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AI AND THE MODERN PRODUCTIVITY PARADOX: A CLASH OF EXPECTATIONS AND STATISTICS

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We live in a paradoxical age. When it comes to technology and the economy we see transformative new technologies everywhere except in the productivity statistics. Systems using artificial intelligence (AI)—and machine learning in particular—increasingly match or surpass human-level performance; news about the rapid pace of technological advancement abounds, and market capitalizations for technology firms are at all-time highs. Yet, measured productivity growth in the United States has declined by half over the past decade, and real income has stagnated since the late 1990s for a majority of Americans. Labor productivity growth rates also fell in a broad swath of developed economies in the mid-2000s, and have stayed low since then.

What can explain such inconsistencies? Our new research takes a close examination of recent patterns in aggregate productivity growth for a better understanding of the apparent contradictions.

AI, MACHINE LEARNING ADVANCES

In the past, computer-driven automation depended on explicit specification of rules and routines for executing tasks. Software engineers needed to specify inputs, process, and outputs for each program they wrote. Machine learning represents a fundamental change from the first wave of computerization by using categories of general algorithms (e.g., neural networks) to figure out the relevant mapping of task inputs to outputs on their own, typically using very large data sets of examples. The vast majority of recent breakthrough successes in supervised learning are attributable to deep neural nets, which can be used to approximate any arbitrary mathematical function.

Deep neural nets have made impressive accuracy gains in perception, an essential skill for many types of human work. For example, error rates in labeling the content of photos on ImageNet, a dataset of over 10 million images, have fallen from more than 30% in 2010 to less than 5% in 2016—and most recently, as low as 2.2% with SE-ResNet152, as shown in Figure 1)[1].

Error rates in voice recognition are also falling rapidly. The Switchboard public-domain speech recording corpus of conversations, often used to measure progress in speech recognition, have improved from 8.5% to 5.5% over the past year (Saon et al., 2017). Exceeding the five percent

1 http://image-net.org/challenges/LSVRC/2017/results; ImageNet includes labels for each image, originally provided by humans. For instance, there are 339,000 labeled as flowers, 1,001,000 as food, 188,000 as fruit, 137,000 as fungus, and so on.

IN THIS RESEARCH BRIEF

- Machine learning represents a fundamental change from the first wave of computerization by using neural networks to figure out the relevant mapping of tasks on their own. The vast majority of recent breakthrough successes in supervised learning are attributable to deep neural nets.
- Aggregate labor productivity growth in the U.S. averaged only 1.3% per year from 2005 to 2016, less than half of the 2.8% annual growth rate sustained from 1995 to 2004. Fully 28 of 29 other countries for which the OECD has compiled productivity growth data saw similar decelerations.
- The evidence and explanations for the latest productivity paradox indicate no inherent inconsistency between forward-looking technological optimism and backward-looking disappointment. Both can simultaneously exist.
- Like other general-purpose technologies, AI's full effects won't be realized until waves of complementary innovations are developed and implemented. Still-nascent, technologies can potentially combine to create noticeable accelerations in aggregate productivity growth.

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threshold is important, because that roughly reaches the performance of humans on each of these tasks using the same test data.

Clearly, these and other milestones are impressive technologically, but they can also change the economic landscape, creating new opportunities for business value creation and cost reduction. For example, a system using deep neural networks was tested against 21 board certified dermatologists and matched human performance in diagnosing skin cancer (Esteva et al., 2017). Facebook uses neural networks for over 4.5 billion translations each day.[2]

PRODUCTIVITY DECELERATION

Concurrent with these advances, however, measured productivity growth over the past decade has slowed to half of its level in the preceding decade—and the decline is widespread.

Specifically, aggregate labor productivity growth in the U.S. averaged only 1.3% per year from 2005 to 2016, less than half of the 2.8% annual growth rate sustained from 1995 to 2004. Fully 28 of 29 other countries for which the OECD has compiled productivity growth data saw similar decelerations. What's more, real median income has stagnated since the late 1990s and non-economic measures of well-being, such as life expectancy, have fallen for some groups.

Some of this negativity about the impact of technological progress has spilled over into long-range policy planning and corporate plans, as well. The U.S. Congressional Budget Office, for instance, reduced its 10-year forecast for average annual labor productivity growth from 1.8 percent in 2016 to 1.5 percent in 2017. Although modest, that drop implies U.S. GDP will be considerably smaller 10 years from now than it would in a more optimistic scenario—a difference equivalent to almost $600 billion in 2017.

2 https://code.facebook.com/posts/289921871474277/transitioning-entirely-to-neural-machine-translation/

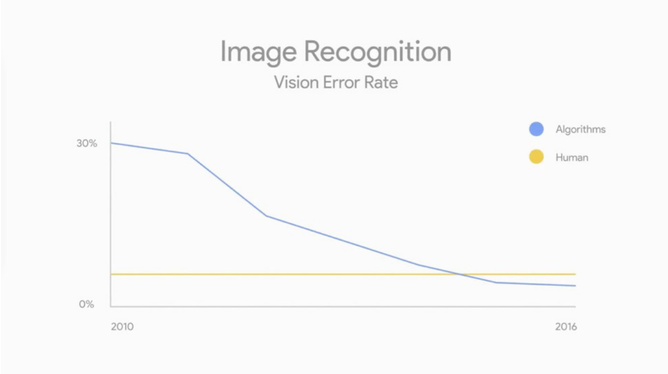

Figure 1. The six-year improvement in AI vs. Human Image Recognition Error Rates

Nevertheless, in our research we find that it's not the first time we've seen economic contradictions of this nature. In fact, we appear to be facing a redux of the paradox first observed by Robert Solow in 1987[3]: We see transformative new technologies everywhere but in the productivity statistics.

In our paper, we review the evidence and explanations for the latest productivity paradox, and propose a resolution based on a surprising and significant conclusion: There is no inherent inconsistency between forward-looking technological optimism and backward-looking disappointment. Both can simultaneously exist.

Indeed, there are good conceptual reasons to expect them to simultaneously exist when the economy undergoes the kind of restructuring associated with transformative technologies. Disparities between future company wealth and the measurers of economic performance are greatest precisely during times of technological change. Our evidence demonstrates that the economy is in such a period now.

FOUR EXPLANATIONS FOR THE PARADOX

Our study led us to four possible reasons for the clash between expectations and statistics: False hopes,

3 Solow, Robert. (1987). "We'd Better Watch Out." New York Times Book Review, July 12: 36

mismeasurement, redistribution, and implementation lags. While a case can be made for each, we contend that implementation lags are probably the biggest contributor to the paradox. Specifically, the most impressive capabilities of AI—those based on machine learning—have not yet diffused widely. More importantly, like other general-purpose technologies (GPT), their full effects won't be realized until waves of complementary innovations are developed and implemented.

Each of the first three reasons—false hopes, mismeasurement, and concentrated distribution—relies on explaining away the discordance between high hopes and disappointing statistical realities. In each case, one of the two elements is presumed to be "wrong." In the misplaced optimism scenario, the expectations for technology by technologists and investors are off base. In the mismeasurement explanation, the tools we use to gauge reality accurate. And in the concentrated distribution stories, private gains for the few, don't translate into broader gains for the many.

But the fourth explanation allows both halves of the seeming paradox to be correct: In other words, there is good reason to be optimistic about the productivity growth potential of new technologies, while at the same time recognizing that recent productivity has been stagnant. It takes a considerable time—more than is commonly appreciated—to sufficiently harness new technologies, especially, major technologies with such broad potential application that they qualify as GPTs. These will ultimately have an important effect on aggregate statistics and welfare. Still, the more profound and far-reaching the potential restructuring from transformative technology, the longer it will take to see the full impact on the economy and society.

The primary source of the delay between recognition of a new technology's potential and its measureable effects is the time it takes to build and scale the new technology to have an aggregate effect. The other requirement is that complementary investments are necessary to obtain the full benefit of the new technology. Therefore, while the fundamental importance of the core invention and its potential for society might be clearly recognizable at the outset, the myriad necessary co-inventions, obstacles, and adjustments needed along the way await discovery over time; the required path may be lengthy and arduous.

THE PROMISE OF AI

This explanation resolves the paradox by acknowledging that its two seemingly contradictory parts are not actually in conflict. Rather, both parts are in some sense natural manifestations of the same underlying phenomenon of building and implementing a new technology.

Historical stagnation does not justify forward-looking pessimism. In addition, simply extrapolating recent productivity growth rates forward is not a good way to estimate the next decade's productivity growth either.

One does not have to dig too deeply into the pool of existing technologies or assume incredibly large benefits from any one of them to make a case that existing, but still-nascent, technologies can potentially combine to create noticeable accelerations in aggregate productivity growth.

Take the example of autonomous vehicles. According to the U.S. Bureau of Labor Statistics, in 2016 there were 3.5 million people working in private industry as "motor vehicle operators" of one sort or another (this includes truck drivers, taxi drivers, bus drivers, and other similar occupations). Suppose that over time, autonomous vehicles were to reduce the number of drivers necessary to do the current workload to 1.5 million—not a far-fetched scenario given the potential of the technology. Total nonfarm private employment in mid-2016 was 122 million.

Therefore, autonomous vehicles would reduce the number of workers necessary to achieve the same output to 120 million. This would result in an increase in aggregate labor productivity (calculated using the standard BLS non-farm, private series) of 1.7 percent (=122/120). If this transition occurred over 10 years, this single technology would provide a direct boost of 0.17 percent to annual productivity growth over that decade.

This gain is significant, and it doesn't include many potential complementary productivity gains that could accompany the diffusion of autonomous vehicles. For instance, transportation-as-a-service might increase over individual car ownership. Thus, in addition to the obvious improvements in labor productivity from replacing drivers, capital productivity would also be significantly improved. Of course, the speed of adoption is important for estimation of the impact of these technologies.

Although this and other examples suggest non-trivial productivity gains, they are only a fraction of the set of applications for AI and machine learning that have been identified so far. James Manyika and his colleagues analyzed 2,000 tasks and estimated that about 45% of the activities that people are paid to perform in the U.S. economy could be automated using existing levels of AI and other technologies. The researchers stress that the pace of automation also will depend on non-technical factors, including the costs of automation, regulatory barriers, and social acceptance.

GENERAL-PURPOSE TECHNOLOGIES TAKE TIME

The relatively slow adoption of IT systems and E-business transformation are good indicators of AI adoption rates--organizational inertia, hiring, and complementary restructuring must be tackled in order for the technology to have maximum impact. The potential of E-commerce to revolutionize retailing was widely recognized, and even hyped in the late 1990s, but its actual share of retail commerce was miniscule, 0.2% of all retail sales in 1999. Only after two decades of widely predicted, yet time-consuming change in the industry, is E-commerce in 2017 starting to approach 10% of total retail sales and companies like Amazon are having a first-order effect on more traditional retailers' sales and stock market valuations. Self-driving cars may follow a similar adoption curve.

As important as specific applications of AI may be, we argue that the more important economic effects of AI, machine learning, and associated new technologies stem from the fact that they embody the characteristics of GPT. Most importantly, machine learning systems can spur a variety of complementary innovations. For instance, machine learning has transformed the abilities of machines to perform a number of basic types of perception that enable a broader set of applications.

When one thinks of AI as a GPT, the implications for output and welfare gains are much larger than in our earlier analysis. For example, self-driving cars could substantially transform many non-transport industries. Retail could shift much further toward on-demand home delivery, creating consumer welfare gains and further freeing up valuable land now used for parking. Traffic and safety could be optimized, and insurance risks could fall. With over 30,000 deaths due to automobile crashes in the U.S. each year, and nearly a million worldwide, there is an opportunity to save many lives.

What's more, the required adjustment costs, organizational changes, and new skills can be modeled as intangible capital. A portion of the value of this intangible capital is already reflected in the market value of firms. However, we need to ensure that national statistics don't fail to measure the full benefits of the new technologies and their true value in the future.

Realizing the benefits of AI is far from automatic, and it's probably more subtle than we—and shareholders—typically imagine. Theory predicts that the winners will be those with the lowest adjustment costs and the right complements. With a realistic roadmap, we all can prepare and share in the eventual benefits.

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The full working paper can be found here: http://www.nber.org/papers/w24001

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