THE RACE BETWEEN MAN AND MACHINE:IMPLICATIONS OF TECHNOLOGY FOR GROWTH, FACTOR SHARES, AND EMPLOYMENT

By Daron Acemoglu and Pascual Restrepo

Several commentators are concerned about the possibility that new technologies and automation will render labor redundant,[1] and will fuel further increases in economic inequality. But should we really fear new technologies? What does history teach us?

Looked at through the lenses of history, one particularly perplexing question is this: If automation tends to reduce labor demand and the share of labor in terms of national income, why has economic growth over the last 200 years--which has seen many waves of automation technologies--been accompanied by a broadly stable share of labor and growing labor demand?

To examine this problem, we developed a framework in which automation does, indeed, replace labor in tasks it was previously performing, reduce the labor share in national income, and may reduce labor demand. In developing the framework, we found a possible explanation and answer to the labor/growth question: Automation's impact, under some plausible conditions, can be counterbalanced by the creation of new tasks.

At the same time that new technologies are automating tasks previously performed by human labor, technological change is also introducing new ones in which labor has a comparative advantage relative to machines. So, for instance, concurrent with the British Industrial Revolution's automation of textile work, metal works and parts of mining, came the introduction of engineering, repair, clerical managment, and financial work. And as mechanization of agriculture automated agricultural production, there was a simultaneous expansion in manufacturing and clerical occupations for workers to move into.

There is no necessity that the creation of new tasks will proceed at the same pace as automation.

While it would be simple to draw conclusions based on these findings alone, we found several counterpoints, contradictions, and nuances to address. For one, there is no necessity that the creation of new tasks will proceed at the same pace as automation. If it doesn't, growth will not be balanced and may work against the interests of labor. There is a powerful force toward balanced growth, however: If new technologies are developed by profit-seeking firms, then these technologies are more likely to be introduced when there is more automation taking place.

This is true because automation tends to reduce the labor share as it increases productivity more than wages. This makes new tasks that use human labor less costly and more profitable. Although there is no guarantee that this explanation is powerful enough to establish a balance of economic growth, under plausible conditions, it does.

Additionally, we considered why recent automation has outpaced other types of technological change while wages are stagnant and there are sharply declining labor share and lower employment in many advanced economies. We found several possibilities.

First, we can be experiencing a temporary phenomenon which will self-correct. Second, perhaps more plausibly, this could be a result of the change in society's ability to create automation technologies. If the relative cost of creating automation technologies gets lower, automation will surge ahead, with potential adverse consequences for labor. This doesn't imply the demise of labor, because the same forces will make the economy ultimately settle into a new balanced growth path with lower labor share and perhaps, lower employment.

IN THIS BRIEF

1. The accelerated automation of tasks performed by labor raises concerns that new technologies will make labor redundant. Yet, we have lacked a comprehensive framework incorporating such effects, as well as potential countervailing forces.
2. This paper is a first step in developing a conceptual framework to study how machines replace human labor and why this might (or might not) lead to lower employment and stagnant wages.
3. We consider new, more complex tasks in which human labor has a comparative advantage to machines. In these cases, long-term employment and the labor share can remain stable even in the face of rapid automation.
4. Both automation and the creation of new tasks increase inequality in the short run, but standardization limits increased inequality in the long run.
5. Automation reduces employment because it raises aggregate output per worker more than it raises wages, reducing the labor share and putting downward pressure on labor supply. On the other hand, new tasks increase employment and raise wages more than aggregate output, increasing the labor supply.

[1] Brynjolfsson and McAfee 2014 , Akst 2013, Autor 2015

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But there are several caveats. It is possible, at least theoretically, for the economy to invest so much in automation that over time labor gets more and more squeezed, with disastrous consequences.

Moreover, even if there are self-correcting forces, the amount of automation in the economy may not be optimal. The economy typically generates excessive automation because firms have incentives to meet when they pay high wages, whereas, a welfare-maximizing social planner would take the opportunity cost of labor into account.

Lastly, even if the labor share in employment recovers, inequality may be permanently higher because new tasks may create a comparative advantage for more highly skilled workers at the expense of lower skilled workers.

THE FRAMEWORK

As noted, in our framework tasks previously performed by human labor can be automated and new versions of existing tasks can be created. In a static model, where capital is fixed and technology is exogenous, automation yields a reduction in employment and the labor share, and may even reduce wages. In the case of new task creation, however, the opposite effects are found.

Our more general model endogenizes capital accumulation and focuses on the creation of work as well as on inequality implications. In this scenario, we find that if the long-run rate of capital relative to wages is sufficiently low, the long-run equilibrium involves automation of all tasks. Otherwise, there exists a stable, balanced growth path in which the two types of innovations go hand-in-hand. Stability, therefore, is a consequence of the fact that automation reduces the cost of labor production and thus discourages further automation.

Today, even as industrial robots, digital technologies, computer-controlled machines, and AI replace labor, we are again witnessing the emergence of new work.

When we also introduce workers with different skill levels, we show how inequality increases during transitions driven both by faster automation and the introduction of jobs, and characterizes the conditions under which inequality stabilizes in the long run.

The recent declines in the labor share, in national income, and in the employment-to-population ratio in the United States[2] are often interpreted as evidence for claims that as digital technologies, robotics, and artificial intelligence (AI), penetrate the economy workers will find it increasingly difficult to compete against machines, and their compensation will experience a relative or even absolute decline. The framework helps to see the likelihood of these interpretations.

The stability of the balanced growth path implies that periods in which automation runs ahead of jobs tend to trigger self-correcting forces, and as a result, labor share and employment stabilize and could return to their initial levels.

The framework not only helps understand how and when automation will transform the labor market, but also recognizes that similar claims have been made, but have not always come true, about previous waves of new technologies. John Maynard Keynes famously foresaw the steady increase in per capita income during the 20th Century from the introduction of new technologies, but incorrectly predicted that this would create widespread technological unemployment as machines replaced human labor.[3]

In 1965, economic historian Robert Heilbroner confidently stated that "as machines continue to invade society, duplicating greater and greater numbers of social tasks, it is human labor itself—at least, as we now think of labor— that is gradually rendered redundant."[4] Wassily Leontief was equally pessimistic about the implications of new machines. Drawing an analogy with technologies of the early 20th Century that made horses redundant, he speculated 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." [5]

This paper is a first step in developing a conceptual framework to study how machines replace human labor and why this might (or might not) lead to lower employment and stagnant wages. The creation of tasks--in which labor has a comparative advantage and complements technology—responds to Leontief's analogy: The difference between human labor and horses is that humans have a comparative advantage when new and more complex

[2] Karabarbounis and Neiman 2014; Oberfield and Raval 2014
[3] Keynes 1930
[4] Quoted in Akst 2014, p. 2.
[5] Wassily Leontief

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tasks are introduced. Horses did not. If this comparative advantage is significant, and the creation of new tasks continues, long-term employment and the labor share can remain stable—despite rapid automation.

Today, even as industrial robots, digital technologies, computer-controlled machines, and AI replace labor, we are again witnessing the emergence of new work--ranging from engineering and programming functions, to those performed by audio-visual specialists, executive assistants, data administrators and analysts, meeting planners, and social workers. Indeed, during the last 35 years, new job titles have accounted for a large fraction of U.S. employment growth. Approximately, 60 percent of the 50 million or so jobs added during this 35-year period are associated with the additional employment growth.

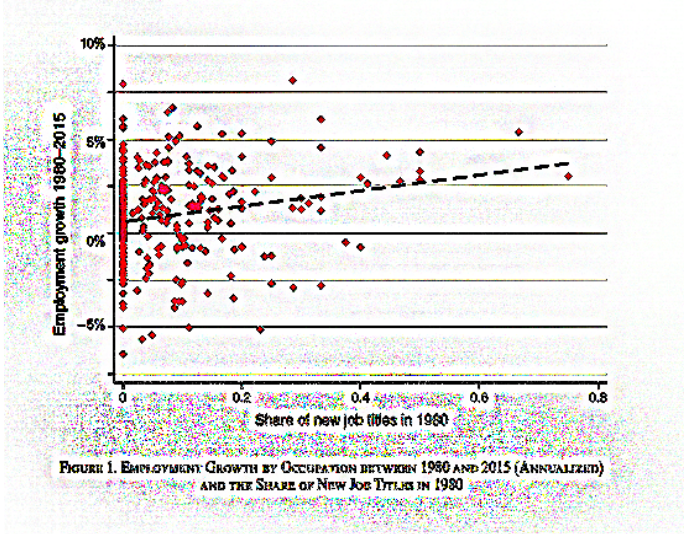

FIGURE 1. EMPLOYMENT GROWTH BY OCCUPATION BETWEEN 1980 AND 2015 (ANNUALIZED) AND THE SHARE OF NEW JOB TITLES IN1980[6]

STATIC AND DYNAMIC MODELS

In a static model, in which capital is fixed and technology is exogenous, there are two types of technological changes: Automation allows firms to substitute capital for tasks previously performed by labor, and new jobs enhance labor productivity. Our static model provides a rich but tractable framework that clarifies how automation and the creation of new tasks shape production possibilities and determine factor prices, factor shares in national income, and employment. In this model, automation always reduces the labor share; conversely, the creation of new tasks increases wages, employment, and labor share.

The stability of the balanced growth path implies that periods in which automation runs ahead of jobs tend to trigger self-correcting forces, and as a result, labor share and employment stabilize and could return to their initial levels. Whether this is the case depends on the reason why automation paced ahead in the first place. If this is caused by the random arrival of a series of automation technologies, the long-run equilibrium takes us back to the same initial levels of employment and labor share. If, on the other hand, automation surges because of a change in the innovation possibilities frontier--making automation easier relative to the creation of new tasks--the economy will tend toward a new balanced growth path with lower levels of employment and labor share. In neither case does rapid automation necessarily bring about the demise of labor.

We also consider three extensions of our model. First, we introduce heterogeneity in skills, and assume that skilled labor has a comparative advantage, which we view as a natural assumption. Because of this pattern of comparative advantage, automation directly takes jobs away from unskilled labor and increases inequality, while new tasks directly benefit skilled workers and at first increase inequality, as well. Over the long run, however, job standardization helps low-skill workers.

Second, we study a different structure of intellectual property rights that introduces the creative destruction of profits, which is absent in our main model, though it is often assumed in the endogenous growth literature. The results are similar, but the conditions for uniqueness and stability of the balanced growth path are more demanding.

Finally, we discuss the welfare implications of our model and study the efficiency properties of automation and creation of new technologies, and point to a new source of inefficiency leading to excessive automation: When wages are above the opportunity cost of labor (due to labor market frictions), firms will choose automation to save on labor costs.

CONCLUSION

Automation on the whole reduces employment because it raises aggregate output per worker more than it raises wages; it may even reduce wages. On the other hand, the creation of new tasks always increases employment and raises wages more than aggregate output, increasing the labor supply.

[6]The data for 1980, 1990, and 2000 is from the U.S. Census. The data for 2015 is from the American Community Survey.

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The main new feature of our framework is that in addition to automation, there is another type of technological change complementing labor. In our model, this takes the form of new, more complex versions of existing tasks, and it is assumed that labor has a comparative advantage. These results highlight that while both types of technological changes undergird economic growth, they have very different implications for the factor distribution of income and employment. Because firms make automation decisions according to the wage rate, not the lower opportunity cost of labor, there is a natural bias toward excessive automation.

Regarding the inequality implications of automation and related new technologies, it is possible that inequality among skill types, as well as the distribution of income, will continue.

More study is needed in several areas:

• Our model imposes that it is always the tasks at the bottom that are automated; in reality, it may be those in the middle. Incorporating the possibility of such "middling tasks" being automated is an important generalization; however, ensuring a pattern of productivity growth consistent with balanced growth, in this case, is more challenging.

• There may be technological barriers to the automation of certain tasks (e.g. on the feasibility or speed of automation).

• We have focused on the creation of new labor-intensive tasks as the type of technological change that complements labor and plays a countervailing role against automation. Another interesting area to investigate is different types of technologies that may complement labor.

• Our analysis of the creation of new tasks focused on skills acquisition. In practice, the inability of the educational system to adapt to the requirements of these new forms of work could become a bottleneck that prevents a rebound in the demand for labor following a wave of automation.

• Finally, and perhaps most important, our model highlights the need for additional empirical evidence on how automation impacts employment and wages (which we investigate in a subsequent paper (Acemoglu and Restrepo 2017a), and how the incentives for automation and the creation of new tasks respond to policies, factor prices, and supply.

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REPORT

The full research paper can be found on the MIT IDE site here: http://ide.mit.edu/sites/default/files/publications/aer.20160696.pdf
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