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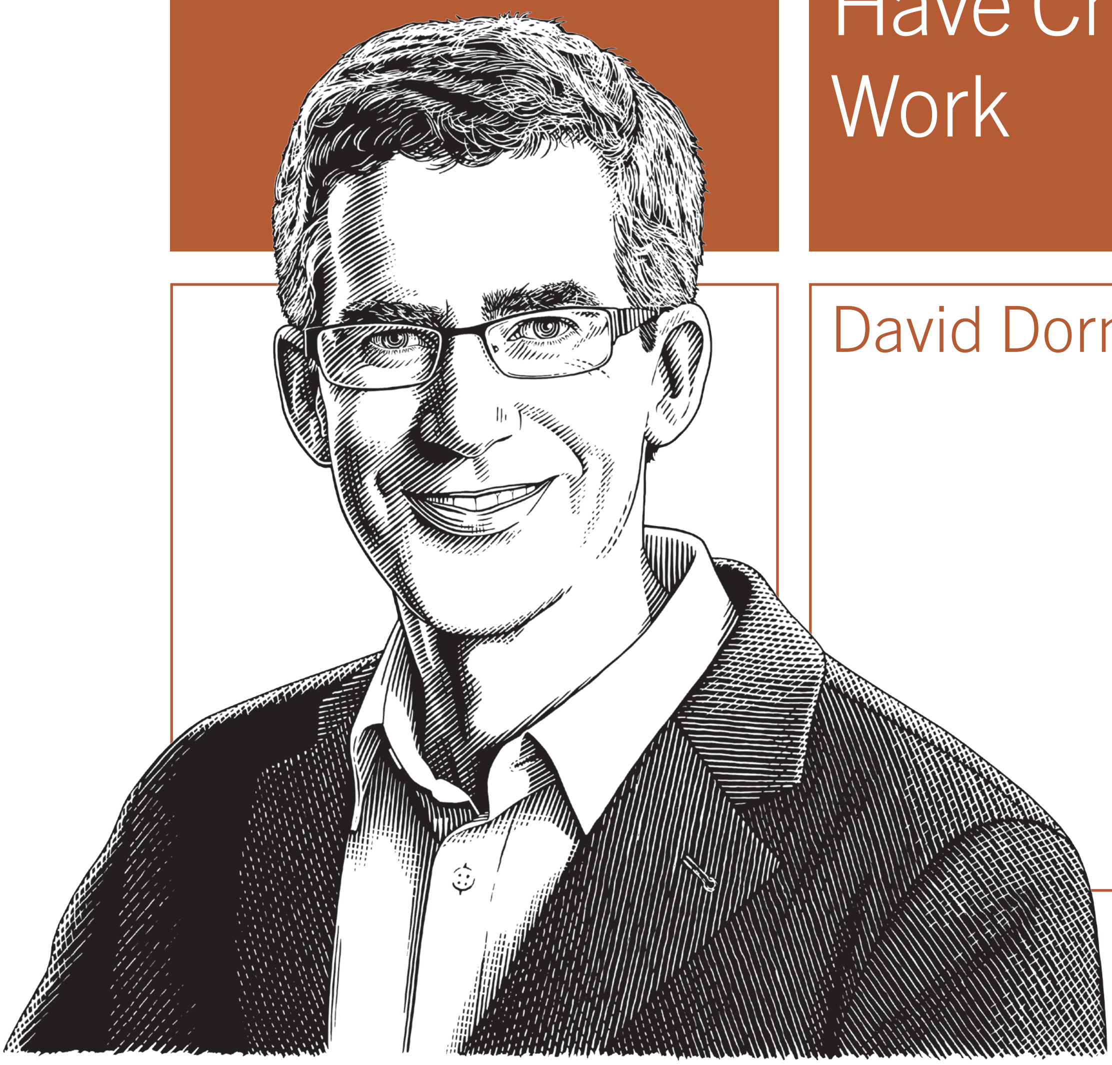
The Rise of the Machines

How Computers Have Changed Work

David Dorn



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About the Author

Prof. David Dorn

– Professor at the Department of Economics, University of Zurich
– Affiliated Professor at the UBS Center

Contact david.dorn@econ.uzh.ch

David Dorn is Professor of International Trade and Labor Markets at the University of Zurich and Affiliated Professor at the UBS Center. He was previously a tenured Associate Professor at the Center for Monetary and Financial Studies (CEMFI) in Madrid, a Visiting Professor at Harvard University, and a Visiting Scholar at Boston University, MIT, and the University of Chicago.

His research connects the fields of labor economics, international trade, economic geography, and macroeconomics. In particular, he studies how globalization and technology affect labor markets.

Professor Dorn is a Research Fellow of the Centre for Economic Policy Research (CEPR) in London, the Institute for the Study of Labor (IZA) in Bonn, and the Center for Economic Studies/ifo Institute (CESifo) in Munich. He is on the Editorial Board of *The Review of Economic Studies*, and an Associate Editor of the *Journal of the European Economic Association*.

His research on the labor market impacts of technology was funded in part by the Swiss National Science Foundation (SNSF) and the Spanish Ministry of Science and Innovation.

Abstract

The so-called “Rise of the Machines” has fundamentally transformed the organization of work during the last four decades. While enthusiasts are captivated by the new technologies, many worry that these machines will eventually lead to mass unemployment, as robots and computers substitute for human labor.

This Public Paper shows that these concerns are likely to be exaggerated. Despite rapid technological progress and automation, unemployment has not dramatically expanded over time. Instead, employment shifted from the most highly automated sectors to other sectors that experienced less technological progress, as well as emerging sectors that were created by new technology.

While computers have little impact on overall employment, however, they contribute to rising inequality. Machines have overtaken humans in their capability to execute well-defined routine tasks precisely, and many of the production and clerical jobs that specialize in these tasks have been irreversibly lost. As a result, the employment structure of labor markets in developed countries has become increasingly polarized as employment concentrates in a set of highly paid and a set of lowly paid occupations, both of which are difficult to automate.

As computerization changes the composition of human labor rather than decreasing its overall amount, policymakers should not be primarily concerned about mass unemployment. Instead, the more immanent policy challenges caused by computerization result from changing skill demands in the labor market and rising economic inequality among workers.

Introduction

The first fifteen years of the 21st century have been a difficult period for workers in developed economies. In many wealthy European, North American, and East Asian countries, the share of population holding a job has declined, and wage growth for the average worker has slowed or even turned negative. The "Great Recession" of the years 2007–2009 is to blame for an important part of this decline in workers' fortunes. However, the employment rate in the United States had already been falling for several years prior to this crisis, and labor markets in many countries remained depressed for a remarkably long time after the recession had officially ended.[1] New evidence also suggests that the fraction of national income obtained by workers has been declining for at least three decades in developed countries.[2]

It is therefore natural to hypothesize that labor markets are not just in a temporary slump, but instead face a fundamental force that increasingly deteriorates workers' outlook for finding a job. Computer technology is an obvious candidate for that role. Whether one enters an office building or a factory, the widespread use of personal computers, communication devices, computer-guided machines, and robots is a striking feature of the workplace of the 21st century. Computer technology often replaces work tasks that humans previously executed, and one thus wonders whether continued technological development will eventually lead to the obsolescence of most human labor.

This essay discusses the impact of technology on the labor markets in developed countries. It argues that an imminent large decline in the demand for human labor is far from certain, and that speculation about the long-term evolution of employment is inherently difficult. However, there are already hundreds of years of experience regarding the technological change of the past, and researchers have been able to study the impact of computer technology on the labor market for several decades. I argue that the evidence from the distant and recent past reveals recurring patterns, which may usefully guide expectations about technology's impact on labor markets in the near future.

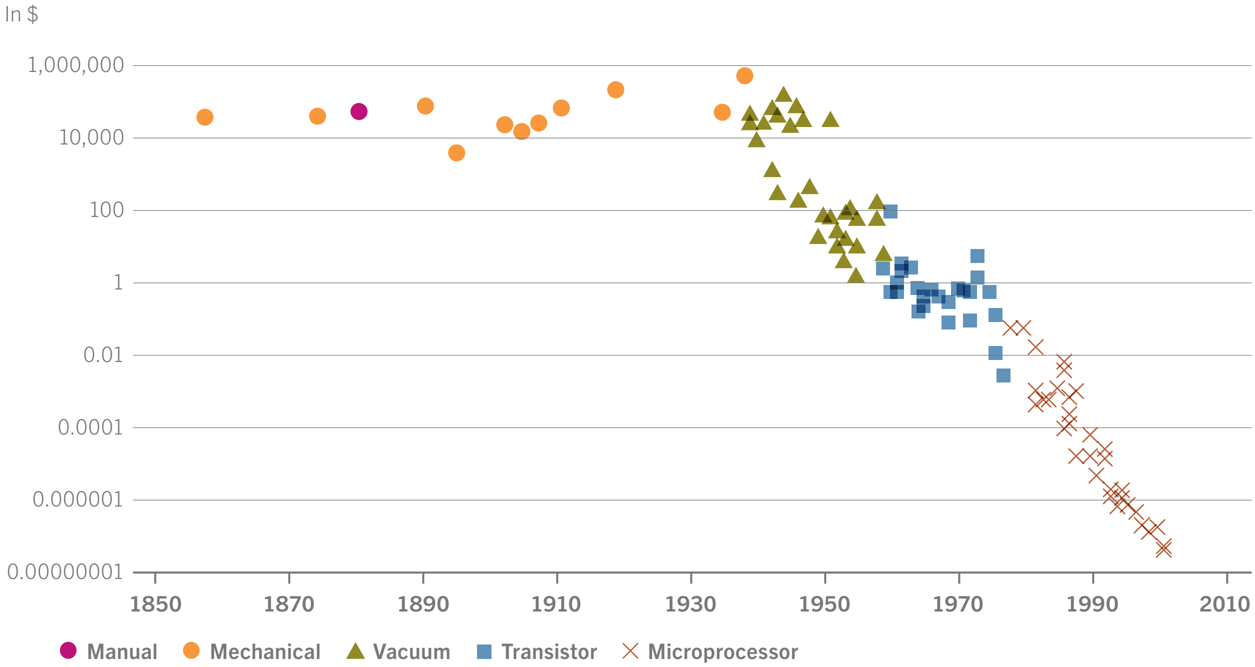
Is Technological Development Just Beginning or About to End?

Gordon E. Moore, co-founder of Fairchild Semiconductor and Intel Corporation, predicted in 1975 that technological progress in the semiconductor industry would allow a doubling in the number of electronic components per microchip every two years, thus leading to rapid progress in computer processing power. This prediction, which became known as "Moore's Law," has held up remarkably well since then. The dramatic progress in semiconductor technology led to great performance improvements in many electronic devices, and to rapidly declining prices of computing equipment. Data compiled by the economist William Nordhaus indicates that the cost per million computing operations has been falling spectacularly since the 1950s (Figure 1).[3]

Computers are not only becoming cheaper and more powerful, but also more versatile. New applications in areas such as machine learning, artificial intelligence, and mobile robotics hold great promise for expanding the use of computer technology to an ever-wider set of tasks. One of the most publicized innovations in recent years is the self-driving car, which may profoundly reshape ground transportation in the 21st century.

Erik Brynjolfsson and Andrew McAfee, two scholars at the MIT Sloan Business

Fig. 1 **Evolution of cost per computing operation (1850–2010)**



Note: The costs represent $ per million standardized computing operations per second (MSOPS).

Source: Nordhaus (2001)

School, argue that the rapid fall in computer prices and the wider applicability of computer technology are heralding a "Second Machine Age" that will transform the economies of developed countries to an even greater degree than the Industrial Revolution.[4] As ever-cheaper robots are able to execute an ever-greater range of tasks, firms will only hold on to workers as long as a machine cannot execute their jobs more cheaply. The result is enormous downward pressure on workers' wages, and as these wages fall below a reservation level—the minimum level of wages that makes it worthwhile for people to hold a job—a rapidly growing pool of unemployed individuals will form.

A technology-driven disappearance of most employment opportunities will profoundly change society, and will require a new organization of many public institutions. Despite the chilling outlook of mass unemployment, the Second Machine Age will not only produce losers, however. The widespread use of cheap robots in production will lower production costs, and the resulting productivity increase raises aggregate societal wealth. However, these gains are likely to be concentrated among a small group of owners of computer capital, while a much larger fraction of the society will suffer from the loss of gainful employment. It is an interesting intellectual exercise to think about appropriate public policies that could successfully deal with a workless and highly unequal society.

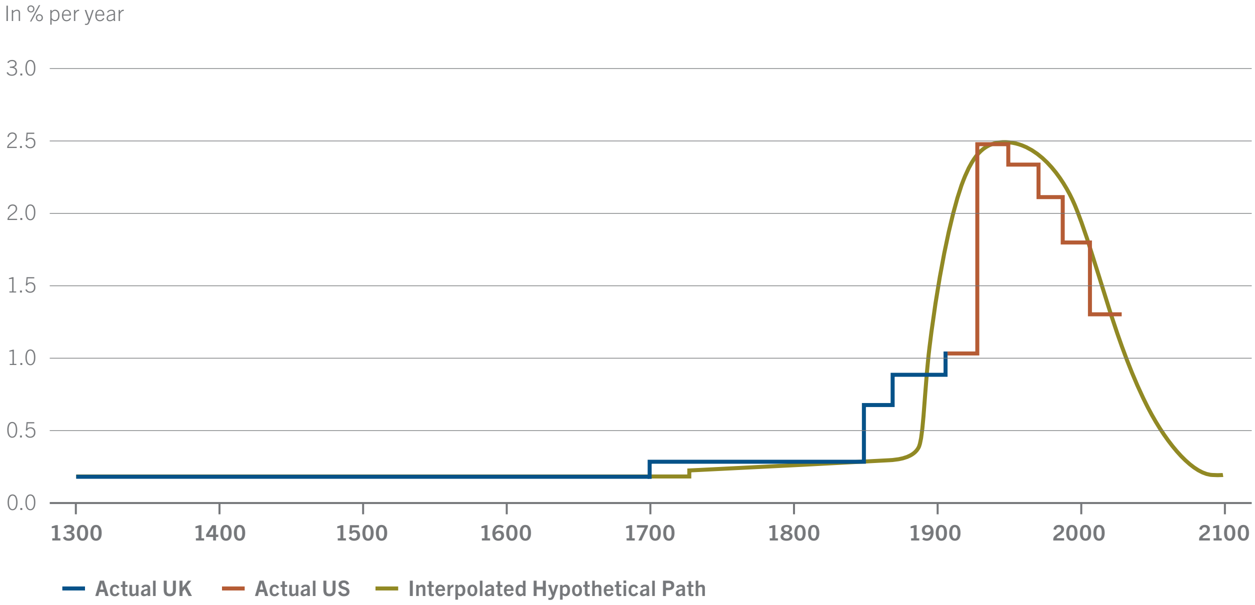
The jobless robot age predicted by Brynjolfsson and McAfee is, however, far from certain. Quite to the opposite, Robert Gordon, an economic historian from Northwestern University, posits that technological change is slowing rather than accelerating.[5] He argues that the period of greatest technological advance in history is not the computerization of the late 20th and early 21st century, but the hundred years from the early 1870s to the early 1970s. This century of "Great Innovation" saw the discovery of electricity and the development of a panoply of electrical devices; the invention of the internal combustion engine which revolutionized transportation; a great improvement in sanitary and living conditions due to running water, indoor plumbing, and central heating; the ability to rearrange molecules which permitted great progress in the development of pharmaceuticals, plastics, and other chemical products; and the introduction of major communication and entertainment technology, following the invention of the telephone, the phonograph, photography, radio, and motion pictures within a span of just fifteen years.

Annual growth of U.S. GDP per capita accelerated during the Great Innovation period, and peaked at a 2.5% average gain per year between 1950 and the onset of the oil crisis in 1973. In the four decades since, average annual GDP growth has been one-third lower at 1.6% per year. While annual growth even exceeded 4% in the ten years during the 1950–1973 period, such a high growth rate has never again been attained during the last thirty years. This slowdown in economic growth is not unique to the United States, but it is even more pronounced in Japan and in the major European economies.

Gordon argues that the slowdown in economic growth results from a slowdown in innovation. The Great Innovation century, which was characterized by major developments in multiple important technologies, has been followed by a period with a comparatively one-dimensional development in computer technology alone. Indeed, Gordon makes the provocative prediction that innovation and economic growth will continue to slow as it becomes increasingly difficult for humanity to come up with fundamentally novel discoveries (see Figure 2).

Of course, pathbreaking future innovation is extremely difficult to predict. Who would have foreseen today's omnipres-

Fig. 2 **Economic growth in countries with technological leadership (1300 – 2100)**



Note: Growth in real GDP per capita with actual and hypothetical paths.

Source: Gordon (2012)

ence of the internet-connected multipurpose smartphone just thirty years ago? But as much as it is problematic to extrapolate the slowdown in economic growth into the future, one can also not confidently extrapolate past trends in the development of computer technology—or foresee an acceleration of that development—in order to conclude that an age of robots is immanent and inevitable.

While long-term predictions are notoriously difficult, this essay argues that one can learn important lessons from past experience. Historical evidence not only allows assessing the impacts of past technological change on the labor market, but these impacts can be contrasted with past predictions about the transformative effects of technology. Indeed, concerns about the replacement of workers by machines date back many centuries, and there also is mounting evidence on the role of computers and robots in the labor market during the last three to four decades.

Drawing on Past Experience: A Short History of Technological Change in Textile Production

Humans have been producing textile clothing for thousands of years. In this production process, cotton, wool, or other fibers are first converted to yarn, then yarn is converted to cloth, and finally cloth is converted to clothing. While the basic sequence of production steps remained unchanged over time, there were dramatic improvements in the execution of each step. During the Industrial Revolution, the textile industry was at the forefront of a broader trend towards mechanization of production. Yet already prior to that transformative period, the textile sector provided a useful example for the study of technological change and its labor market implications.

A first major innovation in the textile sector affected the process of spinning, i.e., the conversion of fiber to yarn. Historically, humans would attach fibers to a spindle and rotate that spindle by hand in order to twist fibers to yarn. From about the 13th century onwards, these hand spindles were gradually replaced by spinning wheels, which took advantage of the rotational energy of a wheel, and greatly increased the productivity of the spinning process.

The introduction of the spinning wheel met occasional resistance from the crafts guilds that controlled production in many European territories. According to historical documents, the city council of Cologne decided in the year 1412 that a local merchant by the name of Walter Kesinger would not be allowed to construct a spinning wheel, after he had seen such a machine during travels in Italy. The council argued that many spinners would lose their livelihood if the use of the new, more productive technology were permitted.[6]

Mechanization also reached the second production step of the textile industry, the weaving of yarn to cloth. As of the 17th century, a predecessor of the mechanized loom permitted the simultaneous production of up to 24 woven ribbons, a dramatic improvement over the classical loom that could only produce one ribbon at a time. To prevent employment loss among ribbon weavers, the German emperor prohibited the use of this mechanized ribbon loom in 1685, and regents of many other European territories did the same.

The imposition of technology bans in an attempt to prevent employment loss, however, proved counterproductive in the long run. Right outside the borders of the German empire, craftsmen in the Swiss city of Basel adopted the new ribbon-weaving machine, and were thus able to produce at much lower cost than their German counterparts. Competitive pressure from technology adopters eventually led to growing opposition against the German empire's machine ban, which was finally revoked in the mid-18th century.[7]

The process of textile production soon changed even more dramatically with a series of inventions in the late 18th century, at the start of the Industrial Revolution. The spinning wheel was replaced by the "Spinning Jenny," a multispindle spinning frame that could produce many yarns at a time. Weaving was revolutionized by the introduction of the power loom, an automated loom that was powered by steam or water energy rather than by human hand.

The new production technology required expensive machines and access to a central power source. Therefore, the decentralized home production of yarn and cloth by spinning wheels and handlooms was replaced by mass production in factories. In a mechanized factory, a single worker was able to produce an output that would have required dozens of workers prior to the Industrial Revolution.

The massively reduced need for human labor in textile production led to popular unrest in England. Unemployed workers protested against the new system of factory production, and in some cases attacked factories and smashed machines. The British government reacted by making "machine breaking" a capital crime. The protesting workers, who became known as Luddites after their alleged leader Ned Ludd, were persecuted and their movement broken up.

A common theme during these centuries of technological progress in the textile industry was the fear that new labor-saving technologies would lead to long-term mass unemployment. Indeed, the introduction of new machines certainly disrupted the labor market, and many workers lost their jobs when their work tasks became mechanized. While concerns about technology-induced unemployment were well founded in the short run, the predicted long-term decline in employment never materialized.

An intuitive, and yet profoundly mistaken view of the labor market is that there is a fixed amount of work, which can either be done by humans or by machines. According to this view—known to economists as the "lump of labor fallacy"—an increasing use of machines in the production process nec-

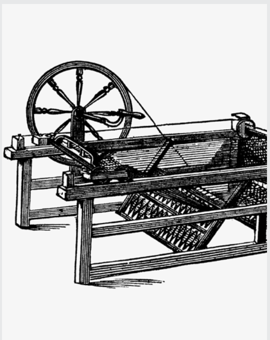
Key technological changes in the spinning industry

Hand spinning

Woman using a hand spindle. Detail from an Ancient Greek Attic white-ground oinochoe (wine jug), ca. 490 BC, from Locri, Italy.

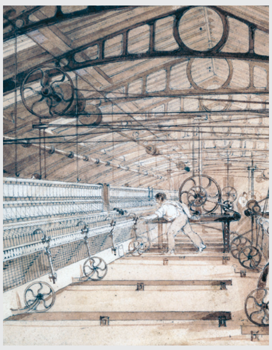
Spinning wheel

Woman spinning with a wheel, from the Elizabethan era, early 17th century.



Spinning frame

The improved "Spinning Jenny" that was used in textile mills, England, 18th century. A worker operating a "Spinning Jenny" with 60 spindels could replace about 25 hand spinners.



Automated spinning machine

Factory building with "Mule Jenny," England, 1834. A worker operating a "Mule Jenny" with 14 spindles could replace about 175 hand spinners.

essarily reduces the work that is available to humans. This contention is a fallacy because it fails to recognize two channels through which even labor-replacing new technologies can create additional employment.

First, new technology is often associated with the emergence of new industries and occupations. The development of spinning machines and power looms, for instance, led to the creation of many jobs in a new machine-producing industry. Second, there is a less obvious but probably more important job creation effect that operates via changes in prices and consumer spending. Mass production in the textile industry led to a dramatic drop in the price of clothing. This price decline allowed consumers either to buy a greater quantity of clothing with the same amount of money, or to buy the same amount of clothing at lower cost while expanding purchases of other goods and services. The resulting increase in demand for clothing and other outputs led to greater production and rising employment in many sectors of the economy, particularly in those that were not directly exposed to labor-saving technology.

Over time, technological change did not eliminate employment, but it strongly changed its composition. From the 19th to the late 20th century, a large part of employment first moved from agriculture to manufacturing, and later from manufacturing to the service sector. It would have been unthinkable two centuries ago that agriculture, which employed the large majority of workers at that time, would account merely for a few percentage points of overall employment today, despite producing a much greater output. Yet unemployment has not shown a pronounced upward trend over time, as workers have found new employment opportunities in industries like healthcare, finance, and entertainment, where the rising employment shares would have been equally difficult to foresee. By ignoring the emergence of new employment opportunities, many past observers of technological change have fallen victim to the "Luddite fallacy" of wrongly predicting a rise of long-term unemployment (see box on the next page).

The Luddite fallacy in numbers

Fig. 3 **Unemployment rate**

Unemployed in % of economically active population aged 16 and over

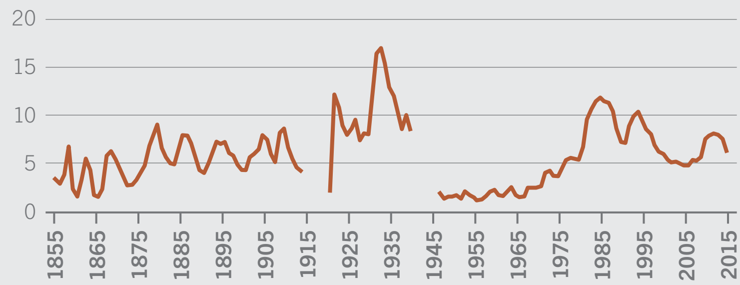
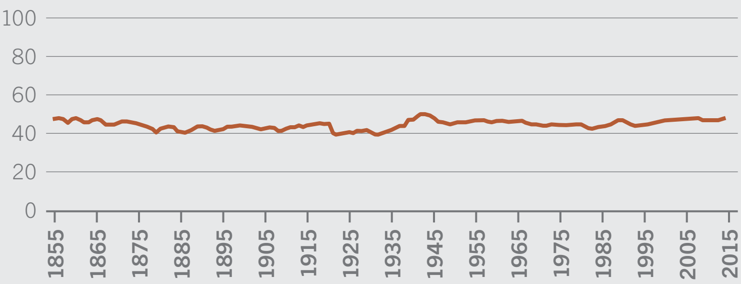


Fig. 4 **Employment levels**

People in work in % of total population



Source: Bank of England "The UK recession in context–what do three centuries of data tell us?" Data Annex, Version 2.2, July 2015.

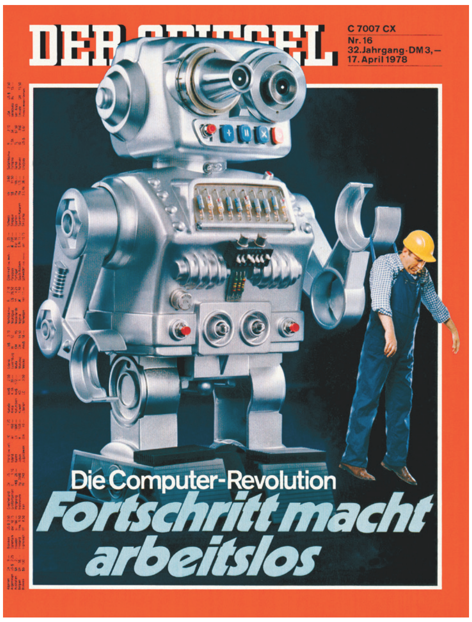
Historical data from the United Kingdom, where the Luddites staged their protests in the early 19th century, illustrate the extent of the so-called "Luddite fallacy." Despite fundamental technological change, unemployment levels show no secular trend. They are, however, characterized by strong cyclical movements, rising rapidly after World War I, in the Great Depression, during the "stagflation" period of the 1970s, and in the wake of the recent financial crisis. This absence of a long-term trend is not due to changing definitions of unemployment. As Figure 4 makes clear, the percentage of workers in the total population has remained remarkably stable, hovering around 50 percent for a very long time.

The Computer Revolution: Renewed Fears about the Automation of Work

The last and continuing wave of technological change that reached the labor market is the adoption of computer technology in the workplace. Its predecessors date back at least to the Industrial Revolution, when the French inventor Joseph Marie Jacquard developed a loom operated by replaceable punched cards, which controlled a particular sequence of the loom's operations. The same principle of operating machines with programs stored on punched cards was later used in mainframe computers from the 1960s onwards.

The start of the computer revolution is, however, often dated to the late 1970s or early 1980s. Production in factories was already changing rapidly at that time, as computer-guided production machines became more widely and cheaply available. These devices included computer numerical control (CNC) machines that were operated by a computer program, and industrial robots that could move a robot arm around multiple axes. Computerization also started to affect office work, most notably due to the introduction of personal computers in the early 1980s. The IBM Personal Computer was released in 1981; the downmarket Commodore 64, which became the best-selling computer of all time, followed in 1982, and Apple introduced its iconic Macintosh in 1984. Continued technological development has since led to ever more powerful and versatile computers, production machines, and robots. And great advances in communication technology, including the World Wide Web and wireless communication devices, have further increased the reach of these machines.

The computer revolution quickly ignited fears about mass unemployment. As early as in 1978, the German news magazine *Der Spiegel* titled: “The computer revolution: progress creates unemployment.” It argued that computers differed from earlier technological innovations, since they not only eliminated many jobs in automating sectors, but also failed to create a meaningful number of new jobs in computer production or elsewhere in the economy. The article cited a British union leader who predicted that by the year 2000, most jobs would have been replaced by computers. This pessimistic prediction turned out to be quite mistaken. The unemployment rate of the United Kingdom (see Figure 3), which



Cover of the 16/1978 edition of the German news magazine *Der Spiegel*.
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stood at 6% in 1978, again hovered around 6% in the year 2000, when supposedly most work should already have been lost. And it remained at 6% in 2015, a full 37 years after *Der Spiegel* wrongly predicted a “social catastrophe” of unprecedented mass unemployment.

> The fact that computers failed to eliminate most human labor in the past four decades despite predictions to the opposite invites a healthy skepticism about renewed claims that robots are just about to take over from humans.

More likely than not, today’s technology enthusiasts will be seen as the next victims of the Luddite fallacy within a few decades, thus joining the many previous pundits that predicted the end of human work in the past.

Of course, the fact that computers did not create mass unemployment does not mean that they had no impact on labor markets. Quite to the contrary, many economists consider computerization, along with the globalization of goods flows and worker flows, as the main driver of change in labor markets during the last three or four decades. A closer look at computers’ effects on workers during that period is warranted both in order to understand the recent past, and to provide some guidance for thinking about possible future impacts of computer technology.

Computers in Economic Theory

Skill-Biased vs Task-Biased Technological Change

Computers became an important topic on the research agenda of macroeconomists and labor economists in the 1990s. Researchers had observed that the wage differential between university-educated workers and those with lower educational attainment had risen rapidly during the previous decade, both in the United States and in several other developed countries. A leading hypothesis to explain the growth of wage inequality was skill-biased technological change (SBTC). It posits that new technology and machines augment the productivity of all workers, but that productivity gains are larger for more highly educated workers. The growing productivity advantage of educated workers increases firms' demand for these high-skill employees.

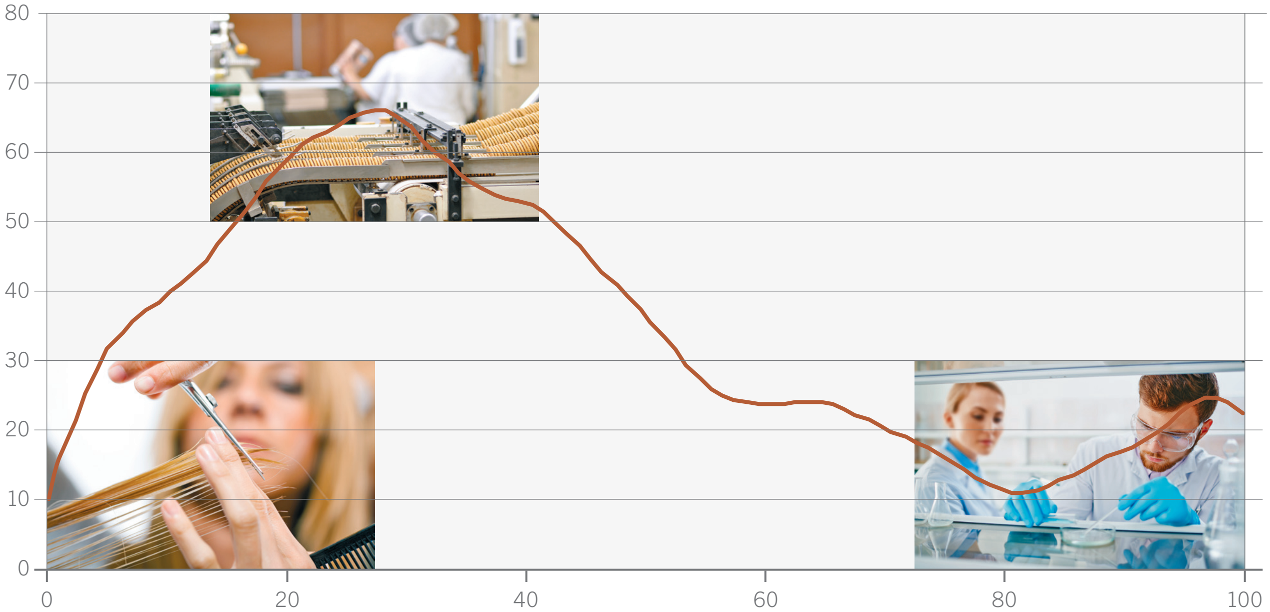
The Harvard economists Claudia Goldin and Lawrence Katz have argued that such SBTC has taken place throughout the 20th century, thus continuously raising the demand for skilled labor.[8] That growing demand coincided with a rapidly growing supply of skilled labor, as average education levels increased dramatically in all regions of the world. The 1980s, however, marked a period during which the growth in the supply of skilled workers slowed in the United States, whereas demand for these workers continued to grow or even accelerated. The excess growth of skill demand relative to skill supply generated an increase in the relative wage of workers with higher education, and thus greater wage inequality in the labor market.

Through the lens of the SBTC hypothesis, computers are seen as the continuation of a long sequence of technological innovations that have favored more highly educated workers. But how exactly could one explain that computers raise the relative productivity of university-educated workers? David Autor and Frank Levy from the Massachusetts Institute of Technology and Richard Murnane of Harvard University conducted field studies that analyzed the introduction of computer technology in firms, and they observed computers' impact on employment levels, wages, and job content of different types of workers. Based on their findings, they formulated a more refined theory for the impact of computers on the labor market, which has become known as the task-biased technological change (TBTC) hypothesis.[9]

In the TBTC model, computers do not have a differential impact on workers based on their education levels, but based on the task content of their occupations. This model draws on the key observation that computers have distinct strengths and weaknesses when it comes to executing different work tasks. A personal computer, CNC machine, or robot is directed by software that was prespecified by a programmer. Computers are thus good at executing tasks that follow a well-defined procedural routine. These "routine tasks" are often found in repetitive production work. The production of car bodies in the automotive industry, for instance, requires that the exact same work steps be repeated over and over, while the margin for error is small in order to ensure high quality and replaceability of parts. Robots are much better than humans at executing such high-precision repetitive work.

Fig. 5 **Which jobs are most exposed to automation?**

Percentage of routine-intensive occupations



Job's percentile in ranking of occupational mean wages

Note: Occupations are ranked by their average hourly wage in 1980. A job at the 20th percentile earns more than 20% of all jobs in the economy, but less than 80% of all jobs. Routine occupations are defined as the ⅓ of occupations with highest routine task intensity according to job task data.

Source: Autor and Dorn (2013)

Routine tasks also appear in a second area of the labor market. Many clerical occupations deal with data work, including data processing, data storage, data retrieval, and data transmission. Whenever these data tasks are executed according to clearly specified rules, then they belong to the set of routine tasks that can readily be done by computers. For instance, computers now execute many tasks that were previously done by accountants, file clerks, or secretaries.

While computers are often better than humans at doing routine tasks, they face important limitations in the execution of other tasks. Machines that follow a prespecified program cannot readily produce new ideas and inventions, and struggle to react to unforeseen influences on their work. Moreover, computers and machines often lack good interfaces for dealing with people and objects. This includes limitations in verbal communication with humans, as well as difficulties with the recognition and physical handling of objects—all tasks that require versatility and adaptation to the environment.

The TBTC hypothesis summarizes tasks that involve problem solving, creativity, or managerial leadership under the term "abstract tasks." These tasks all draw on human ability to react to new developments and problems, and to come up with new ideas and solutions. Occupations that strongly rely on abstract tasks include managers, engineers, medical doctors, and researchers. A common feature of these jobs is that they require a high level of cognitive skill, and typically corresponding to a university education. While computers tend to be poor substitutes for humans in these occupations, they can instead be valuable complements. Many abstract task-intensive occupations become more productive when computers allow a cheaper and more rapid processing, storage, and transmission of data. For instance, an engineer who designs bridges benefits when computers permit a rapid calculation of a planned object's static properties, while a manager of a large company benefits from access to real-time data that indicate the state of operations at the firm's multiple plants. Far from being replaced by machines, these workers specializing in abstract tasks hence stand to benefit from a more widespread use of computers.

The third group of tasks in the TBTC model is referred to as "manual tasks," and is characterized by a combination of fine motoric movement, visual recognition, and verbal communication. Manual tasks are important in personal service occupations such as waiters, childcare workers, or hairdressers, but also in transportation, repair, and construction jobs. Workers in these occupations typically require relatively little formal schooling, since manual tasks build on basic abilities such as verbal communication, seeing and recognizing persons and objects, as well as holding and moving objects with the human hand. Computers have little direct impact on these manual task-intensive jobs, which are not easily automated, but which also do not benefit substantially from an interaction with computers in the workplace.

Cleaners of hotel rooms are an excellent example not only for illustrating a manual task-intensive job, but also for explaining the difference between repetitive and routine work. The sequential cleaning of hotel rooms is certainly a repetitive chore. However, this repetitiveness does not translate to routineness in the sense used here. For hotel cleaning to be a routine job, it would be necessary that the cleaning of one room would encompass exactly the same work steps and physical movements as the cleaning of the next room. But in practice, every guest will leave her room in a slightly different state. Apart from differences in cleanliness, guests can leave towels, pillows, toiletries, pens and many other objects that belong to the hotel in different spots within the room. It would be very challenging for a robot to find and recognize all of the hotel's objects, assess their state of cleanliness, and take the appropriate measures of cleaning or replacing them. Compared to humans, robots are often very limited in their physical adaptability, and cannot grip or clean many different types of objects. An even greater challenge arises when hotel guests leave behind novel objects that they brought into the room, like a pizza box or a jewelry box. It is easy for a human to recognize these objects, and to decide that the pizza box should be discarded while the jewelry box should be kept. The same task, however, presents a major obstacle for a machine.

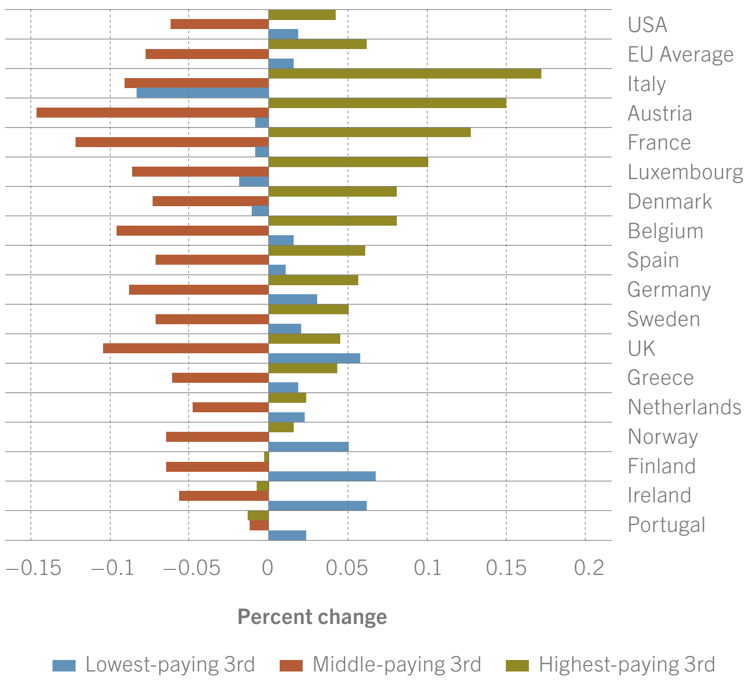
Labor Market Polarization

In summary, the TBTC hypothesis predicts a decline of employment in routine task-intensive occupations as cheaper and more powerful computers become available, while occupations specializing in abstract or manual tasks cannot be readily replaced by machines. These predictions are supported by evidence from many countries in North America, Europe, and East Asia. For instance, my research with David Autor observes that the routine task-intensive occupation groups of production workers, machine operators and clerical workers accounted for a roughly constant 37 to 38 percent of U.S. labor input from 1950 to 1980, before declining rapidly to just 28 percent of U.S. labor in 2005.[10] As routine occupations contracted, managerial and professional occupations that intensively use abstract tasks grew rapidly. Employment in low-skilled service occupations, such as waiters, cleaners, and childcare workers, has been expanding since the 1980s; this work is rich in manual tasks. Occupations in farming, mining, construction, repair, and transportation, which also mostly perform manual tasks, were declining rapidly until 1990, but have since stabilized their employment share.

While the TBTC hypothesis provides clear predictions for the distinct effects of computerization on occupations that use different job tasks, it also has indirect implications for the inequality between workers of different education or income levels. The economists Maarten Goos and Alan Manning pointed out that routine occupations in production and clerical work tend to be clustered towards the middle of the occupational wage distribution.[11] These jobs typically have lower wages than abstract task jobs such as managers and professionals, but higher wages than manual task jobs such as personal service workers. As a consequence, declining employment in routine task-intensive occupations translates to a pattern of employment polarization, as workers become increasingly concentrated in the highest and lowest paid occupations of the labor market. In follow-up research, Goos, Manning, and Anna Salomons showed that this polarization is remarkably pervasive across countries. In all 16 European countries they studied as well as in the U.S., the employment share of occupations with

Fig. 6 **Employment polarization in Europe and in the United States**

Change in employment shares by occupation 1993–2006 in 16 European countries



Note: Occupations grouped by wage tercile: Low, middle, high.

Source: Acemoglu and Autor (2011) and Goos, Manning and Salomons (2009) intermediate wage levels has declined, and in all but one of these countries, both employment in low-wage and in high-wage occupations has grown relative to the middle-wage jobs (Figure 6).[12] While the exact extent and shape of this employment polarization varies by country, it is striking that the same basic pattern is so pervasive despite substantial international differences in industry structures, labor market regulations, and local economic growth. The average changes across European countries are not just qualitatively, but even quantitatively very similar to the trends observed in the United States.

The polarization of the occupational employment structure invites the question whether similar patterns can be observed for wages. In the United States, this is indeed the case. For Figures 7 and 8, the several hundred occupations that are observed in the U.S. Census have been ordered according to their average wage in 1980. During the next 25 years, both occupational employment and occupational wage growth was larger in the highest-paid occupations (on the right side of both graphs) and in the lowest-paid occupations (on the left) than in occupations with intermediate wages (towards the center). Closer inspection of the data suggests that the very pronounced wage growth in high-wage occupations was driven by managerial and professional occupations, whereas wage growth in low-wage occupations stemmed largely from low-skilled service jobs.

International evidence on wage polarization is sparser and less homogeneous than in case of employment polarization. Highly paid occupations experienced both employment and wage gains in many countries, suggesting that the growing supply of highly skilled workers for these jobs has not kept up with growing demand. The expansion of employment in low-paid occupations, however, has coincided with either rising, stagnant or falling wages, depending on country and time period.

Indeed, the U.S. experience of a combined employment and wage growth in low-skilled service occupations is surprising in the context of the SBTC and TBTC theories. Both theories predict that computers enhance the productivity of skilled workers in occupations with abstract tasks, and the resulting growing

Fig. 7 **Employment polarization**

Change in employment share 1980–2005, in %

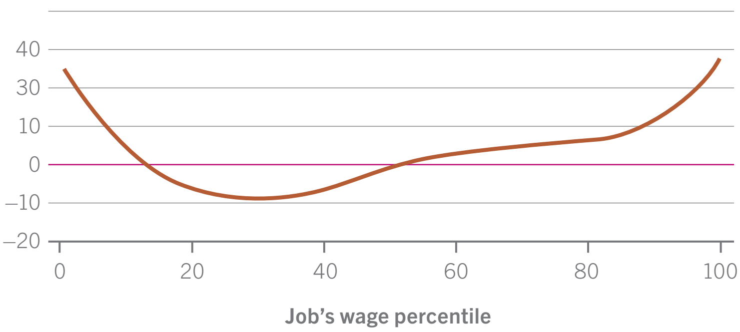
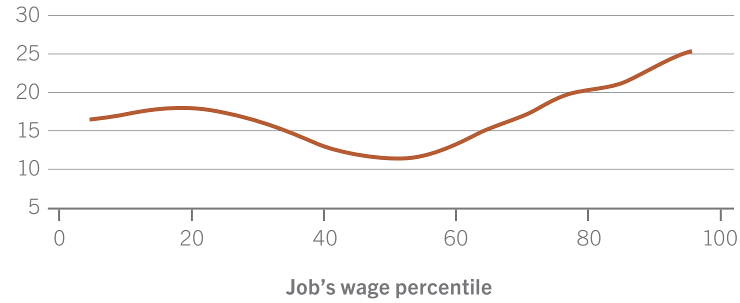


Fig. 8 **Wage polarization**

Wage growth 1980–2005, in %



Note: The graph shows occupational employment and wage growth in the United States. Occupations are ordered on the x-axis according to their percentile in the occupational wage distribution of 1980. Figure 7 measures the relative change in an occupation's share in total employment (for instance, an occupation that expands from 1% to 1.2% of total employment has grown by 20%). Figure 8 measures the change of the mean log real hourly wage by occupation group. Wage changes are expressed in log points, which approximately correspond to percentage changes. The data series in the graph are smoothed.

Source: Autor and Dorn (2013)

demand of firms for skilled workers can readily raise their employment and wages. However, both theories suggest that computers have little effect on the productivity of low-skilled workers. In the task-based view, the employment share of low-skill service occupations and other jobs with manual tasks will expand relative to employment in the routine occupations that become automated. However, as redundant clerical and production workers seek new employment in manual task jobs such as cleaners and waiters, which are readily accessible for workers with little formal education, one would expect wages in these occupations to fall. The observation of a combined increase of employment and wages in low-skilled service occupations thus suggests that a second force must be at work in addition to labor reallocation from routine to manual task-intensive jobs.

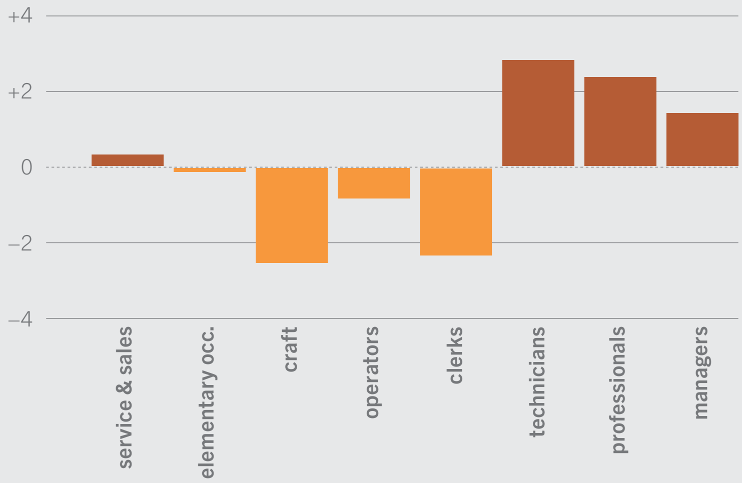
David Autor and I argue that this second force is a growing demand for services that are produced with low-skilled labor. Computerization reduces production costs primarily for manufactured goods, but not for low-skilled services such as cleaning or childcare, where computers hardly affect the production process.[13] When consumers perceive goods and services to be poor substitutes in consumption, then they react to the falling price of goods not by buying a larger quantity, but by using some of the money that is saved on cheaper goods to purchase more services. Increased consumer spending on, for instance, restaurant meals then increases firms' labor demand for workers who produce that service. The rising demand for low-skilled services and the growing supply of workers to these jobs due to the automation of routine work combine to generate growing employment in low-skilled service occupations. This employment growth can be accompanied by wage growth if the demand for low-skilled services grows sufficiently rapidly relative to the increasing supply of workers.

The observation that the demand for low-skilled services is increasing is important because these jobs can provide employment opportunities for workers who have little education or job-specific training. It strongly contradicts the notion that all low-skilled work is rapidly becoming obsolete as a consequence of computerization.

Labor market polarization in Switzerland

Fig. 9 **Employment polarization in Switzerland**

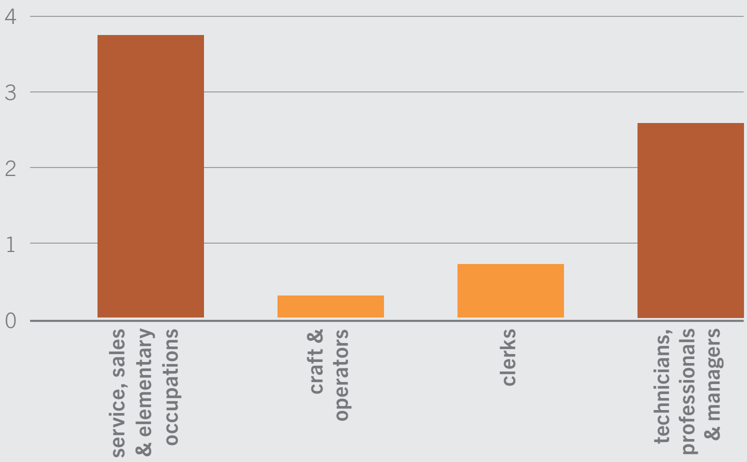
Average change in employment share per decade since 1980, in %



Note: These numbers represent the change in mean log hourly real wages per decade of these occupation groups between 1990 and 2010. For example, the share of managers grew on average by roughly 1.6 percentage points in every decade, so that their share of total employment rose from about 6% in 1980 to around 11% in 2010. The data includes Swiss-born workers only.

Fig. 10 **Wage polarization in Switzerland**

Average change in hourly wages per decade, in %



Note: These numbers represent the percentage changes per decade in the mean log hourly real wages of these occupation groups *over the entire period* from 1991 to 2011.

Source: Beerli and Indergand (2015).

A recent paper of the UBS Center Working Paper Series studies whether the Swiss labor market has polarized analogously to the labor markets in the United States and European Union. Its authors, Andreas Beerli and Ronald Indergand, indeed find evidence for polarization in Switzerland.

Figure 9 shows a pronounced decline of the share of routine task-intensive occupation groups in total employment during the period of 1980 to 2010. Both production and clerical jobs are in decline. Instead, a rising share of Swiss employment concentrates in abstract task-intensive occupations at the top of the wage distribution, such as managers, professionals, and technicians. In addition, there is a small expansion of employment in low-paid service and sales occupations. While Figure 9 is based on data from Swiss-born workers only, Beerli and Indergand also observe employment polarization among immigrants. The authors point out that the polarization of labor demand is a strong driver of the skill-composition of newly arriving immigrants explaining, for instance, why their level of education has increased considerably in the last 30 years.

These unequal fortunes of different occupation groups are mirrored in their rates of wage growth, as shown in Figure 10. From 1991 to 2011, real wages grew most in the lowest-paid occupations (service and sales) and in the highest-paid ones (managers, professionals, and technicians). By contrast, workers in jobs characterized by routine tasks are barely better off than in the early 1990s.

Technology versus Globalization

The task-based model of technological change provides a useful framework for thinking about the use of computers and robots in the workplace. It has also been an empirical success, as its predictions about patterns of occupational employment growth turned out to be consistent with evidence from many developed countries. However, the fact that computerization could be a plausible explanation for employment polarization does not imply that it has to be the only explanation for this trend. Most importantly, many economists have pointed out that in the same period when labor markets were exposed to computerization, they also faced a rapidly progressing globalization.

Globalization is a process of international integration that encompasses rising trade in goods and services, growth in international capital movements, migration of workers, and dissemination of knowledge. Integration has deepened along all these dimensions in recent decades, and progress in computer and communication technology may well have acted as a catalyst for that development. The use of foreign suppliers, for instance, has become more attractive for firms thanks to technology that allows for easy and cheap communication over long distances and seamless tracking of shipments.

Globalization provides an alternative narrative that could explain the decline of middle-wage occupations in many developed economies. Workers in production and clerical occupations may not only be replaced by computers and robots, but also by workers in other countries where wage levels are lower. This spatial reorganization of production can take the form of offshoring, where multinational firms shift part of their operations to another country, or of trade competition, where firms in developed countries reduce employment as they succumb to competitive pressure from imported goods. Global shifts in production are particularly apparent in manufacturing, and closely tied to the spectacular economic development of China. Building on a series of market-oriented reforms, China evolved from being a minor player in international trade in the early 1990s to becoming the world's leading exporter of goods in recent years.

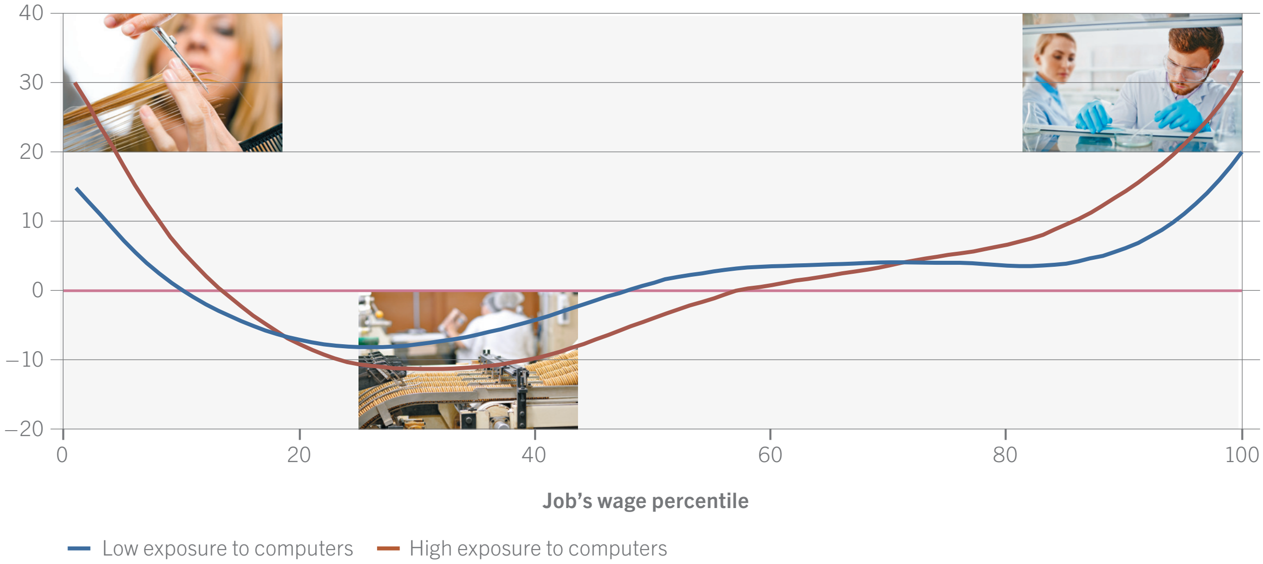
The contemporaneous occurrence of computerization and globalization makes it difficult to estimate their separate effects on employment polarization and other aggregate outcomes in developed economies. My work with David Autor and Gordon Hanson proposes to study the impact of macroeconomic forces on local labor markets in the United States in order to overcome this dimensionality problem.[14] The concept of local labor markets builds on the empirical observation that workers usually seek jobs at workplaces located within commutable distance from their homes. As a consequence, local labor supply and local labor demand combine to form separate market equilibria in different localities, and spatial variation in real wages and employment levels can be quite persistent over time.

Firms in different cities and rural areas of the United States should all have access to the same technologies. Nonetheless, the impact of computerization will have spatial variation. This variation stems from the fact that local labor markets vary in their industry, occupation, and task mix. The historical source of local specialization can be the geographic proximity to important raw materials, access to transportation infrastructure, or even the serendipitous emergence of an important firm around which other related businesses cluster.[15] Importantly, patterns of local specialization are remarkably stable even over long periods of time. For instance, local labor markets that made particularly large use of routine labor in 1950 still have a disproportionately routine-intensive occupation mix half a century later. The historical reliance on routine labor later creates a large potential for the replacement of workers by computers and robots, and thus a particularly pronounced exposure of these locations to computerization. An empirical analysis of U.S. Census data indeed shows that historically routine task-intensive local labor markets, which are dispersed across all regions of the U.S., adopted more computers since the 1980s while witnessing greater declines in routine work. As a consequence, local labor markets with a high initial employment share of routine occupations experienced stronger employment polarization than locations with comparatively little reliance on routine work (Figure 11). Moreover, there was also somewhat greater wage polarization in these local labor markets with greater exposure to computers.[16]

The comparison between local labor markets not only allows establishing a more direct link between computerization and labor market polarization, but also permits the separation of the effects of computerization from those of globalization and other economic forces. In

Fig. 11 **Employment polarization in U.S. local labor markets with different exposure to computers**

Change in employment share 1980–2005, in %



Note: The graph shows employment polarization in the United States separately for local labor markets with above average and below average routine employment in 1980 (high and low exposure to computerization). The vertical axis represents the change in an occupation's share of total employment times 100.

Source: Autor and Dorn (2013)

research with David Autor and Gordon Hanson, I show that the U.S. local labor markets which are most exposed to computerization only partially coincide with the regions that are most affected by the dramatic rise of import competition from China. Econometric analysis can therefore identify the local labor market impacts of these technology and trade forces separately.[17]

An empirical investigation of U.S. Census data shows that the extremely rapid increase of Chinese import competition since the 1990s has led to a substantial decline of employment in all occupation categories of the manufacturing sector. Due to slow reallocation of manufacturing workers to other jobs, this import shock has also reduced overall employment. By contrast, routine task-intensive local labor markets have not experienced a significant overall job loss due to computerization, but their occupational employment structure has polarized both within the manufacturing and non-manufacturing sectors. Consistent with the timeline of technology development, the loss of routine jobs started with the automation of production work in manufacturing during the 1980s, and later became larger in the service sector as computers started to replace clerical work.[18]

Empirical studies focusing on European data reach the same conclusion as the analyses for the United States: The adoption of computers and robots has not caused a notable decline in overall employment. However, computerization contributes to labor market polarization, as middle-wage routine occupations decline while high-wage abstract and low-wage manual occupations expand.[19]

How Can Workers Succeed in a Computerized Labor Market?

Computers are transforming the occupational composition of the labor market. Young adults who enter the labor market today face a very different set of job opportunities than their parents a generation ago. Many production and clerical occupations with intermediate wages hire fewer workers than they used to, and employment polarization is particularly pronounced among the young, who are becoming disproportionately concentrated in high-wage and low-wage jobs.[20] The continued availability of jobs in low-skilled service occupations also offers employment opportunities to workers who have little formal education. Yet the workers who stand to gain most are those in the highly paid managerial and professional occupations where productivity has risen thanks to computer technology.

It is thus an easy policy recommendation that more schooling is desirable in order to help cohorts of young workers succeed in the labor market. After all, the rise of the wage differential between workers with and without university education suggests that the growth in the relative supply of highly educated individuals has fallen short of the growth in relative demand for their labor.

The policy response to technological change should, however, not just be more education, but also different education. Computers have changed, and will continue to change the demand for job tasks in the labor market. Therefore, education should build skills in those tasks where human capabilities remain superior to machines, and not in dimensions where machines have the edge. An education that emphasizes rote memorization and mental arithmetic is no longer able to produce skilled workers who can hope to outdo computers in terms of information storage or calculation. Victories of computers over extremely accomplished humans in quiz shows and chess competitions have impressively shown the tremendous advantage that machines now have in such tasks.

Humans retain an advantage over machines when it comes to problem solving, creativity, and interaction with other humans.

An education that prepares young people for the task demands of the 21st century should thus seek to strengthen skills in these areas, for instance by fostering problem-solving abilities and communication skills through case study projects, group work, and other modern forms of teaching that complement a more traditional mode of instruction based on lectures and memorization.

A greater focus on individualized customer interaction and on innovation and problem solving can also provide a perspective for some of the shrinking middle-wage occupations. Clerical and production jobs that integrate these non-routine tasks cannot be as readily automated as jobs that only execute routine tasks, at least not without a substantial loss in quality. A machine operator who has a thorough understanding of the machine's operation, and of the production process it is embedded in, is harder to replace than an operator who is just familiar with a few buttons on the machine's operating panel. The former will be able to quickly resolve problems and may even propose improvements that raise the efficiency of the production process. Similarly, a salesperson who expertly advises customers and carefully responds to individual customer requests will not as easily lose her job to a machine as a colleague who merely swipes credit cards at the cash register. These jobs with virtuous bundles of job tasks do not require a university education, but benefit from a high-quality vocational training system that combines hands-on experience on the job with schooling that is tailored to the need of a specific occupation.

Will the Lessons of the Past Remain Relevant in the Future?

The prediction that labor-saving technology inevitably causes a long-term rise in unemployment has been proven wrong many times in history, and again during the first few decades of computer adoption. Yet the question persists whether the theory of task-biased technological change, which currently guides many economists' understanding of computers' impact on the labor market, will remain useful in the future as technology evolves further.

A prime example for the expanding possibilities of technology is the driverless car. Just over a decade ago, academic research listed truck drivers as one example of a manual task-intensive occupation that cannot readily be substituted for by technology.[21] In the meantime, however, an immanent automation of their jobs seems inevitable to many observers. And once it is possible to automate drivers, then the replacement of other manual occupations by robots may not be far away.

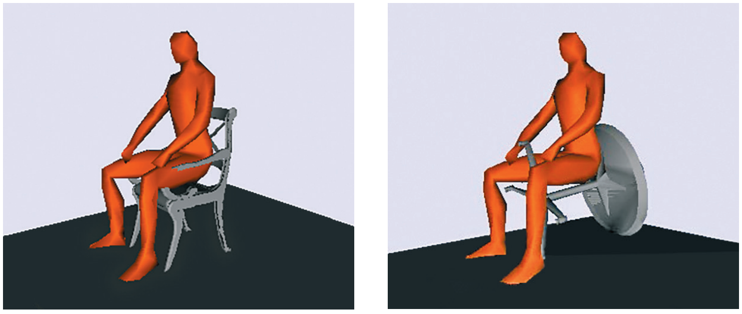
However, enthusiastic predictions about rapid development and adoption of technology frequently underestimate the challenges on the path from an experimental prototype to a large-scale market introduction of a new product. The driverless car, for instance, will only find widespread use once improved technology allows it to negotiate difficult road conditions, once its production costs have been lowered substantially, and once the legal questions surrounding its use have been resolved. None of these arguments negates the possibility that driverless cars will dominate the streetscape a few years from now. Yet each of these obstacles has the potential to greatly diminish the new technology's success. Other means of transportation that were once announced as great breakthroughs, including supersonic airplanes, maglev trains, or solar vehicles, have never become cheap and powerful enough to be adopted widely in the economy.

A further limit to automation stems from the fact that human workers often execute a more diverse bundle of tasks than those that a computer or robot can replace. A truck driver for instance not only steers a truck through traffic, but also loads, controls, and unloads the cargo; deals with the accompanying paper work; and takes care of maintenance and small repairs. The driverless technology alone will thus not be able to substitute for all the work a truck driver does. In some situations, it is feasible to split up the task bundle of an occupation, and have machines execute some parts while other tasks remain in the hands of humans. One example is bank tellers. The work that used to be done by a teller is now split into dispensation of cash, a routine task that automated teller machines handle, and a large set of other customer services, which human employees still execute. A counterexample to this unbundling of tasks is airline pilots. The first crossing of the Atlantic Ocean by a plane flown by an autopilot took place in 1947. But in the almost seven decades since, the job of the airline pilot has not disappeared because pilots are still needed onboard a plane in order to react to unforeseen conditions such as a failure of the aircraft's engines or instruments.

Overall, past experience suggests that predictions of immanent dramatic technology development should be assessed with a healthy dose of skepticism. Yet it is still reasonable to expect that the boundaries between automatable and non-automatable tasks will continue to shift as computers and robots become more powerful and versatile. So far, computers' primary strength has been the execution of tasks that can be characterized by precisely defined routines, and it stands to reason that this fundamental insight will remain valid even as a gradually expanding set of tasks becomes accessible for computer routines.

If instead a paradigm shift should occur, then it may be due to advances in machine learning. A key obstacle to the automation of non-routine tasks is the difficulty for human programmers to specify all the work steps of these tasks exactly in a computer program. Machine learning can help overcome this obstacle by allowing computers to guess the optimal answer to a problem using inductive statistical techniques rather than formal procedural rules. A concrete example is the task of visually identifying a chair.[22] A conventional computer program may specify the typical constituting features of a chair, such as a raised surface, four legs, and a backrest. An accordingly programmed computer will recognize many regular chairs, but not atypical models that have only three legs or lack a backrest. However, if the programmer were to relax the criteria for the identification of a chair, then the computer would start misclassifying other objects like cabinets or tables as chairs. While it is easy for humans to distinguish chairs from other pieces of furniture intuitively, it is surprisingly difficult to convey this human intuition to a computer. Machine learning seeks to circumvent this problem. Instead of providing the computer with a rule-based script to identify chairs, the machine is fed with a training library of labeled pictures or 3-D scans of chairs and other objects. This data allows the computer to statistically infer which attributes increase the likelihood that a given object is a chair. If the statistical model is sufficiently good, then the computer should become able to identify other chairs accurately that were not part of the initial training library.

Fig. 12 **The next frontier? Objects correctly and incorrectly identified as chairs by machine learning**



Source: Grabner, Gall and Van Gool (2011)

How "intelligent" can computers become through machine learning? Some researchers predict that growing computing power and better training databases will eventually allow machines to reach or even exceed many human capabilities. Others, however, expect that machines will remain error-prone. Figure 12 shows the result of a machine learning experiment where a computer identified two objects as chairs that both have a space to sit on and a backrest. However, one of these objects is actually an overturned table. While it seems certain that machine learning technology will improve, it remains an open question whether computers will ever be able to fully understand the intended purpose of an object, just as a human would immediately realize that an overturned table is not meant for seating.

Conclusions

Computer technology has transformed the organization of work during the last four decades. As robots and computers can substitute for human labor, many observers worry that technological progress will inevitably lead to mass unemployment. Historical evidence suggests that these concerns are likely exaggerated. Despite rapid technological progress and automation since at least the Industrial Revolution, unemployment has not dramatically expanded over time. Instead, employment shifted from the sectors that automated the most to other sectors that experienced less technological progress, as well as emerging sectors that were created by new technology.

Empirical research finds that computers have little impact on overall employment, but contribute to rising labor market inequality. Machines have overtaken humans in their capability to execute well-defined routine tasks precisely, and many of the production and clerical jobs that specialize in such tasks have been irreversibly lost. The employment structure of labor markets in developed countries becomes increasingly polarized as employment concentrates in a set of highly paid and a set of lowly paid occupations that both are difficult to automate. The former set includes managerial and professional occupations that require such skills as leadership, creativity, or problem solving, while the latter include service occupations that combine the tasks of visual recognition, verbal communication, and fine motoric movement.

As computerization changes the composition of human labor rather than decreasing its overall amount, policymakers should not primarily be concerned about mass unemployment. Instead, the more immanent policy challenges caused by computerization result from changing skill demands in the labor market and rising economic inequality among workers.

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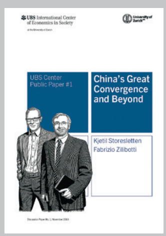

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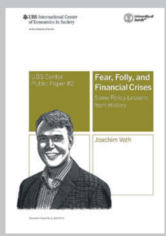

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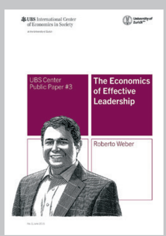

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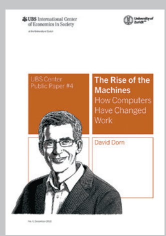

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The UBS International Center of Economics in Society, UBS Center in short, is an Associated Institute at the Department of Economics of the University of Zurich.

It was established in 2012, enabled by a founding donation by UBS, which the bank made on the occasion of its 150th anniversary. In view of the very generous donation, the university named the UBS Center after its benefactor.

The new center of excellence serves two main aims, the first of which is to finance world-class research in economics on all levels, to be conducted at the university's Department of Economics. It thereby supports the department's ambition to further strengthen its position as one of the top economics departments in Europe and to make Zurich one of the best places for research in economics in the world. The center's other aim is to serve as a platform for dialogue between academia, business, politics, and the broader public, fostering continuous knowledge transfer in the process. Delivering on these aims will in turn also contribute to the quality of Zurich, and Switzerland more generally, as leading locations for education and business.

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UBS International Center of Economics in Society
University of Zurich
Department of Economics
Schönberggasse 1
CH-8001 Zurich

Tel. +41 44 634 57 22
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