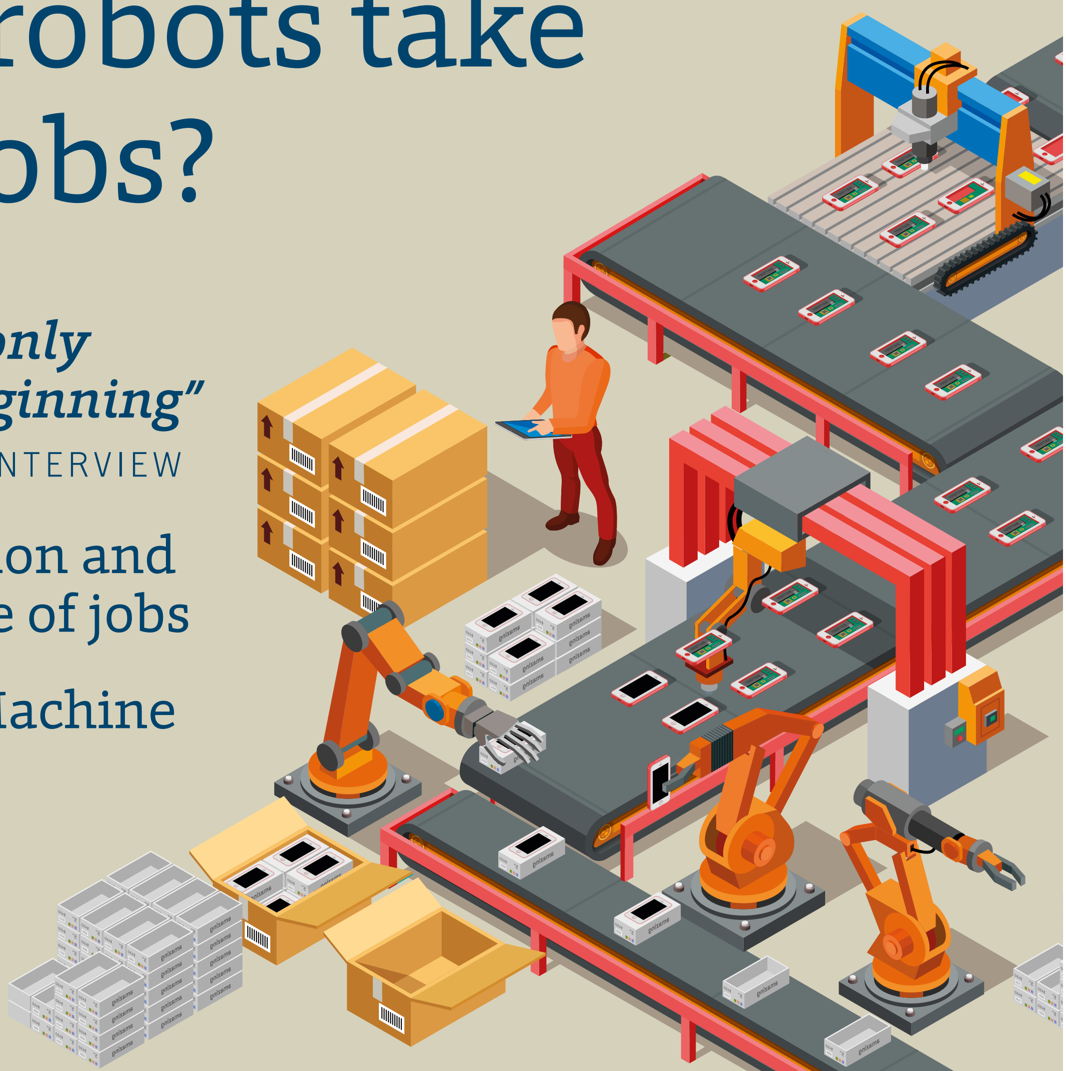
TNIT News

TOULOUSE NETWORK FOR INFORMATION TECHNOLOGY

Daron Acemoglu on:

Will robots take our jobs?

- *"We are only at the beginning"*
  EXCLUSIVE INTERVIEW
- Automation and the future of jobs
- Man vs Machine



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Race against the machine

Jacques Crémer & Priyanka Talim

New technologies have often prompted fear and unrest, perhaps most famously when angry English textile workers smashed weaving machinery during the 19th-century Luddite protests. Today's concerns about the future of jobs are centered largely on the threat that they will be replaced by automated technologies such as artificial intelligence and robotics.

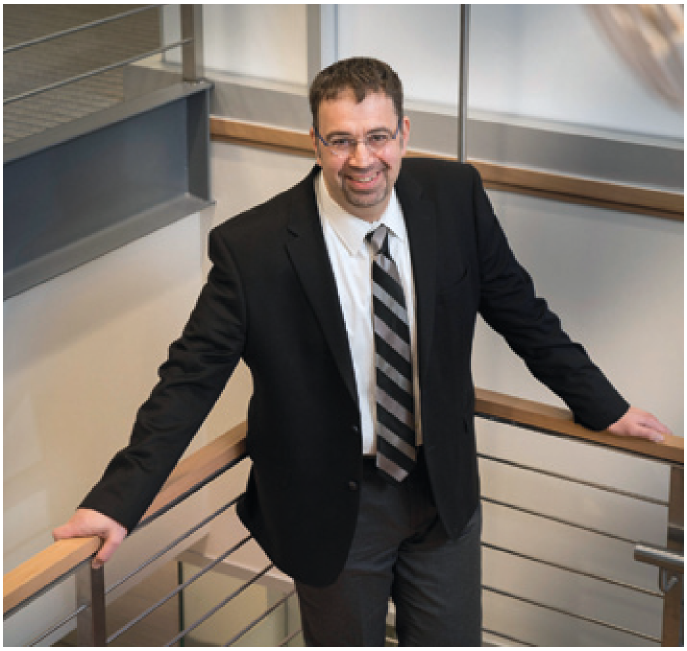
Does the rise of AI and robotics spell disaster for human jobs and economic growth? Can humans keep up with the pace of technological change, creating and adapting to new roles? Two groundbreaking working papers published last year by TNIT member and MIT professor, **Daron Acemoglu**, and his co-author **Pascual Restrepo** of Boston University, have begun to change the way economists address these questions.

In the first of these articles, **'The Race Between Machine and Man: Implications of Technology for Growth, Factor Shares and Employment',** the researchers proposed a new conceptual framework, raising the theoretical possibility that rapid automation need not signal the demise of labor, due to powerful self-correcting forces in the economy.

Focusing on real-world data, the researchers then drew a much gloomier picture in a follow-up paper, **'Robots and Jobs: Evidence from US Labor Markets'.** This is the first study to quantify large, direct and negative effects of robots on employment and wages. Their estimates imply that for every new robot per thousand US workers, about seven workers lost their jobs and wages fell by 1.5 percent.

In this issue of TNIT News, we talk to Daron about the prospects for humanity in an increasingly robotized future, as seen by the press, the public, the Trump administration and economists. We also feature two fascinating essays on the subject by Daron and Pascual, which discuss their research and its implications.

DARON ACEMOGLU ON ROBOTS AND JOBS



A TNIT member and MIT professor, Daron Acemoglu is among the 10 most cited economists in the world according to IDEAS/RePEc. For 'originality, thoroughness, and prolificacy' in economic research, Daron was awarded the John Bates Clark Medal in 2005. TNIT News caught up with him recently to discuss his research on automation.

Your paper 'Robots and Jobs: Evidence from US Labor Markets' has received extensive press coverage. Do you have any concerns that your findings might be misinterpreted? Is the public reliably informed on these issues by journalists and academics?

DA: I don't think the public is reliably informed at all. And yes, I am worried about how academic findings, including my own, will be and are interpreted. The problem is that there is a lot of uncertainty about the effects of new technologies on employment, and this creates room for hype. The media, in this field as in many other areas of technical expertise, is attracted to extreme statements rather than focusing on a balanced discussion of what is known in the academic area. In the context of the future of work, this takes the form of statements claiming that new technologies will bring the end of work for humans. Nothing in the serious research in this area suggests that something like this is in the cards.

‘Our complacency is punctured by paranoia’

> Research does not support a picture of the near future where machines will do all the work

‘The Economist’ and others have used your research to suggest that robots might displace humans in the same way that cars ousted horses. To what extent is this a useful parallel?

DA: That’s not the conclusion I would have drawn. There are different ways of reading our results. On the one hand, the results are large, because the stock of robots in the United States is still small, and our numbers suggest that this might have led to 0.34 percentage points lower employment to population ratio in the United States between 1990 and 2007 than it would have been the case without the additional buildup of this robots stock. So one could go from this and project into the future that with many more robots in the next several decades, we will have a lot more jobs displaced by machines. But the numbers are not that large. Even if we have a huge acceleration in the adoption of robots, we are still talking about a few percentage points lower employment in the next several decades.

So my bottom line is that we have to take the displacement created by new technology seriously, but the research does not support a picture of the near future where robots and other machines will do all the work, and we will all stay at home and play video games (or sip the Burgundy wine all day).

Your colleague at MIT, David Autor, has struck a more optimistic tone about preserving jobs in increasingly automated workplaces, arguing that machines cannot replicate human traits like common sense and empathy. Do you think society is veering toward complacency or paranoia about the dangers of automation?

DA: David and I do not fundamentally disagree. The way I would put it is that some tasks are harder for machines than others. But we have also seen that many predictions about what machines cannot perform have not come true. People used to claim that robots could not perform tasks that required hand-eye coordination, but current robots can do this quite well. (And for full balance, I should say that probably more predictions about what machines will do in the very near future, some from leaders of artificial intelligence and economics, have fallen flat on their face than those on what robots cannot do.) In terms of the reactions of the public, I think we have the worst combination. We have a huge amount of complacency punctured by bouts of paranoia.

To what extent might the market ease the transition to a robot era?

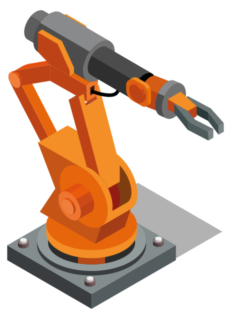
DA: I am a big believer in the market and very cautious about regulation in general. But in this instance, I think we cannot just leave this to the laissez-faire dynamics of the market. First of all, given everything else that’s in place (for example, subsidies to capital, tax credits, accelerated advertisement), there is a strong bias for using machines rather than people. In other words, on first principles, I would expect excessive automation in both Europe and the United States (but there is no systematic work to date to back this claim up). Second, the biggest adjustment we need to make is in preparing our workforce to work productively with robots. For this, workers need to have skills that are complementary to robots, artificial intelligence and other new technologies, rather than skills that are going to be substitutable and thus easily replaced by machines. But we do not at the moment know exactly what bundles of skills are complements rather than substitutes to technology. How can we expect people in their teens to know this and make investments accordingly? Finally, the education system, especially high schools, is broken in the United States and many other advanced economies. There is little that an individual student can do as long as the high-school system is dysfunctional.

What is your reaction to the position of US Treasury secretary, Steve Mnuchin, who said earlier this year that AI’s displacement of human jobs was ‘not even on our radar screen,’ and ‘50 to 100 more years’ away? How should policymakers be preparing for the future?

DA: This is exactly what I would expect from a member of the Trump administration.

David Autor said about your paper: ‘I don’t think it is the last word on its subject, but it’s an exceedingly carefully constructed and thought-provoking first word.’ What do you think might be the next word?

DA: It’s very nice of David to say so. I think the next word will have to come from a much more detailed look at how firms deal with these new technologies. But we also need to start looking at how artificial intelligence is going to be used in service occupations such as accounting, finance, law and so on. We are very much at the beginning of this process of radical automation.



Automation and the future of jobs

by Daron Acemoglu
(MIT, NBER and TNIT)

We are in the midst of huge, transformative changes in the labor market in many developed economies. At the center of this transformation is a wave of technologies based on the computer chip that aim at automating a range of tasks previously performed by labor. Advances in artificial intelligence and robotics are the next potentially powerful phase of this wave. Despite much discussion of automation and what it spells for the future of labor markets, we are far from both a comprehensive framework for studying how automation impacts the functioning of modern labor markets, and from a body of empirical work providing reliable estimates on its impact on employment, wages and productivity.

This essay provides an overview of a conceptual framework for understanding the implications of automation, and a brief discussion of some recent work on the implications of robots on the US labor market. I start with a brief recap of the canonical way in which labor economists and macroeconomists think about the effects of technologies, including computer-based ones, on inequality. I then explain why this framework is not just restrictive, but it flies in the face of several key facts of US labor markets, and even more so after the advent of automation technologies. After outlining an alternative framework and its implications for wages and employment, I move on to a brief discussion of recent evidence on the effects of one salient type of automation technology, robotics, on wages and employment.

ENABLING TECHNOLOGIES

The canonical framework used by labor and macro-economists for thinking about the effects of technology on wages and employment can be summarized as the enabling technology view. Here, new technologies are conceptualized as augmenting the capabilities of some workers and enabling them to perform new functions, increasing their productivity. Arguably the first computer ever invented, the Antikythera mechanism is an example of an enabling technology from ancient Greece around 200 BC. This mechanism enabled skilled early astronomers to calculate the positions of stars and planets, an amazing achievement that would not have been feasible without this technology. Modern examples include computer-assisted design (CAD) machines, which increase the productivity of skilled workers and design tasks and PCs, which have become an indispensable aid to all sorts of managerial and clerical workers.

As these examples illustrate, even in the enabling technology view, new technologies will help certain types of workers more

> **Skill premia and wage inequality increase when technology changes faster than the supply of skills**

than others, and thus could impact inequality. This is in fact the key to the canonical framework for the analysis of labor market and equality first introduced by the Dutch economist Jan Tinbergen, which is then developed and fruitfully applied to data in many settings. An important implication of this framework is obtained by positing that the productivity of and the demand for high-skill workers rather than low-skill workers increases more rapidly over time, increasing the wage premium of high-skill workers. However, this tendency can be counterbalanced by an increase in the supply of high-skill workers, which is the basis of Tinbergen's famous race between technology and supply of education. According to this perspective, skill premia and wage inequality increase when technology changes faster than the supply of skills, and contracts when supply outpaces technology.

Though this framework has been extremely useful in interpreting the broad trends in the labor market of the United States and other advanced economies, it faces at least three fundamental challenges. The first one is that, despite its early success in accounting for the changes in the college premium (average earnings of college-graduate workers relative to high school graduates), this framework has done much less well in recent times.

Second, even more critically, the enabling technology view implies that any improvement in technology should lead to higher wages for all types of workers. But wage declines for low-education workers have been the norm not the exception over the past 30 years in the US labor market. In particular, the real wages of workers with less high school, high school or some college have all fallen sharply since the early 1970s. The inability of this conical framework to account for the pervasive phenomenon of declining real wages of certain groups of workers is one of its most jarring shortcomings.

Third, a more detailed look at distributional wages shows that there are richer dynamics than those that can be explained by a framework where inequality is created by the changing rewards to a single, well-defined type of skill. In particular, wages at the bottom, median and the top move very differently over different time periods. Most notably, in contrast with simple skill-biased technological change view, we do not see an opening of the gap between median and bottom wages. Rather, following a period of sharp falls at the bottom of the wage distribution, there is an extended period from the mid-1980s to the mid-1990s where wages at the bottom are increasing more rapidly than wages in the middle of the distribution.

In contrast to a view based on enabling technologies helping the most highly skilled workers, we see rapid employment growth at the bottom of the wage distribution both in the 1990s and 2000s. The picture that emerges is thus one in which the economy is generating considerably more employment in lower-paid occupations than in occupations in the middle of the wage distribution.

Finally, we can also verify that this is not just a US phenomenon. The middle-paying occupations have contracted in every European country between 1993 and 2006, strongly suggesting that the employment patterns we are witnessing in the United States are due to common technological trends rather than idiosyncratic US factors.

REPLACING TECHNOLOGIES AND AUTOMATION

The alternative to the enabling technologies view is to conceptualize new technologies as explicitly replacing labor in some tasks. Of course, in practice some technologies will be enabling, like the Antikythera mechanism or computer-assisted design technologies, while others will be replacing. The perspective in this essay is that many of the new technologies transforming the labor market are not of the enabling type but clearly replacing and displacing labor, and this has far-reaching consequences.

The classic historical example of replacing technology is the Jacquard Loom, a power loom invented in 1801, which significantly simplified intricate weaving steps in textile manufacturing. Today, various computer-based automation technologies such as automated teller machines, computerized inventory control and mail sorting machines are examples of replacing technologies. Most major replacing technologies that have already started spreading in the economy are industrial robots, which take over various tasks previously performed by semi-skilled industrial workers, and artificial intelligence, which promises to replace workers in many skilled occupations ranging from paralegals to accountants and even some middle managers.

Conceptually, we can make sense of replacing technologies by abandoning the reduced-form formalization of the relationship between technology and factors of production used above, and think instead in terms of tasks that need to be performed for production.

In addition to descriptive richness of this task-based framework, it has the advantage of providing a conceptual framework in which the challenges facing the enabling technologies view can be readily resolved. In particular, in this framework:

- In contrast to the standard framework based on enabling technologies, replacing technologies can reduce wages. This contrasts with the predictions of the canonical model we discussed in the previous section. The key is the difference between enabling and replacing technologies. As already noted, enabling technologies, by augmenting one type of labor or the other, always increase the demand for both factors of production. This is not the case with replacing technologies. Even with a single type of labor competing against technology or capital, a set of tasks shifting from labor to capital can reduce wages. This effect is further strengthened if there are multiple types of labor, and new technologies directly take away some of the tasks performed by a specific type of labor (for example, semi-skilled manufacturing workers or operators).

- For the same reasons as articulated in the previous bullet point, replacing technologies displace workers, and may cause unemployment.

- If new technologies replace tasks in the middle of the pay distribution, they will cause polarization of employment. Intuitively, these new technologies will take away the middle paying occupations, and thus the overall wage distribution will have a smaller, in some sense 'hollowed' middle, causing wage polarization. Interestingly, because workers dislocated by technology from the middle of the pay distribution will compete with others, changes in employment structure may be divorced from wage growth patterns. As a result, we may expect to find faster growth of employment in lower-paying occupations as those dislocated by technology also seek employment in these occupations, which is confirmed by the changes in employment structure shown in the figure below, but this does not necessarily imply faster wage growth in these expanding occupations.

It is also worth noting that the relevance of replacing technologies also stems from the fact that many of the major recent technological waves, which have included advances in automation, robotics and artificial intelligence, fit much more closely with the conceptualization of new technologies. In fact, the spread of industrial robots is a perfect case study for replacing technologies, which we turn to next.

ROBOTS, JOBS AND WAGES

So what do we know about the effects of automation or more specifically robots on jobs and wages? Do they tend to increase wages for all types of workers as an approach predicated on the enabling technologies view would imply? Or do they dislocate many types of workers, reducing their employment and wages as the replacing technologies view would maintain?

Despite the recent ubiquity of these types of technologies, we know surprisingly little about these questions. Most of what we know comes from studies that investigate how feasible it is to automate existing jobs given current and presumed technological advances. For instance, Frey and Osborne (2013) classify 702 occupations by how susceptible they are to automation based on the current set of tasks they perform. They conclude that over the next two decades, 47 percent of US workers are at the risk of automation. A recent report by McKinsey applies this methodology somewhat differently but arrives at similar conclusions: 45 percent of US workers are

Change in employment shares by occupation 1993-2006 in European countries

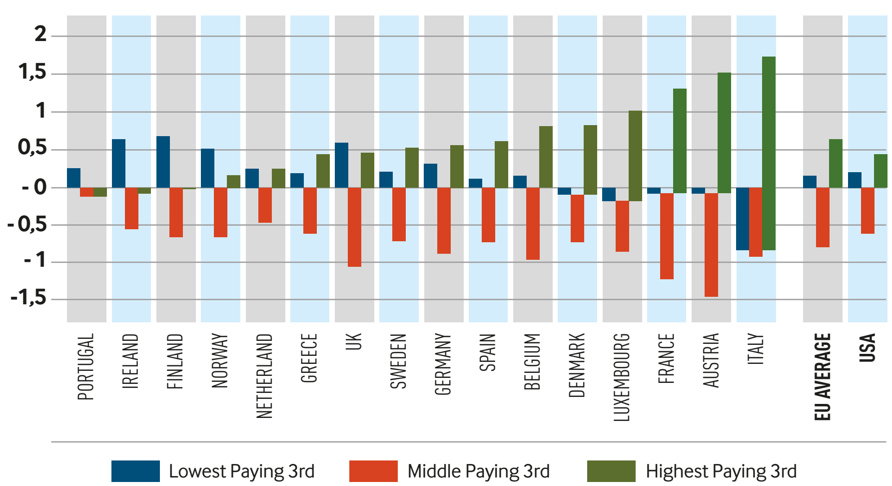


Figure - 1
Acemoglu and Autor (2011) - http://economics.mit.edu/files/7006

> **“One new robot per thousand workers reduces the US employment to population ratio by 0.18-0.34 percentage points and average wages by 0.25-0.5 percent**

at risk of losing their jobs in the face of automation. The World Bank's feasibility study goes even further and finds that 57 percent of jobs in OECD countries could be automated and wither away over the course of the next two decades.

But there are several reasons for not fully trusting the conclusions from these studies. First, it is notoriously difficult to estimate which jobs can be fully automated. For example, another paper utilizing the same broad methodology, Arntz, Gregory, and Zierahn (2016), reaches a very different conclusion because it maintains that within an occupation, many workers specialize in tasks that cannot be automated easily. Their conclusion is that once this type of specialization is taken into account only about 9 percent of jobs in the OECD are at risk. Second, even more fundamentally, these feasibility approaches do not take equilibrium economic responses into account. Feasibility of automating a task does not mean that firms will find it profitable to automate it. And more importantly, the full (and arguably interesting) labor market impacts of new technologies depend not only on where automation and robotics might directly impact, but also on how the rest of the economy will adjust. Most importantly, during several other episodes of major technological change (including rapid automation), other, sometimes new, sectors and occupations have expanded, keeping employment and wages high.

Recent work by Acemoglu and Restrepo (2017), in a working paper titled 'Robots and Jobs: Evidence from US Labor Markets', goes beyond these feasibility studies to estimate the equilibrium impact of industrial robots on jobs and wages. Industrial robots are defined by the International Federation of Robotics (IFR) as "an automatically controlled, reprogrammable, and multipurpose [machine]". That is, industrial robots are machines that do not need a human operator and that can be programmed to perform several manual tasks such as welding, painting, assembling, handling materials, or packaging. Since 1993, industrial robots have been spreading in workplaces, with a global stock reaching more than 1.5 million today. Most experts estimate that robots will become much more ubiquitous in the next decade or so.

Acemoglu and Restrepo (2017) focus on the local labor market effects of robots. Their empirical strategy relies on a measure of change in exposure to robots, constructed using data from the IFR on the increase in robot usage among 19 industries (roughly at the level of two-digit industries) and their employment shares from the Census before the onset of recent robotic advances (in practice 1990). This measure of the change in exposure to robots captures the variation in the distribution of industrial employment across areas around 1990. The reasoning of this measure stems from a simple model of automation and effects of industrial robots, which intuitively relies on the fact that the industry-level adoption of robots in the United States will be related to other industry trends or economic conditions in commuting zones specializing in an industry, the relationship between exposure to robots and labor market outcomes could be confounded. To address this concern, Acemoglu and Restrepo (2017) use the industry-level spread of robots between 1990 and 2007 in other advanced economies, meant to proxy improvements in the world technology frontier of robots, as an instrument for industry trends in the United States. Though not a panacea for all sources of omitted variable biases, this strategy has the advantage of focusing on the variation that results solely from industries in which the use of robots has been concurrent in all or most advanced economies. Moreover, because IFR industry-level data starts only 2004 in the United States, but in 1993 in several European countries, this strategy also enables us to study the impact of industrial robots from 1990 to 2007.

Using this strategy leads to fairly precise, large and negative estimates of robots on employment and wages, very much in line with the replacing technologies view of the world. In particular, in commuting zones that have experienced the largest increase in exposure to robots, there are precisely estimated declines in employment and wages between 1990 and 2007. There are many concerns about the interpretation of these results, especially since other changes affecting local labor markets in the United States might confound the effects of robots. However, these estimates appear to be very robust to controlling for broad industry composition, for detailed demographics, and for competing factors impacting workers in commuting zones - in particular, exposure to imports from China and the decline in routine jobs following the use of software to perform information processing tasks. Perhaps as importantly, most affected commuting zones do not appear to be on a differential trend before the onset of the rising robot usage circa 1990.

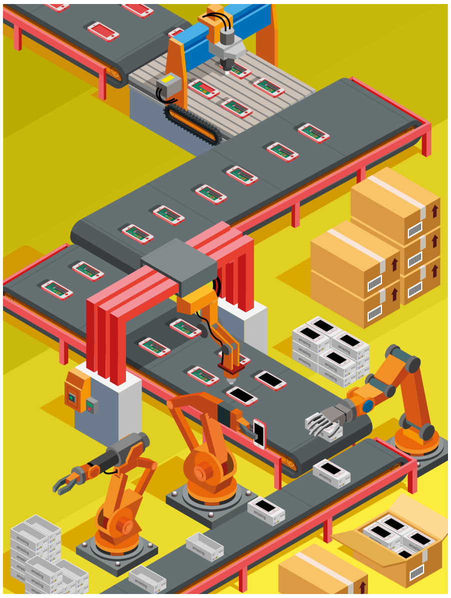
Quantitatively, these estimates imply that one new robot per thousand workers reduces the US employment to population ratio by 0.18-0.34 percentage points and average wages by 0.25-0.5 percent. The employment effects are equivalent to one more robot reducing aggregate employment by about three workers, which is not implausible.

Reassuringly, it appears that the effects of robots are concentrated on the most heavily automated industries; on routine manual, non-routine manual and blue-collar occupations; and on workers with less than college education. The effects on men and women are similar, though somewhat larger on men.

CONCLUSION

To understand the transformative changes our economy and labor market are undergoing, we need to depart from the canonical way in which economists think about technology – as a tide that lifts all boats. Many technologies, which this essay has called 'replacing technologies', displace workers by substituting machines and capital for tasks previously performed by labor. They can reduce, in the short run and the medium run, wages and employment. This makes it more critical to develop a broader approach to the adjustment of the economy in the face of new technologies, because economic adjustment left to its own devices will create considerable hardship for many workers.

After providing a brief overview of this conceptual structure and how it differs from the canonical approach in economics, this essay summarized recent work on the effect of an exemplar of this type of replacing technology, robots, on employment and wages. The evidence indicates large wage and employment losses resulting from the introduction of industrial robots into manufacturing.



IN THE PRESS

Daron's research has sparked extensive media coverage around the world.

- **The Economist:** *http://www.economist.com/news/business-and-finance/21719761-probably-not-humans-have-lot-learn-equine-experience-will-robots*
- **France Inter** *[in French]*: *https://www.franceinter.fr/economie/les-robots-ont-deja-tue-des-emplois*
- **Market Express:** *http://www.marketexpress.in/2017/03/how-many-jobs-do-robots-destroy-answers-emerge.html*
- **The New York Times:** *https://www.nytimes.com/2017/03/28/upshot/evidence-that-robots-are-winning-the-race-for-american-jobs.html*

Man vs Machine

by Daron Acemoglu

(MIT, NBER and TNIT)

The decline in the share of labor in national income, the slow growth of US employment and stagnant real wages have increased the concerns that the wave of new technologies, particularly automation technologies, artificial intelligence and robotics, are making labor increasingly redundant.

Such concerns are not new, however. Keynes articulated similar fears in 1930, introducing the notion of technological unemployment as an ill that would be a byproduct of future economic growth. Another giant of early 20th-century economics, Wassily Leontief, was equally pessimistic about the implications of new machines. By drawing an analogy with the technologies of the early 20th century that made horses redundant, he speculated in 1952 that "Labor will become less and less important…More and more workers will be replaced by machines. I do not see that new industries can employ everybody who wants a job."

Yet, these fears did not come to pass. Could this time be different? Perhaps. But in order to understand whether it is or not, and what can be done about these developments, we need a conceptual framework to shed light on why past episodes of technologies replacing labor in a range of tasks did not lead to technological unemployment, and on the contrary, were based on typically accompanied by wage and employment growth.

One obvious reason for this is that during many episodes of major technological changes, we witness not only the replacement of labor by capital in certain tasks, but also the creation of new industries, occupations and tasks. This is illustrated by technological and organizational changes during the Second Industrial Revolution, which brought about the replacement of the stagecoach by the railroad, sailboats by steamboats, and of manual dock workers by cranes, but simultaneously, there was also another process of technological changes which led to the creation of new labor-intensive tasks. These new tasks generated jobs for a new class of engineers, machinists, repairmen and conductors, as well as modern managers and financiers involved with the introduction and operation of new technologies.

Today, industrial robots, digital technologies and computer-controlled machines are indeed replacing labor and leading to lower wages and employment. Yet simultaneously we are also witnessing the emergence of new tasks ranging from engineering and programming functions to those performed by audiovisual specialists, executive assistants, data administrators and analysts, meeting planners or computer support specialists. Indeed, during the last 30 years, new tasks and new job titles account for a large fraction of US employment growth.

To document this fact, consider data from Lin (2011) that measures the share of new job titles in which workers perform newer

> **The creation of new complex tasks always increases wages, employment and the share of labor and may even reduce the rate of return to capital**

tasks than those employed in more traditional jobs within each occupation. In 2000, about 70% of the workers employed as computer software developers (an occupation employing one million people at the time) held new job titles. Figure 2 shows that for each decade since 1980, employment growth has been greater in occupations with more new job titles. The regression line shows that occupations with 10 percentage points more new job titles at the beginning of each decade grow 5.05% faster over the next 10 years. Similarly, in 1990 a radiology technician and in 1980 a management analyst were new job titles. From 1980 to 2007, total employment in the US grew by 17.5%. About half (8.84%) of this growth is explained by the additional employment growth in occupations with new job titles relative to a benchmark category with no new job titles.

A new working paper by Acemoglu and Restrepo (2016), titled 'The Race Between Machine and Man: Implications of Technology for Growth, Factor Shares and Employment', develops a conceptual framework for understanding how different types of technological change coexist and impact the fortunes of labor. Some, like robotics and automation, replace labor in existing tasks, reducing employment, labor share and potentially also wages. Others, like the creation of new tasks and occupations, increase the demand for labor, raising employment, wages and labor share. It is the balance between these two types of technologies that determines the future prospects for labor.

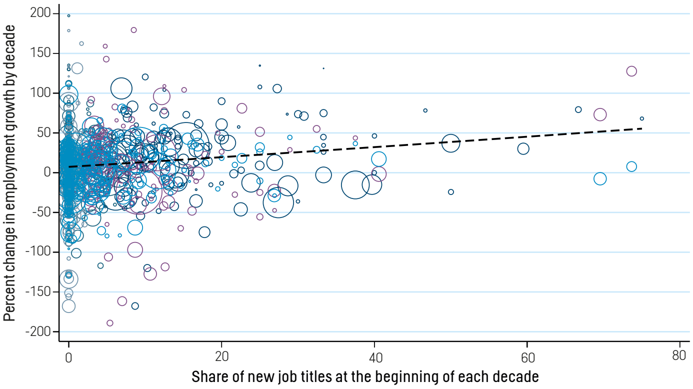


Figure -2
Acemoglu and Restrepo (2016)

More formally, in the model economy, there are two types of technological changes: the automation of existing tasks and the creation of new complex tasks in which labor has a comparative advantage. Our static model provides a rich but tractable framework to study how automation and the creation of new complex tasks impact factor prices, factor shares in national income and employment. Automation allows firms to produce tasks previously performed by labor with capital, while the creation of new complex tasks allow firms to replace old tasks by new variants in which labor has a higher productivity. In contrast to the more commonly-used models featuring factor-augmenting technologies, here automation always reduces the share of labor in national income and employment, and may even reduce wages. Conversely, the creation of new complex tasks always increases wages, employment and the share of labor, and may even reduce the rate of return to capital. Critically, this framework implies that when the creation of new complex tasks keeps up with (or is even faster than) the process of automation, employment and wages will increase even as some workers are being replaced by machinery and new technology. In contrast, when automation runs ahead of the process of creation of new, labor-intensive tasks, technological change will bring lower employment, lower share of labor in national income and also potentially lower wages.

But what determines the pace of these two different types of technological changes? Does the fact that we are seeing more rapid replacement of labor in existing tasks imply that the future is bleak for labor? Or are there powerful self-correcting forces in the economy that could restore some of the lost ground for labor?

To provide a theoretical perspective on these questions, the basic framework outlined above is then embedded in a dynamic setting in which the direction of technological change is endogenous. This, in particular, implies that depending on the profitability of different types of technologies, firms are the ones that invest and develop these technologies. In this setting, Acemoglu and Restrepo (2016) identify a potentially important theoretical effect: If automation runs ahead of the creation of new complex tasks, market forces induce a slowdown of subsequent automation and countervailing advances in the creation of new complex tasks. As a result, there are new economic forces that may restore, in the long run, the share of labor in national income and employment back to their initial levels. The economics of these self-correcting forces are instructive and highlight a crucial new force: a wave of automation pushes down the effective cost of producing with labor. When technology is en-

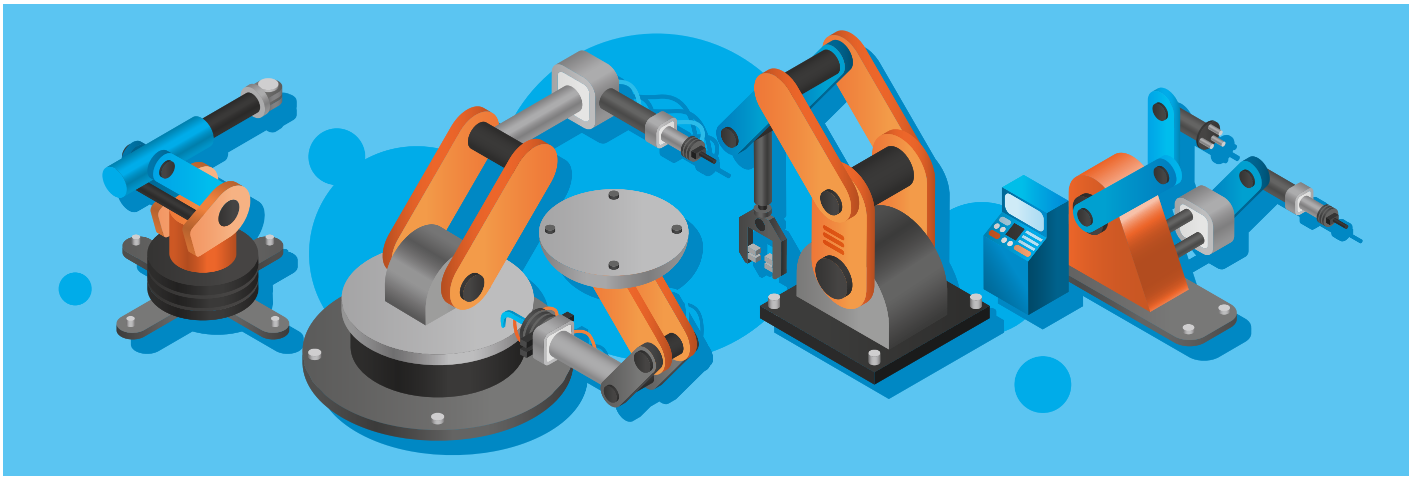
> **"Overall, the central new insight of this framework is the presence of self-correcting forces, which help restore some of the lost ground for labor**

dogenous, this discourages further efforts to automate additional tasks and pushes the economy to redirect its research efforts towards the creation of new (labor-intensive) tasks.

This stability of balanced growth path implies that periods in which automation runs ahead of the creation of new complex tasks tend to self-correct. Contrary to the increasingly widespread concerns discussed above, this framework thus raises the (theoretical) possibility that rapid automation need not signal the demise of labor, but might simply be a prelude to a phase of new technologies favoring labor. In addition, it clarifies the long-run implications of different types of technological shocks. For example, if a wave of automation is triggered by a change in the innovation possibilities frontier (that is, in the technology for creating new technologies) that makes it easier to automate tasks, the economy will settle in a new balanced growth path with a greater share of tasks performed by capital, lower employment and lower labor share.

Overall, the central new insight of this framework is the presence of self-correcting forces, which help restore some of the lost ground for labor because labor becomes cheaper as a result of automation, making the creation of new labor-intensive tasks more profitable. These forces, do not, however, imply that the future is necessarily bright for labor. First, as already noted, these forces might take the economy to a new balanced growth equilibrium (rather than the one we started with) if new technologies also make the creation of further new technologies replacing labor cheaper. In this case, labor will not permanently disappear as a major factor of production, but the future level of employment and labor share may be lower in the future than the past. Second, these economic forces do not imply that the balance between the two types of technologies is efficient. In particular, to the extent that labor gets paid above its opportunity cost (eg, the value of leisure), firms will have a stronger incentive to adopt automation technologies than what a social planner wishing to maximize output would do. This suggests that policies that affect the composition of new technologies might be welfare-improving.

Ultimately, some of the questions posed in this white paper are not just conceptual but also empirical. Only future empirical work can fully inform us about the extent to which new technologies can create sufficient employment opportunities to make up for those lost to automation and robotics. Nevertheless, the conceptual framework outlined here is an important input in understanding how different economic forces might interplay in the future and what types of evidence we should look for.



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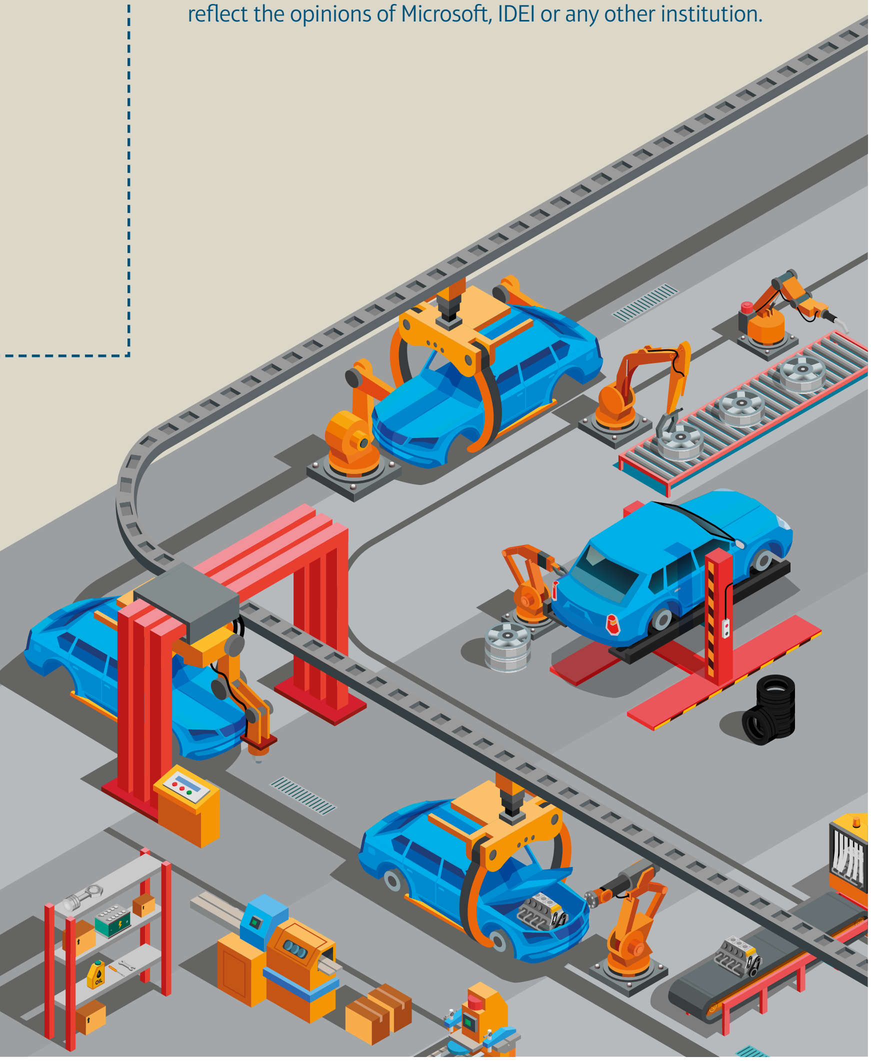

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