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"The rise of the machines: Economic and social consequences of robotization"

- The number of robots used by businesses to boost their productivity has increased rapidly over the past several years. This is a trend that is most likely to continue.
- The productivity impact of robots is already comparable to the contribution of steam engines. And there is evidence that these productivity increases have lifted total labor demand as well as overall wage levels. These effects, however, are not distributed evenly.
- As high-skilled and high-wage workers benefit disproportionately, the increased pace of robotization will further add to already high-income inequality within advanced economies.
- To allow for a broader share of the population to reap the benefits of this technological progress, two sets of actions need to be taken: a rethink of our educational system and a reallocation of income from owners to workers.

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Nontechnical Summary

The root of our problem is not that we're in a Great Recession, or a Great Stagnation, but that we are in the early throes of a Great Restructuring. Our technologies are racing ahead but many of our skills and organizations are lagging behind. So it's urgent that we understand these phenomena, discuss their implications, and come up with strategies that allow human workers to race ahead with these machines instead of racing against them.

Brynjolfsson and McAfee (2012)

Rising inequality and slow productivity gains may be the main economic challenges of the 21th century (see charts 1 and 2). The US presidential campaign or the British referendum to leave the EU are only the latest displays that even in the wealthiest nations on earth a growing number of people feel left behind despite ongoing economic growth. And the increased use of robots should affect both of these developments – positively as well as negatively. As one of the latest stages of technological progress, they should help to lift productivity gains, while at the same time driving income inequality even higher. Views about the growing "robotization" of the economy are accordingly split, as highlighted most recently by the title of a Financial Times special series, "Robots: Friend or Foe?" While empirical literature about the impact of robots on the economy is still in its infancy, there is now a growing number of studies which begin to support the notion that robots lift productivity, wages and even total labor demand, but mostly benefit higher-skilled workers. In this article, we discuss these studies and compare the results with those of previous industrial revolutions. Special focus is then put on policy recommendations that should help to spread the gains of increased robotization more broadly and more evenly. Those range from education and redistribution to ownership rights. The remainder of the paper is structured as follows: The first chapter briefly describes the history of and quantifies the international demand for industrial robots. Chapter two discusses their impact on productivity, wages and labor demand across different skill sets. In chapter three, we propose policy measures that should allow more people to benefit from technological progress, before chapter four concludes.

THE CHALLENGES OF THE CENTURY: HIGHER INEQUALITY AND LOWER PRODUCTIVITY

Chart 1: Labor share and Gini coefficient for the US

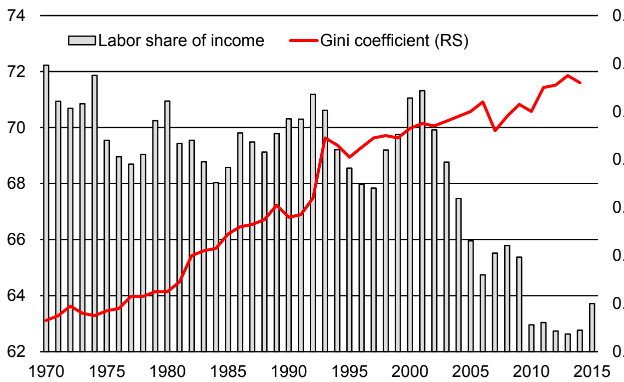
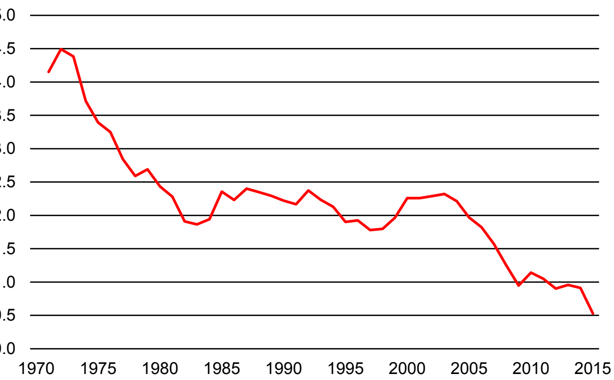


Chart 2: GDP per hours worked for G7 countries, % yoy (5Y MA)



Source: Bureau of the Census, BEA, OECD, UniCredit Research

Industrial robots: The latest stage of progress

From stone tools to robots

2,500,000 years in the making

The desire to invent new tools or "things" in general is as old as mankind itself. It probably all started some 2.5 million years ago with some simple stone tools during the Paleolithic era. Since then, an uncountable number of larger and smaller inventions have followed – many of them aimed to make lives easier for ourselves. In his recent book, Robert Gordon (2016) vividly describes how the introduction of electricity, sewage systems, the telephone, cars, better medication, and several other things have not only boosted productivity gains, but above all lifted the standard of living for all citizens during the late 18th and early 19th century. In addition, businesses are constantly looking for innovations to improve their productivity and to have an edge over their competitors. This has led to the invention of the steam engine and more recently the industrial robot.[1]

The first robot – was a bird

The invention of the first robot probably goes back more than two thousand years as well (to around 350 B.C.), when Greek scientist Archytas is said to have created a mechanical wooden dove capable of flapping its wings and flying up to 200 meters, powered by some sort of compressed air or internal steam engine.[2] And even the first industrial robot, the UNIMATE, was invented more than 60 years ago. It was developed in the mid-50s by George Devol and Joseph Engelberger. From 1961 on, the UNIMATE, a mechanical arm weighing two tons, was used by General Motors on an assembly line.[3] Since that time, the usage of industrial robots has increased rapidly, as businesses from different industries aim to use the latest technology.

The global market for industrial robots

Stock of industrial robots hit 1,500,000 units in 2014 – and is growing exponentially

According to the International Federation of Robotics or IFR (2015), the worldwide stock of industrial robots hit a new record high in 2014 at 1.5 million units. And the stock is not only growing rapidly, but at an accelerating pace. This is demonstrated by the fact that annual robot sales hit a new record high in 2014, at 229,261 units, no less than 29% above the 2013 level, the previous record high (see chart 3). The IFR estimates the value of robot sales to have risen to USD 10.7bn in 2014; including the cost of software, peripherals and systems engineering, the worldwide market value for robot systems is even estimated to have hit a whopping USD 32bn. Compared to the pre-recession average (2005 to 2008), sales levels over the past five years (2010 to 2014) have been 48% higher. A clear sign of the significant rise in global demand for industrial robots. The regional breakdown reveals that 70% of the global robot sales in 2014 went to only five countries: China, Japan, the US, Korea and Germany (see chart 4).

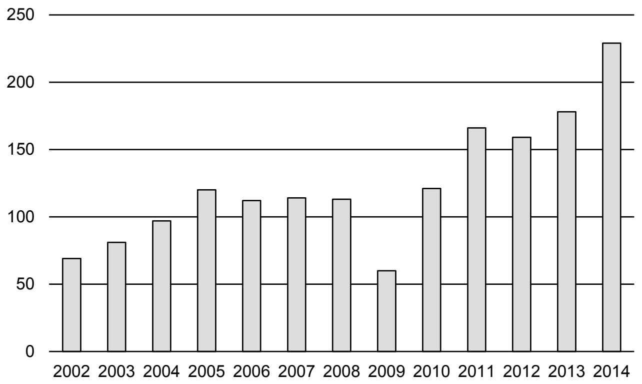
Germany has the highest robot density

Instead of looking at the absolute numbers, which are inevitably biased towards larger economies, Graetz and Michaels (2015) propose a measure that they call "robot density". It is defined as the stock of robots per million hours worked. According to that measure, Germany had by far the highest robot density already back in 1993, followed by Sweden, Belgium and Italy (see chart 5). Moreover, Germany significantly outpaced all other countries in the subsequent 14 years. Other countries with above-average increases in robot density during that period were Denmark, Italy, Korea, Belgium, Spain, France, Finland and the US.

[1] According to IFR, an industrial robot is an automatically controlled, reprogrammable, multipurpose manipulator programmable in three or more axes, which may be either fixed in place or mobile for use in industrial automation applications.
[2] See: Stamp (2013).
[3] See: International Federation of Robotics (2012).

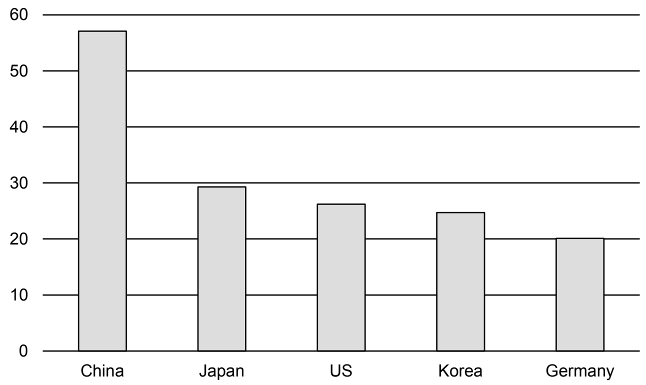
GLOBAL ROBOT SALES RISING STRONGLY

Chart 3: Global sales of industrial robots, in '000 units



FIVE COUNTRIES ACCOUNT FOR 70% OF SALES

Chart 4: Sales of industrial robots by country, in '000 units (2014)



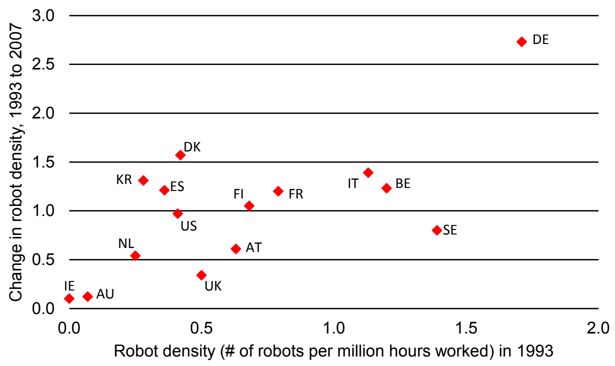
Source: IFR, UniCredit Research

The car industry is the main user of robots – but the electronics industry is catching up

Even more uneven than the distribution across countries is the variation across industries. As highlighted by chart 6, it is the transportation equipment industry, notably the automotive industry, that is by far the biggest user of robots. And while the data compiled by Graetz and Michaels end in 2007, the latest IFR statistics reveal that this trend has continued. Accordingly, the automotive industry remained the most important buyer of industrial robots between 2010 and 2014. During that time, annual sales to the industry rose on average by no less than 27%. The other three major users of robots have been the chemical, the metal and the electronics industries. And while the IFR database confirms that these three industries have remained the main customers of robots (outside the car industry), the ranking has changed over the past few years. The new number two is the electrical/electronics industry, which includes among other things computers and equipment, TV and communication devices as well as medical and optical instruments). In 2014, this sector accounted for 21% of industrial robot sales, while the automotive industry's share was 43%.

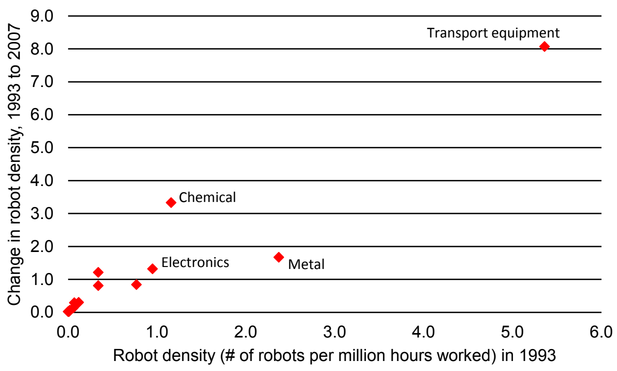
BY FAR THE HIGHEST ROBOT DENSITY IN GERMANY…

Chart 5: Robot density by country



…AND THE CAR INDUSTRY

Chart 6: Robot density by industry



Source: Graetz and Michaels (2015), UniCredit Research

Double-digit growth expected…

Looking forward, there is no reason to believe that the pace of "robotization" will begin to slow any time soon. On the contrary, as the robot density in general industry – outside of the automotive sector – is still relatively low, the potential for further robot installations remains huge. Moreover, the cost of new robots continues to go down, while their capabilities continue to go up. Accordingly, the IFR projects that the pace of yearly robot installations will continue to grow at a double digit rate over the next few years (see chart 7 and table 1). China will remain the main driver of the growth over that period. The IFR anticipates the installation of robots in China to accelerate despite slower GDP growth rates, as Chinese industries and the country's administration have recognized the need for further automation. But annual robot sales are expected to rise by around 10% in the Americas (primarily the US) and Europe as well.

DEMAND FOR INDUSTRIAL ROBOTS EXPECTED TO RISE AT AN EXPONENTIAL PACE

Chart 7: Estimated sales of industrial robots at year-end, number of units (* IFR forecasts for 2015 and 2018)

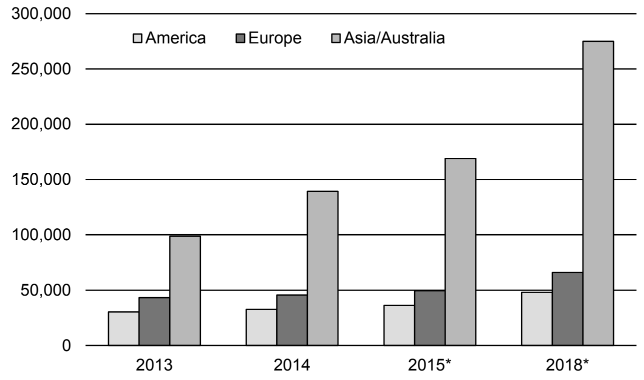
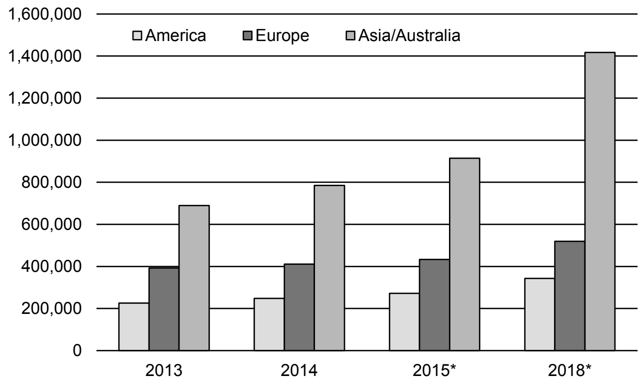


Chart 8: Estimated operational stock of industrial robots at year-end, number of units (* IFR forecasts for 2015 and 2018)



Source: IFR (2015), UniCredit Research

…driven by China

As a result of the above-average growth rate in robot sales, Asia, and China in particular, will expand its dominance and cement its status as the world's leading user of industrial robots. By 2018, China is expected to account for 38% of global robot sales, and no less than 26% of the global robot stock. Including Japan, Korea and other countries, Asia as a whole will be home to more than 60% of the robot stock by 2018, compared to 22% for Europe and 15% for the Americas.

Automotive and electronic industries to remain the drivers

Looking at the various sectors, the IFR anticipates that the automotive and electronics industries will remain the main buyers of industrial robots. But other sectors should accelerate their demand as well. In particular, a pickup in robot orders is anticipated from the rubber and plastics industry, the metal and machinery industry, the pharmaceutical industry and the food and beverage industry.

Robots to have a larger impact

While these numbers, as all forecasts, have to be taken with a pinch of salt, there can be no doubt that the automation of various industries will continue. And judging from experience over the past several years, demand for industrial robots will more likely than not expand at an accelerating pace – not only until 2018 but beyond. Another part of the robot revolution is self-driving cars, which may hit the roads within the next two to three decades. And as "about 10% of the US workforce operates vehicles as part of the job, the automation of driving will eliminate millions of jobs in the U.S. alone."[4] In a nutshell, increasing robot density will have a growing impact on economies, industries and workers. In the following chapter, we will discuss the potential implications of these trends for economic growth and the labor market.

[4] See: Freeman (2016), as well as Ford (2015).

TABLE 1: ESTIMATED YEARLY SHIPMENTS AND OPERATIONAL STOCK OF ROBOTS BY 2018

	2013	2014	2015	2018	Average growth 2014-2018
Estimated yearly shipments of industrial robots, number of units					
America	**30,317**	**32,616**	**36,200**	**48,000**	**10%**
Europe	**43,284**	**45,559**	**49,500**	**66,000**	**10%**
Germany	18,297	20,051	21,000	25,000	6%
France	2,161	2,944	3,200	3,700	6%
Italy	4,701	6,215	6,600	8,000	7%
Spain	2,764	2,312	2,700	3,200	8%
UK*	2,486	2,094	2,400	3,500	14%
Asia/Australia	**98,807**	**139,344**	**169,000**	**275,000**	**19%**
China	36,560	57,096	75,000	150,000	27%
Japan	25,110	29,297	33,000	40,000	8%
Korea	21,307	24,721	29,000	40,000	13%
World	**178,132**	**229,261**	**264,000**	**400,000**	**15%**
Estimated operational stock of industrial robots, number of units					
America	**226,071**	**248,430**	**272,000**	**343,000**	**8%**
Europe	**392,227**	**411,062**	**433,000**	**519,000**	**6%**
Germany	167,579	175,768	183,700	216,800	5%
France	32,301	32,233	32,300	33,700	1%
Italy	59,078	59,823	61,200	67,000	3%
Spain	28,091	27,983	28,700	29,500	1%
UK*	15,591	16,935	18,200	23,800	9%
Asia/Australia	**689,349**	**785,028**	**914,000**	**1,417,000**	**16%**
China	132,784	189,358	262,900	614,200	34%
Japan	304,001	295,829	297,200	291,800	0%
Korea	156,110	176,833	201,200	279,000	12%
World	**1,332,218**	**1,480,778**	**1,664,000**	**2,327,000**	**12%**

*Forecasts made before the Brexit referendum

Source: IFR (2015), UniCredit Research

The impact of robots on the economy: Productivity and the labor market

The good: Rising productivity and higher wages

A comprehensive cross-country and cross-industry study…

From an economic perspective, industrial robots are nothing more than the latest addition to the group of technical innovations. Like many of their predecessors, they should therefore help to make every worker, every machine, industries, and entire economies more productive. And while the empirical literature about the impact of robots is still in its infancy, the evidence that exists supports these theoretical considerations. The following results borrow heavily from Graetz and Michaels (2015), who have to the best of our knowledge released the first and to this day still most comprehensive empirical analysis of this topic. Their newly compiled data set spans 14 industries (mainly manufacturing, but also agriculture and utilities) in 17 developed countries (while China is not included, due to data limitations, the results still give us a good idea about the magnitude of robots' impact). Uniquely, the data allows us to identify the usage of industrial robots by industry and country, and how it has changed from 1993 to 2007.

Box: The issue of measuring productivity

Our analysis, as well as the studies quoted herein, assume that we are able to measure productivity accurately. This assumption is not completely uncontroversial, to say the least. Amid the perceptible slowdown in total factor productivity over the past decade or so, there has been a growing number of experts claiming that the official numbers significantly understate the true trend due to the mismeasurement in particular of the gains from innovation in IT-related goods and services. The latest research from the Brookings Institute (see Byrne et al. 2016) does, however, reject this thesis. While the authors agree that there is significant mismeasurement for IT products, they emphasize that the quantitative effect on productivity was larger in the 1995-2004 period than it has been over the past decade. This means that, if anything, the actual slowdown in productivity gains is larger than suggested by official numbers.

When it comes to robots, in particular industrial robots, their productivity impact should be much easier to measure. There is, of course, the issue with price and quality adjustments, but as they are recurring they should not materially impact productivity gains over time.

…finds a positive impact from robot densification on productivity…

The main result is that the increased use of robots contributed about 0.37pp to annual GDP and thus labor productivity growth.[5] This figure roughly equals ten percent of the aggregate growth of the analyzed countries over the respective period. To put that into a historical perspective, this estimated impact of increased robot density on productivity thus far has been fairly comparable to the contribution of steam technology, but was less than the upper range of estimates of ICT's contribution to EU and US productivity gains from 1995 to 2005, which is estimated to be 0.6 to 1.0pp.[6] However, the total value of ICT capital likely exceeded that of robot services by a factor of at least five. With a further increase in robot usage, the positive productivity impact may therefore continue to rise. Along those lines, Graetz and Michaels already discovered that the productivity impact in countries and industries with a higher robot density was larger than the average 0.37pp.

[5] Graetz and Michaels estimate various specifications of the model (including the use of instrumental variables, country- and industry-specific effects, etc). The effect given here (0.37pp) is from their preferred specification, which the authors themselves call "conservative".
[6] See O'Mahony and Timmer (2009).

…wage gains…

Another important result of the Graetz and Michaels analysis is that some of the productivity gains from robot densification were shared with workers through higher wages. The coefficient linking robot density and overall wage gains was significant and positive, which is an encouraging outcome and would support theoretical considerations.

…and total labor demand.

Moreover, in one of the latest papers on that subject, the ZEW (Gregory et al. 2016) finds that the net effect of robots (they call it "routine-replacing technological change", or RRTC) on total labor demand has been positive. Their baseline estimate suggests that RRTC has increased labor demand by up to 11.6 million jobs across Europe between 1999-2010, which is almost exactly half of the entire employment growth or 23 million in these countries over the period considered. Because while RRTC has on the one hand reduced labor demand by 9.6 million jobs as capital replaced labor, this effect has been overcompensated by positive product demand and spillover effects, which combined have increased labor demand by some 21 million jobs. This, however, is not the end of the story. Because when we start to look closer at the effect of robot densification on different income groups, the results vary. In other words, "While digital [technological] progress grows the overall economic pie, it can do so while leaving some people, or even a lot them, worse off."[7]

The bad: Rising inequality

Technological change is the main reason for rising inequality

There is a growing consensus among academics and politicians that technological change has been the main driver of rising inequality in advanced economies over the past couple of decades.[8,9] And the effect of robots is unlikely to be any different. Most of the more recent studies support the intuitive result that high-skilled and high-wage workers have been the main beneficiary of technological progress and increased robot densification. Interestingly, this has not always been the case, as in the nineteenth century more advanced manufacturing technologies had still largely substituted for skilled labor through the simplification of tasks. In the UK, the first industrial revolution led to a shift towards unskilled workers, with the share of unskilled workers doubling from 20% to 40% between 1700 and 1850.[10] That changed, when in the late 19th and the 20th century demand for high-skilled workers also began to rise. And with the increased use of robots, computers and other machines, the latest round of technological progress now largely comes at the expense of middle- and low-skilled and -wage workers. The question, which of these two groups is being hit harder, is still being debated.

Labor market polarization due to ICT

Several recent empirical studies have highlighted the polarization in the labor market of various advanced economies in the sense that workers in the middle of the wage and skills distribution have fared more poorly than those at the bottom and the top. Chart 9, which is based on Autor and Dorn (2013) and largely resembles Milanovic's (2012) now famous "elephant chart", reveals that between 1980 and 2005 wage gains for middle-income jobs in the US have been way smaller (in some cases even negative) than those for low- and in particular high-income occupations. This observation can be explained by the fact that the technological change over that time period has been biased towards replacing labor in routine tasks ("routine-biased technological change"), which tended to decrease demand for middle-skilled occupations, as well as the reallocation of labor into lower paying service occupations.[11]

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[7] Brynjolfsson and McAfee (2012).
[8] See e.g. Council of Economic Advisers (1997), Jaumotte et al. (2013) or IMF (2007).
[9] In his recent book, Milanovic (2016) highlights that globalization has added to inequality within advanced economies, while helping to reduce global income disparities between countries.
[10] See Frey and Osborne (2013), Haldane (2015), and Marcoline et al. (2016).
[11] See Goos et al. (2014) or Autor and Dorn (2013).

More recent research has linked the labor market polarization of the late 90s in particular to the surge in information and communication technologies (ICT) as industries with faster growth of ICT had experienced greater increases in relative demand for high-educated workers and bigger falls in relative demand for middle educated workers, as well as to the impact of globalization.[12] As a result, middle-skilled groups have suffered a fall in demand. But that may be about to change – to the detriment of lower-skilled workers.

Further technological progress to primarily hurt low-skilled workers

Future advancements in computerization or automation (including robots) are expected to primarily come at the expense of low skilled workers, as wages and educational attainment exhibit a strong negative relationship with the probability of computerization. In particular, a substantial share of employment in service occupations is highly susceptible to further computerization. With regard to the specific impact of robots, there is already evidence that hours worked and the wage bill of skilled workers have increased faster, while low-skilled workers have suffered from robot densification. Middle-skilled workers may have been adversely affected as well, but to a lesser extent than low-skilled workers.[13]

White House warnings

The President's Council of Economic Advisers (2016) even dedicated an entire chapter in this year's Economic Report to "Technology and Innovation", with a special focus on "Robotics" and their effect on workers. According to the CEA's calculations (which are based in part on Frey and Osborne 2013), the median probability of automation (i.e. the risk of losing a job to robots) for workers making less than USD 20 per hour is no less than 83%, whereas workers making more than USD 40 per hour only face a 4% risk of losing their job to robots. Quoting these results, news channel CNBC reported in late February "White House sees robots taking over jobs." In a very recent paper, the OECD (Arntz et al. 2016) suggests that these estimates probably overstate the risk of automation.[14] Their task-based approach comes up with a smaller share of jobs that may be destroyed by robots (see table 2). Their research confirms, however, that the risk of automation declines significantly with the level of education (see chart 10).

WHILE PREVIOUS TECHNOLOGICAL PROGRESS LED TO POLARIZATION, ROBOTS WILL HURT THE LOW-SKILLED THE MOST

Chart 9: Real hourly wages: levels and change

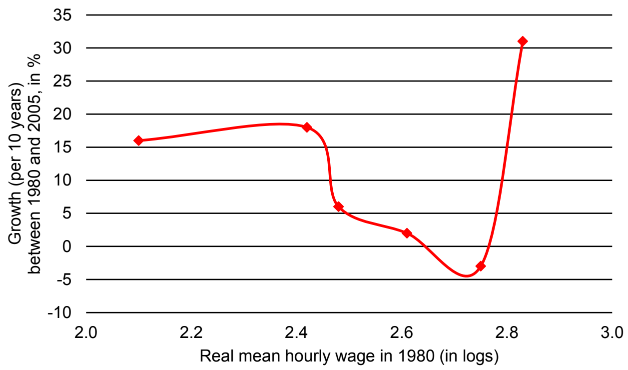
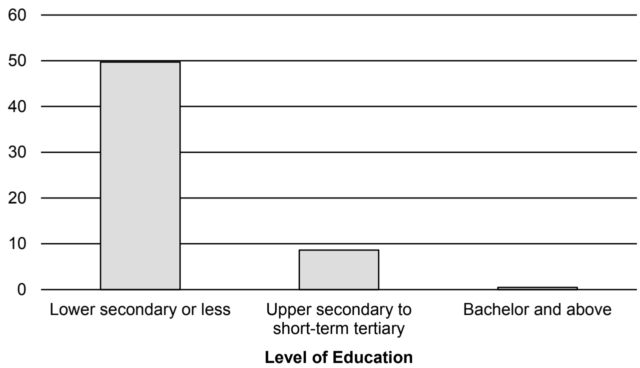


Chart 10: Share of workers with high automatibility by education, %



Source: Autor and Dorn (2013), Arntz et al. (2016), UniCredit Research

[12] See Michaels et al. (2014) and Milanovic (2012).
[13] See Frey and Osborne (2013) and Graetz and Michaels (2013).
[14] Arntz et al (2016) question one of the main assumptions from Frey and Osborne (2013) that whole occupations rather than single job-tasks are automated by technology.

Better safe than sorry

Of course, not everyone is convinced that technological progress, and robots in particular, is indeed the main driver of labor market polarization and rising inequality.[15] And Robert Atkinson (2013), the president of the IT & Innovation Foundation, argues that,"In sum, the worries of machines overtaking humans are as old as machines themselves. Pitting man against machine only stokes antipathy towards technology and could have a chilling effect on the innovation and adoption of technology essential to grow our economy. This is the last thing our economy and workers need […] we are actually at risk of being held back by too little technology." Along the same lines, the PEW Research Center (2014) finds that experts in this field "are deeply divided on how advances in AI and robotics will impact the economic and employment picture over the next decade," and on "whether these advances will displace more jobs than they create." And the recent ZEW study (see above) does support those considerations about robots being a net positive for the economy and the labor market as a whole. However, given the large and growing body of empirical evidence that does link inequality to technological progress, it seems more than prudent to act on the presumption that this causality exists, and in a powerful way. In the following, we discuss several steps that should be taken in order to make further technological progress as beneficial for as many parts of the population as possible. Ideally, these measures would shield workers from the adverse implications. Raising education levels is certainly the most important of these first-best solutions. But as complete protection is not achievable, we also need to discuss additional steps, including ownership rights and redistribution.[16]

TABLE 2: AUTOMATIBILITY BY OECD COUNTRIES[17]

	Share of people at high risk	Mean automatibility	Median automatibility
Austria	12	43	44
Belgium	7	38	35
Canada	9	39	37
Czech Republic	10	44	48
Denmark	9	38	34
Estonia	6	36	32
Finland	7	35	31
France	9	38	36
Germany	12	43	44
Ireland	8	36	32
Italy	10	43	44
Japan	7	37	35
Korea	6	35	32
Netherlands	10	40	39
Norway	10	37	34
Poland	7	40	40
Slovak Republic	11	44	48
Spain	12	38	35
Sweden	7	36	33
United Kingdom	10	39	37
United States	9	38	35

Source: Arntz et al. (2016), UniCredit Research

[15] Some prominent papers here are Card and DiNardo (2002) and Mishel et al. (2013).
[16] Andy Haldane (2015), the Bank of England's Chief Economist names three long-term solutions: relax, retrain and redistribute. But in line with our considerations, he does not seem to endorse the "relax" option, which de facto leaves him with the same two policy recommendations that we describe.
[17] The authors analyze 632 occupations and estimate the probability with which each of these jobs could potentially be automated. "High risk" occupations are those with an automatibility of 70% and more. Mean and median automatibility are calculated across the analyzed occupations.

How to make technological progress your friend

Improve education (and other stuff)

Not only quantity but also quality

If the impact of further technological progress on the labor market is mostly a function of skills, the most obvious policy recommendations point to education. Not only will it be imperative to increase the overall education attainment of a larger share of the population, but the provision of education will have to be effective and appropriately tailored to the demands of today's global, technology-demanding economy. In other words, countries should not only strive for an improvement in overall education levels, but may need to adjust curriculums in order to teach skills that help to robot-proof students' careers.[18]

Raising potential GDP

There can be no doubt that a higher general level of education is beneficial for the economy. Standard & Poor's estimates that adding another year of education to the American workforce, in line with education levels increasing at the rate of educational achievements seen from 1960 to 1965, "US potential GDP would likely be USD 525bn, or 2.4% higher in five years, than in the baseline." And even "if education levels were increasing at the rate they were 15 years ago, the level of potential GDP would be 1%, or USD 185bn, higher in five years."[19]

The rich-poor gap in educational achievements

But in the context of increasing inequality – largely caused by external factors such as technological progress and globalization – raising the overall (average) education level is not everything. Instead, special attention needs to be given to those who suffer the most (or benefit the least) from these exogenous developments. As shown in chart 11, the college education premium for men in the US has more than tripled since the late 70s:[20] While in 1979 men with a Bachelors' degree or more earned 29% more than a high school graduate, they now (in 1Q16) make 95% more. For women, the college premium has doubled from 43% in 1979 to 85%. As if this by itself does not already pose a formidable challenge for policy makers, there is an increasing body of evidence suggesting that not everyone has the same chances to thrive. The Roundtable on Population Health Improvement (2015), citing official statistics from the Department of Education, points out that family income has a bigger impact on college completion rates than the test scores of the respective students in the 8th grade (see chart 12). Along the same lines, Stanford sociologist Sean Reardon (2013) highlights that the differences in educational success between high-and lower-income students have grown substantially. According to his research, the "rich students are increasingly entering kindergarten much better prepared to succeed in school than middle-class students. This difference in preparation persists through elementary and high school." And it is not only that the rich have more money than they used to, but they are using it differently: they are increasingly focusing their resources on their children's cognitive development and educational success because these factors have become more important than they used to be. This has created "a worrisome mutual reinforcement of trends that is making our society more socially and economically immobile." So in order to move towards a society in which educational success is not so strongly linked to family background, notably the wealth and income situation, countries should invest in developing high-quality child care and preschool that is available to poor and middle-class children. But it also means to improve the quality of our parenting by finding ways of helping parents to become better teachers themselves.

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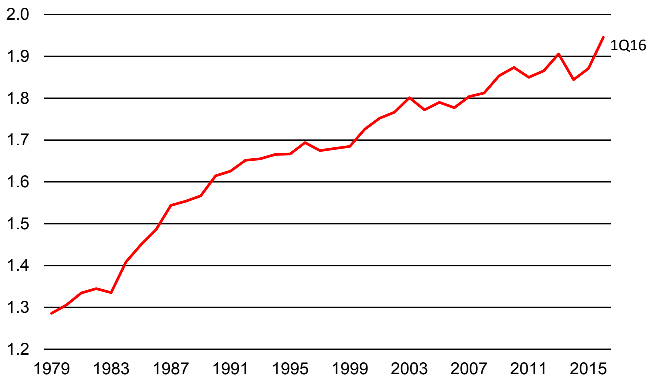
[18] See Rotman (2014), Kearney et al. (2015) and O'Connor (2016).
[19] Maguire (2014).
[20] See also CEA (1997) or Autor (2014a).

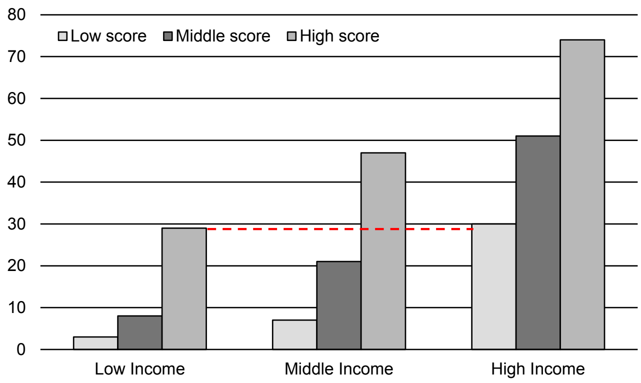
COLLEGE PREMIUM HAS TRIPPLED

Chart 11: College/High School Median Earnings Ratio for Men 25Y+ (Full-Time, Full-year Workers)



FAMILY INCOME MATTERS MORE THAN TEST SCORES

Chart 12: College completion by income status and 8th grade test scores, %



Source: BLS, Roundtable on Population Health Improvement, UniCredit Research

Focus on humans' comparative advantages

In addition, the rise of computers and robots changed the kind of skills demanded from humans: "School education has tended to focus on developing the core cognitive competences – for example, reading, writing and arithmetic. Smart machines have long since surpassed humans in their ability to do the first and third of these. And they are fast catching-up on the second."[21] That begs the question of whether there are other skills where humans' comparative advantage is greater. For example, humans are known to possess an equally-important class of non-cognitive skills – self-confidence, self-esteem, relationship-building, negotiation skills, empathy. Already a decade ago, Goleman (2005) pointed out in his seminal book on this topic that emotional intelligence is even more important for professional success than cognitive skills. More recent studies confirm that these non-cognitive attributes are as, if not more, important than cognitive competences in enhancing jobs, incomes and well-being.[22] There is a "precipitous increase in the wage payoff to synthesis, critical thinking, and related "analytic skills." The payoff to technical and creative skills, often touted in discussions of the third industrial revolution, is shown to be less substantial."

E-I-E-I-O

While improving education should unequivocally be at the forefront of the political response to rising technologically-induced inequality, there are other measures that economists agree on. Andrew McAfee (2015) remembers them through the old nursery rhyme about Old McDonald's farm: E-I-E-I-O:

- **Education**: Focus on skills that technology is not too good at (see above).
- **Infrastructure**: Improve broad infrastructure from roads, airports to networks.
- **Entrepreneurship**: Support young creative businesses, which foster innovation and are a prime source of new jobs.
- **Immigration**: Welcome talented and ambitious people.
- **Original (basic) research**: Support original, early-stage research.

[21] Haldane (2015).
[22] Heckman and Masterov (2007) and Lui and Grusky (2013).

The right question

We are summing up this section with a quote from the MIT's David Rotman (2014): "That's why asking whether technology causes inequality is the wrong question. Instead, we should be asking how advancing technologies have changed the relative demand for high-skill and low-skill workers, and how well we are adapting to such changes." And the main focus should be on education, training and teaching the right skills.

Ownership and redistribution

The right policy mix needs more than education

But even if (and that is a big "IF") politicians do all the right things and follow Old McDonald's nursery rhyme, increased technological progress will most likely still lead to growing income inequality – albeit to a lesser extent than in a situation in which politics does not adjust accordingly. After all, people have different skills, as well as different financial conditions. Both factors impact the degree to which they can benefit from technological progress. In two of the most influential economic books of the past couple of years, Thomas Piketty (2014) highlights the role of (inherited) capital, while Erik Brynjolfsson and Andrew McAfee (2014) describe how human superstars thrive in the new machine age. There is, thus, a growing need to reallocate income from rich to poor and/or from owners to workers.

What are the solutions?

In theory, there are three possibilities to try to partly offset or mitigate the ongoing decline in labor's share of income (see chart 13):

- Higher wages through collective bargaining or minimum wages.
- Redistribute wealth and income through tax-and-spend policies.
- Spread the ownership of capital to ensure a more equitable distribution of robotic rents.

Who owns the robots

The first two options have been the traditional ways to redistribute profitability and income gains, and they will certainly be used again this time. There are, however, tight limits to what can be achieved through them. If robots indeed compete with low and medium-skilled workers, raising (minimum) wages would only accelerate and intensify the substitution of labor with capital. On the redistributive tax-and-spending policies, one option would be a guaranteed basic income, as recommended, e.g. by Martin Ford (2015) in his recent book. But the people of Switzerland just rejected such an option in a referendum. And even if there is public support for such a measure at some point in the future, budgetary constraints and aging populations limit what most countries can do in this respect. Accordingly, we agree with Freeman (2015) that one of the most promising solutions to the long-term challenge posed by machines substituting for labor "is for you, me, all of us to have a substantial ownership stake in the robot machines. […] We must earn a substantial part of our incomes from capital ownership rather than from working. Unless workers earn income from capital as well as from labor, the trend toward a more unequal income distribution is likely to continue, and the world will increasingly turn into a new form of economic feudalism. We have to widen the ownership of business capital if we hope to prevent such a polarization of our economies." And the form of ownership that potentially has the greatest economic benefit in dealing with robotization and the falling share of labor income is employee ownership.

Employee Ownership

According to the National Center For Employee Ownership, NCEO, "Employee ownership" refers to the ownership of a company, directly or indirectly, in part or in whole by some or all of its employees. While a business owner can also be an employee (the CEO, etc.), the NCEO usually refers to ownership by a broad cross-section of employees, including rank-and-file employees, generally through a formal plan offered by the employer. The main vehicle for broad-based ownership in the U.S. is the employee stock ownership plan (ESOP). After the US introduced tax benefits for ESOPs in 1974, the number of ESOP participants surged from an estimated 250,000 in the mid-70s to almost 14 million in 2013 (see chart 14). The other category of employer ownership is equity compensation, which refers to a grant of stock or its equivalent from the employer.

ONE WAY TO TACKLE THE FALLING LABOR SHARE: RISING PARTICIPATION IN STOCK OWNERSHIP PLANS

Chart 13:
Labor Share (nonfinancial corporate sector)

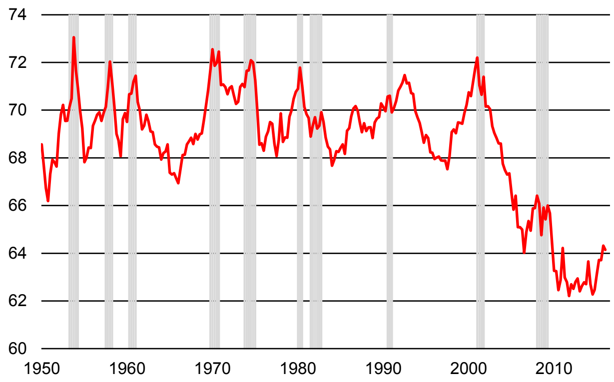
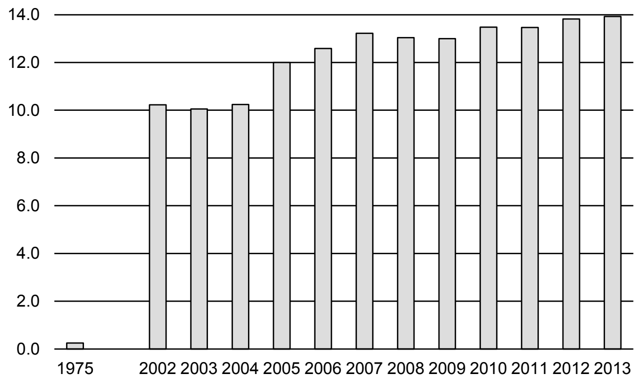


Chart 14: Total participants in employee stock ownership plans in the US (in millions)



Source: BEA, NCEO, UniCredit Research

Better for society and for companies

Governments can help to make these payment and ownership structures more favorable for companies through preferred tax treatment, as e.g. made with the ESOPs in the mid-70s. The EU has endorsed those schemes in various Pepper Reports and encouraged them, but so far only with mixed success.[23] However, at the end of the day, it is up to the companies themselves to increase employee ownership. And the fact that participation in the US has risen dramatically over the past decades even without any further political incentives provides reason for hope. Maybe these government structures do not only allow for a more equitable distribution of robotic rents, but also "generate value for the companies themselves and for wider society."[24] Along the same lines, Freeman (2015) notes, "Firms with compensation policies that give workers some capital stake in their firm have better average performance than others. They do this by inducing workers to work harder and smarter. Exemplar firms throughout the world operate in these ways: John Lewis in the UK, Mondragon in Spain, and Google and most of the high-tech firms in the US."

Separation between ownership and control

One important question related to the redistribution of ownership rights is whether this also leads to changes in control, i.e. who decides how to allocate capital. After all, from a macro perspective, we want the capital to be controlled by those who are allocating it most efficiently. Research on this goes back as far as the early 70s. In expanding the seminal works about worker-managed enterprises by Ward (1958), Domar (1966) or Vanek (1970) to industrial corporations, Atkinson (1973) found that "the separation of ownership and control leads both labor-owned and capitalist firms to grow faster." Along those lines, we think that the main purpose of granting ownership rights to employees should be to cushion the impact of falling labor income by giving them access to capital income, rather than to make the allocation process of capital more efficient.

The risk is that the outcome is binary: either very bad or very good, depending on how the ownership structure is solved: "Whoever owns the capital will benefit as robots and AI inevitably replace many jobs. If the rewards of new technologies go largely to the very richest, as has been the trend in recent decades, then dystopian visions could become reality. But the machines are tools, and if their ownership is more widely shared, the majority of people could use them to boost their productivity and increase both their earnings and their leisure. If that happens, an increasingly wealthy society could restore the middle-class dream that has long driven technological ambition and economic growth." (Rotman 2015)

[23] See Freeman (2015).
[24] Haldane (2015).

Conclusion

The number of robots used by businesses to boost their productivity has increased rapidly in recent years. And there is no reason to believe that this pace of “robotization” will begin to slow any time soon. On the contrary, as the cost of robots continues to fall while their capabilities go up, and with the robot density in most industries still relatively low, the IFR anticipates that the pace of yearly robot installations will continue to grow at double-digit rates for the time being. The productivity impact of robots is already comparable to the contribution of steam engines. And while it is still lagging behind the impact of ICT, one has to keep in mind that the total value of ICT capital by far exceeded that of current robot services. Some of the productivity gains from robot densification are shared with workers through higher wages. The issue is, however, that different income and skill groups do not benefit to the same extent, which means that robotization further adds to income inequality. To allow for a broader share of the population to reap the benefits of this technological progress, two sets of actions should be taken. First and foremost, we need to rethink our education system. As robots and machines are capable of taking over a growing number of tasks, humans have to focus on their comparative advantages, including non-cognitive skills. In addition, advanced countries (notably the US) have to halt and reverse the trend that the quality of student education is primarily determined by parents’ income and wealth, as this unequivocally amplifies the negative inequality spiral. But even if politicians do adopt the necessary changes to the education system, increased technological progress will most likely still lead to growing income inequality, as people have different skills, as well as different financial conditions. Both factors impact the degree to which they can benefit from technological progress. There is, thus, a growing need to reallocate income from rich to poor and/or from owners to workers. One of the most promising solutions to the long-term challenge posed by machines substituting for labor is employee ownership, which allows all workers to earn income from labor as well as from capital.

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