/are-home-health-aids-the-new-turing-test-for-ai/>.
- ⁷⁷ Brynjolfsson, Erik, and Tom Mitchell. 2017. “What Can Machine Learning Do? Workforce Implications.” *Science* 358 (6370): 1530–1534. <https://doi.org/10.1126/science.aap8062>.
- ⁷⁸ Brynjolfsson, Erik, and Tom Mitchell. 2017. “What Can Machine Learning Do? Workforce Implications.” *Science* 358 (6370): 1530–1534. <https://doi.org/10.1126/science.aap8062>.
- ⁷⁹ Webb, Michael. “The Impact of Artificial Intelligence on the Labor Market.” Stanford University Working Paper, July 2019.
- ⁸⁰ In a recent study, the fastest adoption of autonomous trucks and cars suggested the peak of job displacement would occur around approximately 2045, allowing several decades for the labor market to adjust. See Erica Groshen, Susan Helper, et. al, “America’s Workforce and the Self-Driving Future: Realizing Productivity Gains and Spurring Economic Growth”, SAFE, June, 2018. https://avworkforce.secureenergy.org/wp-content/uploads/2018/06/Americas-Workforce-and-the-Self-Driving-Future_Realizing-Productivity-Gains-and-Spurring-Economic-Growth.pdf
- ⁸¹ Our discussion draws in part on Autor, David, Anran Li, and Matthew Notowidigdo. 2019. “Preparing for the Work of the Future: A Research Agenda.” J-PAL: North America.
- ⁸² Since labor market prospects for non-college workers in the U.S. have been stagnant or deteriorating for the better part of four decades (Figure 1), it is far from bold to predict that these trends will continue. But this continuity nevertheless underscores a core theme of this interim report: widespread anxiety about the work of the future likely stems in part from the discouraging reality of recent economic history for the majority of workers.
- ⁸³ Thomas Kochan, David Finegold and Paul Osterman, “Who Can Fix the Middle Skills Gap?” *Harvard Business Review*, December 2012 <https://hbr.org/2012/12/who-can-fix-the-middle-skills-gap>
- ⁸⁴ Abowd and Vilhuber (2011) document that gross worker job-to-job flows greatly exceed net flows, meaning that most job changes are not explained by contractions or expansions of the relevant job categories. John M. Abowd and Lars Vilhuber, “National Estimates of Gross Employment and Job Flows from the Quarterly Workforce Indicators with Demographic and Industry Detail,” *Journal of Econometrics* 161, no. 1 (March 1, 2011): 82–99, <https://doi.org/10.1016/j.jeconom.2010.09.008>.
- ⁸⁵ U.S. Bureau of Labor Statistics, Occupational Employment Projections, Table 1.1: Employment by Major Occupational Group, 2016 and Projected 2026, <https://www.bls.gov/emp/data/occupational-data.htm>
- ⁸⁶ Among currently employed production workers in 2016, however, 367 thousand were ages 65 and older, and an additional 1.52 million were ages of 55 to 64. U.S. Bureau of Labor Statistics, Household Data Annual Averages 2016: Table 11b: Employed Persons by Detailed Occupation and Age, https://www.bls.gov/cps/cps_aa2016.htm
- ⁸⁷ U.S. Bureau of Labor Statistics, *Occupational Outlook Handbook*, <https://www.bls.gov/ooh/healthcare/home.htm>, updated 4/12/2019.
- ⁸⁸ The rapidly growing set of medical aide occupations, including personal care aides, home health aides, and physical therapy aides, presently offers low pay and poor employment security. Paul Osterman, *Who Will Care For Us?: Long-Term Care and the Long-Term Workforce* (New York: Russell Sage Foundation, 2017).

- ⁸⁹ Koenig, Rebecca, “College Isn’t for Everyone. These Jobs May Be Good Options,” *US News & World Report*, January 28, 2019. Notably, of the twelve non-college occupations with median salaries exceeding \$50,000 reported in Koenig 2019, which based on U.S. Bureau of Labor Statistics data, seven are medical technical occupations, three are skilled trades (wind turbine technician, environmental engineering technician, plumber), one is in public safety (patrol officers), and only one is in information technology (web developer).
- ⁹⁰ As reported by the Community College Research Center of Columbia University, 5.8 million students were enrolled in public, two-year colleges and fall of 2017. About 2.1 million were full-time students, and 3.7 million were part-time. About 6.1 million were enrolled in all types of two-year colleges. See <https://ccrc.tc.columbia.edu/Community-College-FAQs.html>
- ⁹¹ An experimental evaluation of the Accelerated Study in Associate Programs (ASAP) initiative developed by the City University of New York (CUNY). ASAP’s supports include enrollment requirements, financial resources, structured pathways to support academic momentum, and advising, tutoring, and career development services. Scrivener et al. 2015 (Susan Scrivener et al., “Doubling Graduation Rates: Three-Year Effects of CUNY’s Accelerated Study in Associate Programs (ASAP) for Developmental Education Students,” Text (MDRC, February 2015), <https://www.mdrc.org/publication/doubling-graduation-rates/>.) and Weiss et al. 2019 (Michael J. Weiss et al., “Supporting Community College Students from Start to Degree Completion: Long-Term Evidence from a Randomized Trial of CUNY’s ASAP,” *American Economic Journal: Applied Economics* 11, no. 3 (July 2019): 253–97, <https://doi.org/10.1257/app.20170430>.) evaluate the benefits of this program for CUNY students using random assignment and find that it increases the graduation rate of participants by 18 percentage points, which is almost double the rate of 22 percent in the control group over three years. After six years, degree completion rates of ASAP students remain 10 percentage points above control group members, indicating that ASAP did not merely accelerate degree completion but increased it in absolute terms. ASAP was subsequently implemented at three community colleges in Ohio. Sommo et al. (2018) report that 19 percent of ASAP participants in the Ohio colleges earned a degree or credential compared with 8 percent of the control group two years after random assignment to the program.
- ⁹² Harry J. Holzer, “Raising Job Quality and Skills for American Workers: Creating More-Effective Education and Workforce Development Systems in the States” (Brookings Institution: The Hamilton Project, November 2011), <https://www.brookings.edu/research/raising-job-quality-and-skills-for-american-workers-creating-more-effective-education-and-workforce-development-systems-in-the-states/>.
- ⁹³ Some examples include the LEAP program in Massachusetts or the Ohio Manufacturing Workforce Partnership (a partnership of Ohio TechNet and the Ohio Manufacturers’ Association among others) both collaborations between higher educational institutions and industry with a focus on advanced manufacturing.
- ⁹⁴ U.S. Department of Education, National Center for Education Statistics, Integrated Postsecondary Education Data System (IPEDS), Finance component final data (fiscal years 2006 – 2016) and provisional data (fiscal years 2004, 2005, 2017). Data accessed August 18, 2019 from <https://nces.ed.gov/ipeds/TrendGenerator>
- ⁹⁵ For more on this topic, see T. Deissinger. and P. Gonon, (2016), “Stakeholders in the German and Swiss vocational educational and training system”, *Education + Training*, Vol. 58 No. 6, pp. 568-577. <https://doi.org/10.1108/ET-02-2016-0034>; Coop programs and other forms of experiential learning that take place at universities are also gaining in importance as outlined in I. Von Weitershausen, “Training for the ‘Work of the Future’: The Role of Work-Based Higher Education Programs in Germany and the United States,” MIT Work of the Future working paper (forthcoming).
- ⁹⁶ An example of an apprenticeship program in the United States that is widely considered to be successful is the Georgia Youth Apprenticeship Program, which benefits from a collaboration between state government, high schools, postsecondary schools, businesses, and worksite supervisors (Robert I. Lerman, Daniel Kuehn, and Jessica Shakesprere, “Youth Apprenticeships in Georgia: Experiences and Recommendations” (Urban Institute, May 2019), <https://www.urban.org/research/publication/youth-apprenticeships-georgia>).
- ⁹⁷ See Nelson Schwartz, “Job Training Can Change Lives. See How San Antonio Does It”, *New York Times*, August, 19, 2019. <https://www.nytimes.com/2019/08/19/business/economy/worker-training-project.html>
- ⁹⁸ David Autor, Anran Li, and Matthew Notowidigdo, “Preparing for the Work of the Future: A Research Agenda” (J-PAL: North America, April 2019).
- ⁹⁹ Lola Fadulu, “Why Is the U.S. So Bad at Worker Retraining?,” *The Atlantic*, January 4, 2018, <https://www.theatlantic.com/education/archive/2018/01/why-is-the-us-so-bad-at-protecting-workers-from-automation/549185/>.

- ¹⁰⁰ I. Elaine Allen and Jeff Seaman, “Changing Course: Ten Years of Tracking Online Education in the United States” (Babson Survey Research Group and Quahog Research Group, LLC., January 2013), <https://eric.ed.gov/?id=ED541571>.
- ¹⁰¹ Maya Escueta et al., “Education Technology: An Evidence-Based Review” (Cambridge, MA: National Bureau of Economic Research), August 2017. Eric P. Bettinger et al., “Virtual Classrooms: How Online College Courses Affect Student Success,” *American Economic Review* 107, no. 9 (September 2017): 2855–75; and Goodman, Joshua, Julia Melkers, and Amanda Pallais. “Can online delivery increase access to education?,” *Journal of Labor Economics* 37, no. 1 (2019): 1–34.
- ¹⁰² While we know a great deal about how infants and children learn, we know relatively little about how adults learn. Research shows that frequent practice problems and feedback, including online quizzes, may double learning attainment, and frequent practice tests dramatically improve information retention. Importantly, “fluid” skills—those that help us with speed of processing or working or long-term memory, decline steadily with age (starting at age 20!). However, “crystallized skills” or domain knowledge—knowing how a machine or a system more broadly works—increases with age well into one’s seventies. This latter point is important to integrate into our strategies for employing older workers over time. As Task Force members from managers of manufacturing firms across the country, older workers possess valuable knowledge that needs to be retained and passed along to subsequent cohorts of workers.
- ¹⁰³ Kana Okano, Jakub R. Kaczmarzyk, and John D. E. Gabrieli, “Enhancing Workplace Digital Learning by Use of the Science of Learning,” *PLOS ONE* 13, no. 10 (October 24, 2018): e0206250, <https://doi.org/10.1371/journal.pone.0206250>.
- ¹⁰⁴ Approximately 30 percent of students who started community college in the fall of 2011 transferred to a four-year institution within six years. <https://ccrc.tc.columbia.edu/Community-College-FAQs.html>
- ¹⁰⁵ “Connecting Credentials: Making the Case for Reforming the U.S. Credentialing System” (Lumina Foundation, June 2015), <https://www.luminafoundation.org/files/resources/making-the-case.pdf>.
- ¹⁰⁶ Approximately 40 percent of students who start four-year degrees do not finish within six years, where the non-completion rate is strongly negatively correlated with the selectivity of the institution. For example, at 4-year institutions with open admissions policies, 32 percent of students completed a bachelor’s degree within 6 years. At 4-year institutions where the acceptance rate was less than 25 percent, the 6-year graduation rate was 88 percent. “The Condition of Education 2018” (U.S Department of Education, May 2018), <https://nces.ed.gov/pubsearch/pubsinfo.asp?pubid=2018144>. Section 2.1: Undergraduate Retention and Graduation Rates.
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- ¹⁰⁸ For further discussion, see also Daron Acemoglu, “It’s Good Jobs, Stupid,” *Economics for Inclusive Prosperity* (blog), June 2019, <https://econfip.org/policy-brief/its-good-jobs-stupid/>.
- ¹⁰⁹ Recommendation of the Investor Advisory Committee, Human Capital Management Disclosure, March 28, 2019. <https://www.sec.gov/spotlight/investor-advisory-committee-2012/human-capital-disclosure-recommendation.pdf>
- ¹¹⁰ This view originates with Milton Friedman in his magnum opus, *Capitalism and Freedom*, “There is one and only one social responsibility of business—to use its resources and engage in activities designed to increase its profits so long as it stays within the rules of the game, which is to say, engages in open and free competition without deception or fraud.” Milton Friedman, *Capitalism and Freedom* (University of Chicago Press, 1962), p133.
- ¹¹¹ Some argue further that a firm’s stakeholders includes its customers and suppliers, who in some sense are among its longest-term investors. See Kent Greenfield, *Corporations Are People Too: (And They Should Act Like It)* (New Haven; London: Yale University Press, 2018).
- ¹¹² David Gelles and David Yaffe-Bellany, “Shareholder Value is no Longer Everything Top CEOs Say”, *The New York Times*, August 19, 2019. Responding to the Business Roundtable’s policy statement, the *Economist* magazine offers a reasoned defense of shareholder capitalism (*The Economist*. “What Companies Are For,” August 22, 2019. <https://www.economist.com/leaders/2019/08/22/what-companies-are-for>). But their editorial does not grapple with the failure of shareholder capitalism to appropriately internalize external costs to workers from firm business practices. These externalities are the basis of our argument.

- ¹¹³ *New York Times* columnist Nicolas Kristof wrote recently, “It was common to scorn union leaders as corrupt Luddites who used ridiculous work rules to block modernization and undermine America’s economic competitiveness. There’s something to those critiques. Yet it’s now clear that the collapse of unions... has been accompanied by a rise of unchecked corporate power, a surge in income inequality and a decline in the well-being of working Americans.” Kristof, Nicholas, “Trump Finds a Brawler for His War on Workers,” *New York Times* August 11, 2019, sec. SR.
- ¹¹⁴ Responding to the slow implosion of traditional employer-based unions, the 21st century has recently seen new models of organization and collective bargaining. New membership models for worker voice are under development that seek to create powerful non-employer-based advocacy organizations that derive power and influence through collective action on behalf of their members.
- ¹¹⁵ Thomas Kochan, “Building the Institutions Needed to Strengthen Worker Voice,” The Aspen Institute, August 7, 2018 <https://www.aspeninstitute.org/blog-posts/building-the-institutions-needed-to-strengthen-worker-voice/>
- ¹¹⁶ See L.S. Jacobson, R.J. LaLonde, and D.G. Sullivan, “Earnings Losses of Displaced Workers,” *The American Economic Review*, 1993, 685–709; Daniel Sullivan and Till von Wachter, “Job Displacement and Mortality: An Analysis Using Administrative Data,” *Quarterly Journal of Economics* 124, no. August (2009): 1265–1306, <https://doi.org/10.1162/qjec.2009.124.3.1265>.
- ¹¹⁷ The National Labor Relations Act of 1935, which establishes the right to collective bargaining, bans the organization of labor unions by employers on the theory that company unions are intrinsically suspect.
- ¹¹⁸ Erik Brynjolfsson and Lorin M. Hitt, “Beyond Computation: Information Technology, Organizational Transformation and Business Performance,” *Journal of Economic Perspectives* 14, no. 4 (December 2000): 23–48, <https://doi.org/10.1257/jep.14.4.23>; Erik Brynjolfsson, Daniel Rock, and Chad Syverson, “The Productivity J-Curve: How Intangibles Complement General Purpose Technologies,” Working Paper (National Bureau of Economic Research, October 2018), <https://doi.org/10.3386/w25148>.
- ¹¹⁹ Tom Kochan, Susan Helper, Alexander Kowalski, and John Van Reenen. “Baseline Memo for Work of the Future Task Force: Interdependence of Technology and Work Systems,” December 2018.
- ¹²⁰ See Nicholas Bloom and John Van Reenen, “Measuring and Explaining Management Practices Across Firms and Countries,” *Quarterly Journal of Economics* 122, no. November (2006): 1351–1408.
- ¹²¹ Nicholas Bloom et al., “What Drives Differences in Management Practices?,” *American Economic Review* 109, no. 5 (May 2019): 1648–83, <https://doi.org/10.1257/aer.20170491>.
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- ¹²³ Nicholas Bloom et al., “Does Management Matter? Evidence from India,” *The Quarterly Journal of Economics* 128, no. 1 (February 1, 2013): 1–51, <https://doi.org/10.1093/qje/qjs044>; Nicholas Bloom et al., “Do Management Interventions Last? Evidence from India,” Working Paper (National Bureau of Economic Research, January 2018), <https://doi.org/10.3386/w24249>.
- ¹²⁴ The Chinese government is reportedly spending in excess of \$1 billion a year on AI. Europe countries, especially France and Germany but also Sweden and the Netherlands, are investing heavily in coordinated ways. The U.K. has announced a \$64 million fellowship fund to attract top machine learning researchers to the country as part of an effort to increase productivity by 25 percent by 2035. Canada started the Vector Institute in Toronto with \$50 million of Canadian federal investment, \$50 million from Ontario, and \$100 million from industry.
- ¹²⁵ Dennis Normille, “Surging R&D Spending in China Narrows Gap with United States.” *Science*, October 10, 2018. <https://www.sciencemag.org/news/2018/10/surging-rd-spending-china-narrows-gap-united-states>.
- ¹²⁶ For more discussion on this history, see Jonathan Gruber and Simon Johnson, *Jumpstarting America: How Breakthrough Science Can Revive Economic Growth and the American Dream* (New York, NY: Public Affairs, 2019).

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