Could official U.S. data—including data showing productivity growth—be failing to reflect a massive process of creative destruction—and disruption—underway? Could today's tech revolution and the application of digitalization and artificial intelligence be having a powerful disruptive effect not fully recognized statistically? And what are the policy implications if productivity growth is being under-measured in the official data?

During the industrial revolution of the late 1800s as the United States was fast becoming an industrial giant, the U.S. economy experienced roughly 8 percent growth and 3 percent deflation. Are there lessons from this period for today's policymakers, who are struggling to make sense of the inexplicable workings of monetary policy even as they continue to undershoot the central bank's inflation targets despite extraordinary levels of monetary stimulus? And who benefits if productivity growth turns out to have been explosive? What about the bulk of the population that doesn't work in technology or own tech-centered stock portfolios?

Could the U.S. Economy Be Experiencing a Hidden Tech-Driven *Productivity Revolution?*

More than twenty important thinkers consider the question.

Thanks to innovation, inflation remains muted, and productivity growth is a bit better than we think and set to accelerate.

MARCO ANNUNZIATA
Co-founder, Annunziata + Desai Advisors, and Co-host, M4Edge tech podcast

This technological revolution will prove more powerful and far-reaching than the first industrial revolution, in my view. Digital innovation has opened new frontiers in product design, through generative design processes, and in manufacturing, through 3D printing. Artificial intelligence has emerged as a new general-purpose technology capable of accelerating progress from biotechnology to materials science, from augmented and virtual reality to autonomous vehicles.

Traditional measurements struggle to cope with this fast and broad-ranging transformation. Academic studies suggest that official statistics underestimate GDP and productivity growth—though measurement issues are unlikely to explain the bulk of the productivity growth deceleration observed in the past ten years. Most of the productivity benefits still lie ahead of us: they will materialize as new technologies scale through new investment, and as companies learn to adapt operations, management practices, and workforce skills to make optimal use of these innovations.

We have evidence that technological innovation is exerting a significant disinflationary impact—from the rapidly falling costs of data computing and storage power, to the increased competition brought about by online retail platforms, to the data-driven efficiency gains in supply chains.

In a nutshell, thanks to technological innovation, inflation remains muted even in a fast-growth environment, and productivity growth is a bit better than we think and set to accelerate a lot more.

What implications should we draw? First of all, we should be more optimistic, as these are positive, welfare-enhancing trends. They can be complex, they make it harder to measure and interpret economic trends, and they bring new challenges—such as identifying and building new skills in the workforce. Some of the challenges, like the benefits, will take time to emerge, and we must be watchful. But on balance, these are good problems to have—especially as the benefits of better products at lower prices in a faster-growing economy accrue well beyond the smaller ranks of technology workers and investors.

Central banks should ponder whether their efforts to boost inflation are justified. Yes, inflation is lower than we expected. But there is no evidence of real and present deflation dangers, and low inflation has not prevented the United States and eurozone from growing at a robust pace in the last few years. Indeed, to the extent that we are underestimating productivity growth, the economy is further away from stalling than policymakers seem to fear. And if ongoing innovation is building steam for a further productivity acceleration, then our economy has even greater pent-up momentum that will come on line over the coming decade.

Discussions of secular stagnation, deflation risks, and additional fiscal and monetary stimulus are then misplaced and mis-timed. Policy efforts should go towards stimulating further private investment, which will accelerate the spread of productivity gains; focusing public spending on upgrading critical infrastructure, including data infrastructure; bolstering education and training to identify and build the right skills and enable lifelong learning; and adapting social safety nets to better assist segments of the workforce at higher risk of disruption.

There are good reasons to believe that productivity data paint a gloomy and unimaginative picture.

SCOTT BESSENT
CIO and Founder, Key Square Capital Management

The prevailing narrative holds that productivity growth has fallen significantly since the financial crisis. Indeed, data from the Census Bureau show productivity growth had grown at an average rate of 2.1 percent from 1980–2009, but has grown at an average rate of only 1.1 percent since. However, there are good reasons to believe that this data paint a gloomy and unimaginative picture.

Economists have produced an ample body of work suggesting that the Consumer Price Index significantly overstates the true rate of inflation. As economist Martin Feldstein pointed out in his September 2016 remarks at the Brookings Institution Conference on Productivity, the most common method used by the Bureau of Labor Statistics to

assess the quality change of a good is to measure the marginal cost of new input requirements directly tied to changes in product quality. To the extent there hasn't been any change in cost, the BLS concludes there's been no change in quality. The BLS similarly relies on input costs when assessing the change in quality of services. Clearly, this methodology misses important quality improvements and leads to an upward bias in the inflation statistics.

But the problem with calculating the CPI runs even deeper. As Brent Neiman and Joseph Vavra note in a recent paper on "The Rise of Niche Consumption," there has been an explosion in the number of products available to consumers. This has allowed households to increasingly concentrate their purchases on a smaller number of preferred products, as consumers increasingly differ on the individual products they purchase. In other words, it's not just that individual products are themselves getting better, but rather there's been a proliferation of new products specifically targeted to meet the individual tastes and preferences of each consumer. This creates welfare benefits for consumers that are not adequately captured by the standard government statistics.

In his important new book, *Narrative Economics,* Nobel laureate economist Robert Shiller cites economist Tjalling Koopmans' famous article, "Measurement without Theory." Koopmans (also a Nobel laureate) asked for theories based on actual human behavior rather than the standard statistical properties of time series data. It is not difficult to posit where Koopmans would have come down on the question of under-measured productivity growth.

Adjusted for measurement errors, inflation has been lower than reported and thus real GDP, properly measured, has been substantially higher. Likewise, as real GDP is imputed from nominal GDP data and then adjusted for inflation, a lower rate of inflation means that the slowdown in both real GDP and productivity growth has been less dramatic than reported.

However, this is not what matters to the average consumer, and knowledge of these corrected statistics is unlikely to quell the populist fervor we are witnessing around the world. For what matters to individuals is not whether their absolute welfare has improved, but rather how their absolute welfare has changed relative to the welfare of those around them.

In fact, rather than appreciating the dramatic improvement in living standards allowed by the digital revolution, most Americans likely adhere to the narrative that technology is destroying their future earning capacity. This two-century-old existential fear, coupled with levels of wealth inequality not seen since the early 1900s, has the potential to further inflame both nationalist and socialist populist political gains.

Francis Browne contributed to this article. The views presented in this article are purely the opinions of the author and are not intended to constitute investment, tax, or legal advice of any nature and should not be relied on for any purpose.

We might hit an inflection point where productivity finally starts to take off, but I am increasingly pessimistic.

JASON FURMAN

Professor of the Practice of Economic Policy, Harvard University's Kennedy School, and Nonresident Senior Fellow, Peterson Institute for International Economics

The official statistics miss a lot of the productivity growth in the economy. They miss the full benefits of Google searches, Amazon Prime, Wikipedia pages, and online travel booking, among other items. A common feature of every item in this list is that they were all widely available by 2007. So the 2.7 percent annual productivity growth from 1995 to 2007 was understated, possibly by a lot. We have continued innovating since then but at nowhere near the pace. So while the 1.3 percent annual growth in productivity since 2007 has also been understated, it has not been understated by as much as it was in the earlier period. As a result, the slowdown in productivity growth is—if anything—even larger than what is shown in the official statistics.

This introspective judgment is borne out in a range of studies that have attempted to quantify bias in measures of prices, or conversely of productivity. These measures typically find that, if anything, the bias has gotten smaller over time. Still, this seems completely counterintuitive. How could it be?

First, technology is only a small subset of our economy and innovation has not been nearly as large or consequential in larger sectors such as construction, education, or healthcare. Second, technology has done more to offer new options for consumers than to change business processes. Third, much of what technology offers consumers is new ways to use their time that are often marginal improvements at best. YouTube may be great, but what matters is how much better YouTube is than television. Finally, as Nicholas Bloom, Charles Jones, John Van Reenen, and Michael Webb have argued, new ideas may simply be

becoming harder to find. The combination of artificial intelligence and robotics enabling the mechanization of the picking of soft fruits like strawberries is simply much less economically important than everything else we mechanized in agriculture without the benefit of the artificial intelligence, like the harvesting of grains. Similarly, personalized medicine is making amazing advances but often limited to treating much narrower categories of diseases than previous innovations, such as antibiotics.

Moreover, as economist Robert Gordon has pointed out, it is hard to argue the latest technologies are anywhere near as transformative as those in earlier periods. Take the 1890s, a decade that saw the invention of or major innovations and commercialization of American subways, aspirin, bottle caps, diesel engines, escalators, gasoline-powered cars, motion pictures, paper clips, radio, rubber surgical gloves, steel-framed skyscrapers, typewriters, vertical filing cabinets, wireless telegraph, x-rays, and the zipper. Compare that to smartwatches.

We might hit an inflection point in the future where productivity finally starts to take off, but I am getting increasingly pessimistic with each passing year. Assuming it does not happen, what does it mean for policymakers? Monetary policymakers may decide that bias in inflation is so large and variable that we should target something we can more easily measure, like nominal GDP. Most important, however, it is an argument against policymakers complacently assuming technology will ride to the rescue all on its own and an argument for policymakers stepping up structural policies, including public investments in innovation and the promotion of competition, to help the innovation process along.

History suggests that for rapid productivity growth, innovation itself is not enough. It must be broadly applied.

MAREK DABROWSKI
Non-Resident Scholar, Bruegel, and CASE Fellow, CASE-Center for Social and Economic Research

In the last decade, most advanced economies have grown more slowly than before. In Japan, a slowdown began in the 1990s. Slower growth has frequently been seen as a legacy of financial crises, especially that of 2007–2009. Indeed, shocks generated by that crisis in particular include a far-reaching financial disintermediation that depressed demand in short term. However, it coincided with a deterioration of several supply-side factors. The first was related to demography, that is, the stagnation or decline of working-age population and population aging. So far, the United States has been less affected than Japan, Europe, or China, but a slower increase in the U.S. labor force is visible. Increasing immigration and a higher retirement age can neutralize partly negative demographic trends, but both meet political resistance.

Lower productivity growth as compared with the 1990s and early 2000s is the second factor. Perhaps this phenomenon is also partly related to demography (is an aging society equally as innovative as a younger one?), or perhaps it is just a matter of the technology cycle.

Is actual technological progress under-measured? There is no empirical evidence in favor of such a hypothesis. Can one expect a new wave of technological revolution, this time related to robotization, artificial intelligence, big data, or any other great innovation? Maybe, but we do not know when exactly it will happen. History suggests that for rapid productivity growth, innovation itself is not enough. It must be broadly applied, as happened with electricity and the combustion engine in the first half of twentieth century and, more recently, with computers. It is also worth noting that the recent wave of trade protectionism, foreign investment screening, and security-motivated restrictions on technology transfer will harm both technological progress (which requires global cooperation), and its fast and broad application.

Can monetary policy help accelerate economic growth in such circumstances? Not at all. Advanced economies do not suffer from insufficient demand. The International Monetary Fund estimates of output gap show that the eurozone is growing at potential and the United States above potential. Additional monetary (or fiscal) stimulus is unable to push up economic growth on a sustainable basis because these economies are supply-side constrained. Therefore, the recent monetary easing decisions of the U.S. Federal Reserve and the European Central Bank cannot bring the expected growth effects. On the contrary, they may do more harm than good if they contribute to further financial disintermediation and new financial bubbles.

Similarly, attempts to deliver on declared inflation targets (usually 2 percent) are pointless because there is no evidence that such an inflation rate is better for economic growth and employment than a slightly lower one such as 1.5 percent. In fact, the latter is closer to the literal meaning of price stability, which is the overarching mission of most central banks. Hence, central banks should revise down their operational inflation targets rather than push inflation up.

My answer is an emphatic yes: the problem is with statistics and not with the evidence of eyes and memories.

JAMES K. GALBRAITH
Lloyd M. Bentsen, Jr., Chair in Government/Business Relations, Lyndon B. Johnson School of Public Affairs, University of Texas at Austin, and 2020 recipient, Veblen-Commons Award

An excellent question, because it gives me a chance to celebrate having made this precise point five years ago. In *The End of Normal: The Great Crisis and the Future of Growth* (Free Press, 2014), I devote a chapter to the digital revolution. My answer is an emphatic yes: the problem is with statistics and not with the evidence of eyes and memories:

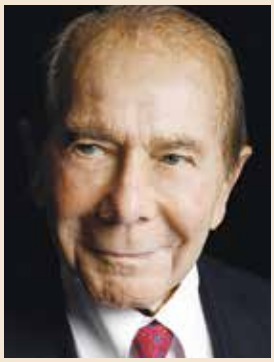
> *With the digital technologies... [f]irst, the price of the equipment required to make the new digital products—measured per unit of output—falls rapidly over time, reducing the value of business investment in the GDP. Second, the products themselves replace marketable output. Communications, information, education, entertainment, and (perhaps especially) retail sales, all previously paid for on a per-unit basis, start arriving for free. They are still part of life—of activity—even to a greater extent than ever before. But they drop out from the economy. The activities in question no longer provide income, and so they no longer provide jobs, and so they no longer form part of what we measure when we speak of economic growth. In this sense, the new technologies save both labor and capital, which accounts for the fact that the ratio of employment to GDP has not fallen as the technologies diffuse. The main effect is on the measured growth of GDP itself, not on the relationship of GDP growth to employment growth.*

In the previous technological wave, automobiles, roads, service stations, and repair shops replaced horses, largely raised and maintained off-market, while appliances, restaurants, and laundries replaced home production—unpaid and unmeasured. The effect then was to boost our measure of economic activity. The effect now is to depress that measure, while dis-employed office and service workers go the way, alas, of the horses.

New patterns of international trade compound the illusion. In the previous century, business investment had large elements of cement and steel, along with heavy machines produced in the United States. In today's economy, business investments have large elements of imported electronics—and imports are subtracted from GDP. So a business boom adds less to GDP than it used to.

Is there a cure? Yes, and we've found it. It consists of expanding and improving services, public goods, and maintenance, including especially education, health care, and the environment. Growth in service jobs explains why unemployment has come down. The difficulty is in the distribution of incomes and the structure of demands. We've got too many dog-walkers, security guards, tattoo parlors, and nail salons, but not enough nurses and school teachers because (guess what?) we don't pay those middle-class professionals enough to compensate for the training and the stress.

Raise the minimum wage. Provide health care and higher education free of debt. Expand Social Security. Tax high incomes and estates. If we rebuild the middle class, the new technologies will work out fine.



It may be some time before the increases in economic productivity from new technologies are fully realized, but they will be substantial.

MAURICE R. GREENBERG
Chairman and CEO, C.V. Starr and Co.

With the global population now reaching close to 7.7 billion, all world leaders will continue to search for ways to improve the living standards of their people. History has shown us that increases in economic productivity are closely related to an increase in living standards, and that the only permanent way to increase productivity is through technology innovation.

During my long career, many examples come to mind—jet engines, fiber optics, advances in health care, mobile phones, personal computers, and the internet, all of which have led to significant improvements in economic productivity. More recently, rapid advances in cloud computing, robotics, artificial intelligence, and automation technologies, including machine learning and natural language processing, have laid the blueprint for the next generation of technological innovation.

It may be some time before the increases in economic productivity that these new technologies bring are fully realized, but there is no doubt they will be substantial.

Governments and companies that embrace them will be the winners and those that resist will not. Kai-Fu Lee, one of the leaders of artificial intelligence development in China, stated on a "60 Minutes" broadcast that artificial intelligence would prove to be more significant than the development of electricity.

It is true that new technologies when introduced into the workforce can be a source of temporary or permanent disruption for the economy as business processes and employees adapt to and are trained in the new technologies. There are predictions that within fifteen years, artificial intelligence will be able to replace around 40 percent to 50 percent of present jobs in the United States. Even if this disruption takes longer to become a factor, the disruption to the job markets will be very significant and have many ramifications.

Disruptions resulting from technological innovation can lead to productivity growth being under-measured by official statistics, which may be happening now, but over the longer term, significant increases in productivity will be realized.

There are economic policy implications if increases in productivity are not accurately captured in official statistics. For example, if productivity growth is being under-measured, this could disrupt the resetting of interest rates and improper measures could be utilized in the consideration of interest rate changes. Who benefits if productivity growth turns out to have been explosive? Consumers could benefit as there could be lower prices, while workers in clerical or repetitive-type jobs would be adversely affected (for example, by loss of jobs).

It is up to policymakers and business leaders to come together to discuss the impact of technological innovation on the economy so that better economic policies can be put forth.

According to the International Data Corporation *Worldwide Artificial Intelligence Systems Spending Guide,* worldwide spending on artificial intelligence systems is forecast to reach $37.5 billion in 2019 and is expected to increase to $97.9 billion in 2023. At Starr Insurance Companies, we have invested in and partnered with Amenity Analytics, which develops cloud-based text analytics solutions using natural programming language processing and machine learning.

Tools offered by Amenity are currently being used or are in development to help us learn more about the risk profiles of target companies to which we would like to offer insurance products, enhance and improve our underwriting capabilities, and other uses are also being considered. Our business processes are being streamlined and employees trained to incorporate these new technologies. We intend to further integrate these and other technologies into our insurance and investment businesses in the coming months.

Technology innovation will continue and hopefully past advances will pave the way for future innovations that will be used to protect our natural resources, advance healthcare, improve living standards, and make the world a safer and more peaceful place for all.

The current innovation ecosystem faces important headwinds.

CATHERINE L. MANN
Global Chief Economist and Managing Director, Citi

Artificial intelligence, 5G, digitalization, freemium models of business—innovations, but where is the productivity? Without a doubt, there is robust innovation in accessing, aggregating, and deploying data to better understand existing as well as create new firms and production technologies, and both meet and create customer and business demands. Is the United States experiencing an unmeasured productivity miracle, somewhat akin to the Solow paradox of the 1980s? Unfortunately, the current innovation ecosystem faces important headwinds, which collectively lead to more modest prospects for productivity growth going forward. It is unlikely that productivity growth is so mis-measured as to give a false signal about the state of U.S. firms, workers, and the U.S. economy. Policy changes are needed to underpin faster productivity growth.

What headwinds hold back innovation and productivity that are not related to measurement, and that proper measurement will not solve? The first headwind is a stalled diffusion process. Frontier firms innovate. But other firms either cannot absorb the new ideas or intellectual property rules prevent them from accessing the innovations. The creative destruction process seems to have changed, with more low-productivity firms remaining. Many metrics of business dynamism have slowed.

The second headwind is lower competitive pressures. Although the productivity growth of frontier firms has been more dramatic than that of the laggards, the wave of mergers and acquisitions in the recent decade appears to

have reduced the incentives to innovate to "beat the competition." Measured productivity growth at the frontier has moderated.

A third headwind has been a retreat from globalization. Globalization as measured by trade intensity (exports plus imports as a share of GDP) stalled a decade ago, hand-in-hand with the productivity-growth slowdown. Foreign direct investment flows have fallen off. With reduced prospects for new customers and expanding markets abroad, there may be less incentive to innovate to reach scale or to meet heterogeneous tastes.

A fourth headwind is unproductive financial investment flows. More financial capital appears to flow to non-innovative uses such as debt build-up, mergers and acquisitions, and buy-backs. Firms that engage in more research and development to support innovation are not necessarily rewarded by investors. Government spending on basic research, which all companies can share to support their own innovative efforts, has deteriorated.

The final headwind is rising inequality. The relationship between innovation and inequality is complex. Certainly productivity and innovation gains that are measured are returned to stockholders and workers at the frontier firms. But with regard to measurement issues, if the U.S. economy was experiencing an unmeasured productivity miracle, it seems unlikely that so much of the unmeasured gains would go to the lower end of the income distribution so as to alter the widening income and wealth gap, within and across generations.

In sum, mis-measurement of productivity does not materially impact these five forces affecting innovation and productivity growth. A real productivity miracle requires addressing these headwinds.

Economists are lousy at predicting future productivity growth.

ROBERT LITAN
Non-Resident Senior Fellow, Brookings Institution

Economists are lousy at predicting future productivity growth, the engine of improvement in average living standards. That is because the growth of productivity largely depends on the pace of advances in diffusion of disruptive innovations, such as those in artificial intelligence, which economists, or even the technologists themselves, cannot come close to confidently forecasting. We are thus left with at least three scenarios, and little basis for attaching any probability to each.

Skeptics such as Northwestern University's Robert Gordon, author of the magisterial *The Rise and Fall of U.S. Growth,* are likely to claim that the pace of advance in artificial intelligence, like that of the information technology revolution itself, is being over-hyped. If this is case, the United States and the rest of the world must learn to cope with continued slow growth—something no one seems to have handled well so far, judging by rising nationalism and political polarization.

Artificial intelligence enthusiasts claim we have seen nothing yet, and that advances in artificial intelligence eventually will put productivity growth on a much higher path. Cassandras fear that this outcome will lead to substantially higher levels of unemployment, claiming that this time will be different: unlike the pattern of the last two hundred years of productivity growth, the AI-induced boost to productivity in the future will be so large and so sudden that millions of people rendered unemployed will never find another job. Hence the support for a "universal basic income," which would do little to help the displaced while greatly enlarging an already bloated federal budget deficit.

The Cassandras also ignore the fact that faster productivity growth will lower the prices of many goods and services, enabling consumers to spend on other things—like education, health care, and entertainment, among other industries, that will need more workers over time to meet the demand. The labor market eventually will adapt to market-driven changes, as it always has.

The clear policy challenge: government must do its part to smooth this adjustment process by enabling workers to gain new skills continuously throughout their working lives, on their current jobs (by using fiscal and monetary policy levers to keep the economy "running hot" as it has been in recent year) or outside work, through support for skills certificate programs offered by community colleges and private educators (regulated to prevent fraud, including mandated disclosure of data on job placement rates in the certificated fields and initial salaries for those gaining such jobs).

In addition, government should provide "place-based" assistance for areas hard hit by productivity or climate change-induced disruption—preferably by subsidizing the wages of new hires rather than the Opportunity Zones authorized by the 2017 tax bill, which seem to be subsidizing mainly high-end residential real estate construction even in those zones (such as apartments for well-heeled students in some university towns).

In fact, that same set of policies—people- and place-based assistance—is warranted in the middle scenario in which artificial intelligence and other sources of productivity growth keep it on modest path—say at 1.5–2.0 percent annually, a little bit above where we have been, but not so rapid as in the high-growth scenario.

Politicians in both parties so far have paid insufficient attention to these remedies, preferring to take the time-worn path of least resistance: promising voters to "save their jobs" through various means, such as firm-specific handouts or trade protection. I hope, perhaps in vain, that at some point our leaders will just level with voters: tell them that trying to hold back technological progress is impossible, that promises to do so cannot be fulfilled, and government does best when it helps people who need help to swim in the river of change rather than letting them drown.

If productivity were actually stronger than is currently measured, we should see evidence of higher wages and earnings in the regular statistics.

JIM O'NEILL

Former Commercial Secretary to the Treasury, United Kingdom, and former Chairman, Asset Management, Goldman Sachs International

Until a few years ago, I was quite a big fan of the idea that our nominal and real GDP were being underestimated, especially in economies where the services sector is a dominant part of the economy. It is quite clear that the measurement of many technology-based services businesses is quite difficult, and it is intuitively sensible that their contribution to GDP is underestimated.

However, as statisticians have got wise to this dilemma, and have started to explore, and in some cases try to employ, techniques which use modern technology to survey people about the nominal value they attach to such services, the subsequent revisions to GDP haven't been spectacular. At some point, perhaps the imagined and understandable productivity benefits of many of these things may come through, and then productivity will rise.

However, as we creep through time, I think there are evidential reasons to doubt these ideas. First, if productivity were actually much stronger than is currently measured, we should also see evidence of the parallel higher wages and earnings in the regular statistics, and quite clearly in many countries, including the United States and United Kingdom, this has not happened despite very strong employment levels. Indeed, a separate surprise remains just how soft wage growth is despite extremely strong levels of reported employment. It is also the case that if true growth were stronger than reported, then government finances should be higher than is often reported, as tax revenues would be higher.

Second, and it is this last observation that has got me exploring this idea, perhaps the way modern financial management, and indeed overall risk management, has evolved, many companies—especially publicly quoted ones—are not incentivized to invest in fixed capital, and with the flexible labor markets apparent, it is easier to hire people instead of investing. This is especially true in some modern tech industries where the fixed capital requirements are less than in historic industries. This can easily explain the productivity weakness, if true, as essentially the result of business leaders preferring the flexibility and price of labor to that of capital. If this is true, policymakers should explore some of the regulations governing how companies are managed, and especially how CEOs are given incentives, including share options.

Third, while many modern technologies seem to have improved our lives, as is becoming recognized in some aspects of life, perhaps we are all spending too much time online and this is not making us more productive. A controversial way of trying to test ideas like this is to change the perception, and perhaps reality, that many online services are free.

What market prices are telling us is that productivity growth is slower than it used to be.

J. W. MASON

Assistant Professor of Economics, John Jay College-CUNY, and Fellow, Roosevelt Institute

How many hamburgers equal one haircut?

In itself, this question doesn't make sense. They're just different things. What we can compare

is how much they cost. This is true across the board—the only way we can convert all the endlessly varied objects and activities that make up "the economy" into a single number is through their market prices. Markets are what let us express all the various products of human labor as a single quantity we call output.

This means that productivity is only meaningful in the context of market prices. There are lots of things that people do that are useful, important, even essential to economic life, from raising children to following the law, that can't be expressed as output per hour.

So it doesn't really make sense to ask if the nonmarket effects of technological change mean we are undermeasuring productivity. A new technology may transform our lives in all sorts of ways, but we can't talk about its effect on productivity except insofar as its products are sold. There's no other basis on which productivity can even be defined—we have to go by market prices. And what market prices are telling us is that productivity growth is slower than it used to be.

This slowdown is not really surprising. Manufacturing—where the transformation of work by technology has gone farthest, and where productivity growth is almost always fastest—is steadily shrinking as a share of the economy.

It is true that we often think of economic growth as something broader than market prices. It's supposed to describe a more general rise in living standards. So a more meaningful way to ask the question might be: Does measured productivity growth accurately reflect the material improvements in people's lives?

The answer here is indeed no. But unfortunately, in the rich countries at least, the mismeasurement probably goes the opposite way as the question suggests.

Measures such as life expectancy used to be closely linked with economic growth. In poor countries, this is still the case—higher GDP is associated with longer lifespans, lower child mortality, and similar improvements in health and wellbeing. If anything, today's GDP growth may be associated with even faster improvement than we would expect based on the historical record. But in richer countries the opposite is true—higher GDP no longer translates reliably into better health outcomes. In some places—such as the United Kingdom, and much of the United States—life expectancy is actually falling, even as income per capita continues to rise.

Leisure time is another measure of wellbeing. Presumably if people were having an easier time meeting their material needs, they would choose to take more time off work. (Adam Smith once suggested that the amount of leisure people enjoyed was the only meaningful standard of economic value across countries.) On this measure too, living standards seem to be falling short of GDP growth rather than running ahead of it. Between the end of World War II and the early 1980s, the average weekly hours of an employed American fell by almost 15 percent. But since then, average hours per worker have been essentially flat. This makes the postwar growth performance look even better, and the more recent performance worse, than the headline numbers suggest.

It seems likely that measured productivity overstates, rather than understates, our real improvement in living standards, at least in the United States. If so, the policy implications seem clear. Policymakers should worry less about growth, and more about concrete interventions that we know improve people's lives—things like universal access to childcare and health care, high-quality education, and paid time off for all.

Our traditional measures of productivity have yet to capture the full scale and scope of accelerating technological disruptions.

MOHAMED A. EL-ERIAN

Chief Economic Advisor, Allianz; Chair, President Obama's Global Development Council; and Professor of Practice, Wharton School, University of Pennsylvania

An increasing number of today's technological innovations are changing not just what we do, but also how. This is particularly the case for areas that are influenced by the combination of big data, artificial intelligence, and mobility. It's a global phenomenon that is only likely to accelerate, raising a broader host of economic, regulatory, and social questions.

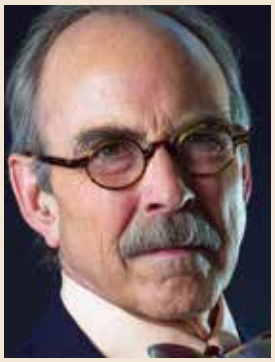
One of the lessons from past technological shocks of this magnitude is that it takes time for them to be embedded deeply in economy-wide structures—and for at least one good reason. Established companies need time to incorporate the innovations in a full internal investment cycle, and also to adapt their internal procedures and external footprints accordingly.

This is but one of several reasons why our traditional measures of productivity have yet to capture the full scale and scope of a series of accelerating technological disruptions that have important economic, financial, institutional, social, political, and geopolitical dimensions. The net aggregation has the potential to be positive and beneficial.

But the underlying input-output equations involve significant compositional effects that need to be taken seriously, as well as a range of consequential uncertainties.

You need only look at what's happening to Big Tech to observe the complexities in play. Undoubtedly these companies' innovations have enabled and empowered people to do more, including expanding the range of anywhere/anytime/any place activities. The combination of what I call the Amazon/Google/Uber influences has been to significantly enlarge the range of direct, better-informed, and monitorable activities that the population at large can undertake using both existing and new assets. But it has also raised serious questions about behavior modification, and it is empowering bad actors—both of which speaks to a larger reality: what has been enabled is now outpacing not only what governments and society can keep up with, but also what the Big Tech companies themselves are prepared to handle.

The next few years will see innovations being reflected in a shifting distribution of potential outcomes for the economy which, importantly, will also be more bi-modal in shape (that is, with fatter negative and positive tails, and with a less dominant belly/center). Ensuring that these tails are tilted more to the positive end of the distribution is a major challenge for governments and companies, and also a shared responsibility.



The reported recent slowdown in productivity growth reflects both measurement methods developed for a manufacturing—not service—economy, and lags before general adoption of advanced technologies.

WILLIAM H. JANEWAY

Special Limited Partner, Warburg Pincus, Affiliated Member of the Faculty of Economics, Cambridge University, and author,* Doing Capitalism in the Innovation Economy: Reconfiguring the Three-Player Game between Markets, Speculators and the State *(2018)

The U.S. economy is experiencing a technological revolution of a depth and scale comparable to the impact of steam and electrification. This revolution has been ongoing since the 1980s and has not been so "quiet": it encompassed the great dot.com/internet bubble of the late 1990s and also played a critical role in generating the global financial crisis of 2008. While the hype about artificial intelligence is grotesquely overstated versus the limited capabilities of current machine learning techniques, never before has so much data been generated and captured for analysis and action, with consequences potentially productive and destructive.

The digital revolution has enabled the second great globalization of economic life due to extreme reductions in the friction of moving goods, capital, and work across borders. Another great wave of automation is transforming both the content and the management of work, with a definite bias in favor of capital and against labor. And the financialization of the economy is a third outcome, from the securitization of assets of all kinds—from mortgages to student loans—to the derivative securities that served, in Warren Buffett's famous phrase, as "financial weapons of mass destruction."

Altogether, these effects of the digital revolution have overwhelmed the capacity of states to buffer their constituents. Not only has it challenged the authority of the state at multiple levels and across multiple dimensions, it is even undermining the integrity of the political process on which the authority of the state ultimately rests. There is a profound irony here, given that all the technologies, from silicon to software, that combined to generate the digital revolution were sponsored by the American state.

As they have matured, digital technologies have become more accessible: open-source tools and "cloud" computing resources have rendered experimentation radically less expensive. And the internet itself offers a friction-free channel for marketing and delivery of new digital offerings. Hence the proliferation of the "unicorns." But note: from Uber to WeWork, these ventures have been paying their bills not by selling services to paying customers, but rather by selling securities. The entire unicorn bubble is a consequence of the historic reduction of nominal interest rates to minimal, even negative levels, driving investors to reach for returns however speculative. This phenomenon is highly vulnerable to any normalization of monetary policy.

The reported slowdown in productivity growth in recent years reflects both the application of measurement methods developed for a manufacturing economy to an overwhelmingly service economy and the long lags between deployment of advanced technologies at the frontier and their general adoption. But the ongoing digitalization of economic life can be seen in increased concentration across almost all industries accompanied by increased profits and reduced labor share.

As inequality remains stuck at levels not seen in a hundred years, re-legitimizing state engagement with the economy is urgently needed. There are encouraging signs: from the increasingly animated discussion of anti-trust policies relevant to a digital economy to the California

legislative initiative with respect to "gig" employment. Yet in the age of Trump and Brexit, our system is stressed to extremes. Tech revolutions do that.

We are not measuring the impact of technological change adequately.

MICHAEL J. BOSKIN

Hoover Institution Senior Fellow and Professor of Economics, Stanford University, and former Chair, President's Council of Economic Advisors

There is no question that technological innovation has had important impacts in the last several decades. Whether that has been, or will be, an acceleration from past trends is an open question. A dynamic market economy is always innovating, disseminating innovation, and adjusting to technology developments. Fundamental forces, such as demographic shifts, alter demand patterns. Entrepreneurs and firms respond with new products, improvements in existing products, new processes, and new distribution channels. Statistical systems are challenged to keep up in real time and legal and regulatory systems are challenged to keep up without stifling innovation.

We are not measuring the impact of this technological change adequately. Economists have known for well over a century that traditional price inflation and therefore real GDP and productivity measures fail to account adequately for substitution biases, quality change, and new products. Economist Irving Fisher declared in a 1922 book that his entire life work would be worthwhile if we switched to what Erwin Diewert labeled superlative index numbers. It took three-quarters of a century for government statisticians to begin incorporating Fisher's insights into the consumer price index. Delays also occur in implementing measures to partially adjust for quality change and new products.

Particular attention has been focused on the fact that important new services are provided "free" to consumers, such as internet search and social media. Of course, consumers are paying by allowing these firms to use their data to generate revenue from advertising, which is treated as an intermediate input to the industry paying for the advertising.

Economist Robert Gordon argues that more recent technology does not pack the productivity-enhancing punch of previous generations of new products, from electricity to automobiles, household appliances to airplanes. Optimists respond with the promise of nanotechnology, artificial intelligence, and machine learning. Historically, the "killer app" that drives productivity has sometimes taken considerable time, and a product detour, from the original idea. Watt's steam engine was for lifting water out of coal mines; steam ships and locomotives came later. Marconi's wireless was to compete with the telegraph; he never envisioned mass broadcast radio or cell phones.

Some important uses of technology are in sectors such as healthcare, where it is difficult to measure outcomes, and especially how they are valued since most consumers do not pay for them at the margin when decisions are made. Several decades ago, MIT's Robert Solow opined that "you can see the computer age everywhere but in the productivity statistics." Eventually they did show up, and accounting for the decline in computing prices added a quarter point to real GDP growth for decades. Perhaps any "above and beyond trend" productivity effects from modern technology will eventually show up as well.

But it is also possible that some of the value will be in non-market activity not usually included in GDP, such as intrafamilial sharing of photos. That has real value, but is different from traditional productivity measures used to construct estimates and forecasts of real GDP and tax revenue. Finally, the contribution to real income nets out the value of displaced economic activity, such as newspapers and magazines, traditional photography, and so forth, and only counts the net increase.

Modern technology developments have combined with globalization as a deflationary force. Central banks, including the Federal Reserve, need to understand these phenomena in the conduct of monetary policy. Economist Brent Moulton, who spent more than thirty years working at the U.S. Bureau of Economic Analysis and the U.S. Bureau of Labor Statistics, provided an excellent survey last year of research measuring potential biases, and many improvements made by statistical agencies, since the 1996 Boskin Commission Report estimated an upward bias of a little more than a percentage point. My best judgement is that any additional, above trend, overstatement of inflation caused by widespread use of recent technology innovation is likely balanced by statistical improvements made since then. Only time and research will tell whether new technologies prove to be as productivity-enhancing as previous advances, and if the size of biases in measures of real GDP, productivity, and inflation has changed considerably.

In the meantime, central banks are quite aware of biases in the measurement of inflation. (Indeed, then-Bundesbank board member Otmar Issing led a delegation from the Bundesbank to see me at Stanford University to

discuss these issues shortly after the publication of the Boskin Commission Report.) That is one reason 2 percent is the inflation target and for their use of the PCE deflator rather than the CPI. Their main task in this regard is to stay on top of, and contribute to, the estimates of these biases.

If we overestimate price increases, we underestimate real output and hence labor productivity.

RICHARD N. COOPER
Maurits C. Boas Professor of International Economics, Harvard University

The short answer is "yes." Technological advances abound, affecting many areas of both production and consumption. Productivity growth for the economy and for particular sectors over a period of time is measured by deflating the changing value of production by price increases over that period. If we overestimate price increases, as I believe along with the late Martin Feldstein, especially for hard-to-measure services which take up an ever-increasing share of employment, by the same token we underestimate real output and hence labor productivity. This is especially true of the rapid advancements in medical care, a large and growing fraction of American production and consumption. The same observation can be made of all modern economies, but services make up a higher fraction—85 percent—of U.S. employment than is true elsewhere.

Real growth today is nothing like the 8 percent growth of the late nineteenth century, which was augmented by high and increasing immigration as well as by the spread of steam power, electricity, and the new internal combustion engine. But it is significantly higher than that recorded today.

I would not particularly emphasize artificial intelligence, but rather digitization of the whole economy, of which artificial intelligence is only a part, along with cloud computing, analysis of larger amounts of data, the so-called internet of things, and so on. Artificial intelligence will proceed, but much more slowly than currently hyped. Electricity took five decades to be widely and efficiently absorbed by the U.S. economy. Human behavior and institutions and regulations have a high degree of inertia—everywhere, not just in the United States.

Who will benefit? In the first instance, the owners of the firms which successfully produce the new technology, and of those traditional firms that digitize their activities quickly and efficiently, as well as workers with the relevant talent and training to produce and install the new technologies. But as the ownership spreads through purchases of stock, for example by college endowments, life insurance companies, and especially pension funds, many more people can enjoy the benefits, and still more people as consumers by the greater variety and lower prices that digitization will permit. Many existing jobs will disappear, as happened in the late nineteenth century, but that will take place over many years. And as in the past, many new jobs will be created by increased consumption, especially of new activities, such as recreational skiing created after the Second World War.

You don't have to be an economist to know that something big is underway in the technology arena.

JAMES E. GLASSMAN
Managing Director and Head Economist, JPMorgan Chase's Commercial Bank

There is nothing quiet about today's technological revolution and it's touching everyone, those who work in the tech sector as well as those who don't. Technological innovation probably is underrepresented by our metric system, but what is measured is visibly transforming business, the workplace, and home life. Today's vintage of technological innovation, like that of the past, gives workers better tools to do their jobs and supports stronger pay gains. But it also displaces routine work. That diverts more and more of the economic value of what workers do to profits and away from labor compensation, creating big challenges for people whose skills aren't keeping up. New technologies create new opportunities, but workers need to invest in new skills to take advantage of those opportunities, and that doesn't happen overnight.

You don't have to be an economist to know that something big is underway in the technology arena. Many auto

workers saw it when many of their jobs were replaced by robots. We can see it in the hours we save going to the mall with one or two clicks on our mobile phones. We can see it in the sprawling retail distribution centers and the struggles of shopping malls to find new purpose. We can see it when our flights are disrupted by bad weather and we are able to rearrange travel plans and pick new airplane seats in seconds on our mobile phones. We can see it in the innovative ride-sharing services and new options for renting vacation stays. Businesses see it in the insights they gain from machine learning and mining of the exponential growth of data. We can see it in the experimental convenience stores that have no checkout operations. We can see it in the vast array of financial services available on mobile phones. And we can see it in the access available on mobile phone apps to the services that are interconnected on the internet. These are only some of the most visible features of today's technological revolution.

Add it all up and it is pretty clear that it takes a lot less time to accomplish traditional tasks than it used to. That's called productivity. The explosion of labor productivity may be more visible on the home front (household production) than in the business arena. That may explain why the productivity metrics don't show what we all know is occurring, that labor productivity is rising quickly. But we also know that the metrics can be behind the times when technology is opening up new frontiers of activity. For example, it wasn't until hedonic price measures were employed to capture the idea that the economic contribution of information technology improves with every successive vintage of technology that we solved MIT Professor Robert Solow's 1990s riddle that we could see computers everywhere but in the metrics.

Technological brings metrological challenges, and some of the economic value in the e-commerce arena probably is not fully captured by traditional measures of economic activity. For example, the subsidies provided to consumers (free shipping and other amenities) that are effectively funded by optimistic stock market valuations because investors are betting that today's disruptive technologies will be tomorrow's standard, even if these companies are not very profitable yet, are not reflected in GDP. They won't be until the advertising costs that support new ideas are reflected in the price of products consumers buy. And it has become more challenging to measure labor productivity because the internet blurs the line between work and leisure, making it more difficult to estimate the true amount of time put into work (for many people, work at the office doesn't look very different than life at home).

But what we can see of today's technology footprint is striking and unprecedented. It is particularly visible in the way that income flows to the various factors of production. For example, the share of income accruing to labor compensation averaged about 56 percent of total Gross Domestic Income from the end of World War II to the late 1990s, but since then has shrunk to 53.8 percent. The inverse image? After-tax profits have been grinding up to near 10 percent of GDI since the late 1990s from 6 percent on average for most of the post-World War II era.

The economic story driving that widening distribution of aggregate income to labor and profits (and this underpins the widening distribution of income in the United States) is evident in the decoupling of real hourly compensation and labor productivity since the late 1990s. Hourly pay tends to match the trend in labor productivity. It's a logical textbook story. But in the late 1990s, real hourly pay began to lag labor productivity, implying that more and more of the economic value of labor is flowing to capital and, therefore, profits. That's the result of innovation that displaces routine work. It's easiest to visualize this by thinking about the business model of Amazon, ride sharing services, and other industries where superstar enterprises are forging new frontiers. The record high value of the U.S. stock market relative to the size of the economy (1.5 times nominal GDP, far above the historical tendency to match GDP) implies that equity investors now believe the technology story has legs.

This is *the* economic story of our time. And it is a story that most other economies are facing as well. It brings opportunity and challenges. It transforms the way the economy works. And it reverberates through the nation's political discussions because it is socially disruptive. Technological innovation makes old ways of doing things obsolete but it also brings new opportunities that, when people have time to invest in new skills, are favorable. Today's technological revolution will be lifting the nation's living standard to new heights.

Policymakers must proactively consider the empowerment of full individual data ownership.

JENNIFER ZHU SCOTT
Associate Fellow with dual fellowships of the Asia Pacific Programme and Digital Society Initiative, Royal Institute of International Affairs (Chatham House)

Historically, the indicators of future wealth and the metrics of economic performance often show significant discrepancies during the times of fundamental

technological transformation. To assume that we are living at such a time can be an attractive temptation. Powerful innovations such as artificial intelligence and machine learning could indeed be the next general purpose technology (GPT) that fundamentally transforms economies, similar to electricity, the steam engine, the internal combustion engine, and computers. However, so far, despite the great capacity promise, artificial intelligence is only benefiting a fraction of the total economy. The tech and tech-friendly industries have started to see some great results, while many traditional industries that remain a large part of the total output are scrambling to adapt.

Productivity in the United States has been growing consistently since the post-war era, although at a different rate in different periods. In the mid-2000s, we witnessed a productivity fall in developed countries, including the United States. Between 2005–2016, the aggregate labor productivity growth in the United States averaged 1.3 percent (compared to around 2.8 percent between 1995 and 2004), while the tech industry has arguably created the most excitement (and wealth) during this time. It is easy to confuse such excitement with the actual artificial intelligence general applications to every corner of the economy.

Indeed, that is not to say such hidden (or visible) productivity growth will not happen soon. What happened bears no responsibility to repeat in the future. The productivity deceleration in the past decade and a half do not predict what might be forthcoming. An optimistic way to view this productivity growth pause is that the real artificial intelligence transformation has just started. When artificial intelligence indeed becomes a GPT and is applied to all industries, the United States could witness another industrial expansion more potent than the late 1800s.

Having said that, the United States in the late 1800s was a different country than the United States today. The young country was an energetic challenger to the establishment at the time: Britain. Since the United States took over from Britain and became the global innovation powerhouse, it has never been challenged in the area of innovation and technology until now. The United States was also a much more open country in late 1800s. People from all over the world moved to the United States to build, create, produce, and innovate. Today, the United States is the establishment being challenged by China. The United States is also increasingly inward-looking, with a considerable part of the country supporting the anti-immigration policies the current administration has carried out. Anti-China approaches in the fields of tech and academic research are arguably the only genuinely bipartisan issue in the United States.

Technologies such as artificial intelligence and machine learning are different beasts compared to internal combustion engines. They require greater connectivity, the efficiency of a global supply chain, and careful moral considerations for the future of our species. Such requirements are beyond nationalities and borders. The two artificial intelligence superpowers owe humankind to collaborate while competing healthily.

Domestically, there are large populations in the United States that are not working in the tech industry and may never be able to own tech stocks. In order to include them in the forthcoming artificial intelligence economy, policymakers must proactively consider the empowerment of full individual data ownership. The economics of data are well established between large corporates. However, the producers of such a source of wealth—the individuals—are not part of this game. Realizing the economic value of data for the individuals would allow a more inclusive artificial intelligence economy. It also could become a source of universal basic income.

There is little reason for policymakers to abandon the proposition that productivity growth has been in long-term decline.

MARK SOBEL
U.S. Chair, Official Monetary and Financial Institutions Forum, and former Deputy Assistant Secretary for International Monetary and Financial Policy, U.S. Treasury

Will artificial intelligence and other new technologies prove transformative, bolstering total factor productivity growth and helping the world escape a continued grinding down in global growth? Are we excessive techno-optimists or pessimists?

These are questions studied in a specialized corner of the economics profession. Alas, our crystal balls cannot answer those questions.

Robert Gordon, in *The Rise and Fall of American Growth,* is surely right to argue that not all innovations are equally transformative and that many recent innovations, notwithstanding hype, have failed to meet the transformational qualities of those—such as in transportation and energy—of the Industrial Revolution.

At the same time, the famous Solow Paradox observed that the computer revolution was everywhere, except in the productivity statistics. Solow's statement was

soon followed by an acceleration in productivity. The paradox points out that it is hard to recognize transformations, especially as they are taking place.

Where there is agreement, though, is that the diffusion of innovative new technologies into production processes, daily economic life, and higher total factor productivity can take a long time, if not decades, to materialize.

Many new artificial intelligence technologies are still coming of age and only now—literally—being road-tested.

Higher total factor productivity growth can have important implications for macroeconomic policy management, which often depends on judgments about whether an economy is overheating. Were officials to miss a jump in total factor productivity growth, policy settings for stabilization could prove too restrictive. Were officials to erroneously presume a jump in total factor productivity growth had taken place, policy could be too accommodative.

Artificial intelligence and other new technologies may well boost future total factor productivity growth and provide a welcome fillip to economic activity. But in the meantime, there is little reason for policymakers to abandon the widely accepted proposition that productivity growth has generally been in long-term decline and that it will continue to face headwinds from an aging population, the shift toward services economies, and other factors. It would be premature for the formulation of macroeconomic policy to assume that higher potential growth is buried in the data.

A broad technological revolution is coming, but it's not here yet.

MICHAEL MANDEL

Chief Economic Strategist, Progressive Policy Institute, and Senior Fellow, Mack Institute for Innovation Management at Wharton

Overall, the official data—and especially the slow rate of measured productivity growth—accurately reflect our two-speed economy. A broad technological revolution is coming, but it's not here yet.

So far the information revolution is primarily concentrated in "digital" industries such as tech, communications, content (such as movies and print), and ecommerce, which together make up less than 10 percent of gross domestic product.

Meanwhile, the bulk of the private sector—primarily comprised of "physical" industries such as manufacturing, construction, agriculture, and healthcare—has lagged far behind in spending per worker on information technology equipment, software, and cloud services.

Think about it: Audiences are justifiably amazed by the use of sophisticated digital technologies to portray *Iron Man*'s armor on the screen. But manufacturers are nowhere close to being able to build his armor or anything similar in real life. Manipulating bits and bytes is easy, doing the same for atoms is hard.

By my calculations, productivity in the relatively small digital sector rose by almost 60 percent from 2007 to 2017, which likely underestimates true growth. But those gains were not enough to overcome the slow productivity growth in the more important physical industries. Over the same period, productivity in the rest of the non-health private sector rose by only 5 percent.

Other economic indicators show the same dichotomy. Prices in the digital sector fell by 15 percent, while rising by 21 percent in rest of the non-health private sector. Both real pay growth and job growth in the digital sector were more than double that of the rest of the non-health private sector.

This division is profoundly economically and politically unhealthy. The regions that are the focus of the digital economy have zoomed ahead, while the regions that are dependent on physical industries have been left behind. This is not a measurement problem.

But there's good news, as digitization is slowly taking hold in the physical sector. Amazon and other ecommerce companies have transformed lowly warehouses into data-driven, robot-filled ecommerce fulfillment centers. These ecommerce fulfillment centers are creating hundreds of thousands of new jobs for "tech-enabled" workers with a high school education, at wages significantly higher than brick-and-mortar retail.

Similarly, manufacturing is going digital after a long delay. Robots are spreading out of the automotive sector to other manufacturing industries, and 3D printing is becoming more common. Moreover, new "manufacturing platforms" are making it easier for small and medium-sized factories to participate in the global economy.

The ongoing digital transformation of the physical sector won't immediately show up in the productivity statistics. For example, the measured productivity of the warehouse industry is down 28 percent since 2012, despite the digitization of distribution. The reason? The measured output of ecommerce fulfillment centers does not take into account consumer gains from millions of fewer hours spent in driving to malls, standing in line to pay, and other unproductive shopping activities.

We have suffered so far from a lack of tech-based innovation, not an excess. As digitization spreads, so will the gains for workers and consumers.

Statistics cannot fully capture nascent changes we do not yet fully understand.

HOLGER SCHMIEDING
Chief Economist, Berenberg

We are living through a profound revolution in technology. The way in which humans inform themselves and communicate and interact with one another is changing beyond recognition. A generation ago, my parents and I used similar sources of information, one or two newspapers, three TV channels, radio, and the hearsay of friends, family, and colleagues. Today, my four children receive, process, and spread information in a completely different way. The interaction between humans and technology looks set to evolve further with hitherto almost unimaginable combinations of human intelligence and machine learning.

Never before have so many people worked so hard to expand the frontiers of knowledge. And never before have they been able to spread their insights so easily and cheaply. It makes intuitive sense to presume that technological progress is more rapid than our backward-looking statistics suggest.

Statistics are good at measuring what we know well. But they cannot fully capture nascent changes we do not yet fully understand. As a result, they may underestimate the impact of the changes. Of course, we cannot be sure. Some technological advances are showing up more in how well we can enjoy our free time rather than in the monetary value of the goods and services we sell to each other.

Even if we knew for sure that our statistics underreport the gains in productivity and real GDP, the policy impact would be limited. We might learn that inflation is even lower than we thought it is. At face value, the threat of disruptive deflation may then loom larger. But a supply-driven decline in prices would be a positive, not a negative. The risk that faster productivity growth could cause harmful deflation, namely a reluctance of consumers to buy today as they wait for goods or services to be cheaper tomorrow, seems remote. The major effect of the technological revolution is not to make similar things cheaper. Instead, it improves the quality and usefulness of new products. This is a reason to buy rather than to hold back.

In the same vein, uncovering a more benign split of nominal GDP growth between more real growth and less inflation courtesy of a faster gain in productivity would not be a reason to change nominal interest rates.

Instead, we ought to address the distributional effects of disruptive technological changes. The capacity of individuals and societies to learn and adjust is limited. Today's technological revolution may well be comparable to that of the late 1800s. Mass industrialization raised real GDP dramatically. But it also spawned social counterreactions that caused grave damage in the decades thereafter. Today, improving public infrastructure and public education systems, and distributing the gains from technological changes more fairly through the tax and welfare system, ought to be at the top of the policy agenda. Otherwise, the populist backlash against free exchanges of goods, services, and ideas could continue to mount. That facts seem to play a diminishing role in many policy discussions ought to serve as a warning signal.

There are doubts whether we are measuring nominal output or price changes accurately.

RICHARD JERRAM
Chief Economist, Top Down Macro

Economics has been struggling with the apparent contradiction between slow productivity growth, as measured in the macro data, and the rapid technological change apparent in our daily lives. Part of the problem is that GDP is poor at incorporating "free" consumer services that occupy a growing part of our leisure time. It is a measure of economic output, not well-being. Even so, there are doubts whether we are measuring nominal output or price changes accurately, and consequently, questions over the real pace of productivity growth.

Rather than trying to measure productivity through imperfect metrics such as national accounts data, we

could look for the shadows from the effect. For example, if there is a quiet technological revolution in progress, then we would expect to see a large transformation in the labor market, as some skills become redundant and others become much more valuable. The data give no support for this, with workers leaving or joining firms at a pace that is consistent with the current unusually low level of unemployment.

Similarly, if we are in a period of creative destruction driven by technological change, then we would expect to see a rise in both the number of new ventures being established and older ones failing as they lose viability. However, entry and exit rates for firms in the United States have remained subdued in recent years, at a pace well-below historical averages.

A different problem could simply be recency bias, where we are so amazed by the latest inventions that we forget how dramatically life changed in the 1960s, 1970s, or 1980s. I was born into a world of black-and-white television, bank tellers, slide rules, phone boxes, and crushingly expensive international travel and communication. It seems hard to argue that recent inventions are as transformational as personal computers, email, and mobile phones, and equally difficult to find the effects in the data.

After the financial crisis, productivity growth performed particularly poorly in the United States.

MICHAEL HÜTHER
Director, Cologne Institute for Economic Research, and Gerda Henkel Adjunct Professor, Stanford University

During the post-World War II period, many industrialized economies experienced a deindustrialization in combination with declining or low productivity growth. Stimulated by post-war investments and reunification, the German economy constituted a notable exception as it secured reasonable productivity growth until the early 2000s, when it converged into the typical low total factor productivity growth trajectory. At the time, the impressive rise of Silicon Valley tech companies triggered significant fears in Germany that the important manufacturing sector could become a commodity provider for data-driven businesses from the United States. Politicians and scholars alike prophesied the end of manufacturing-led growth and the golden age of highly innovative tech companies.

What is more, several scholars underlined the productivity-hostile environment resulting from structural factors such as demography, climate change, and globalization. In this view, productivity decreases are especially expected in manufacturing economies that depend on an aging workforce, face the costs of decarbonization, and are constantly threatened with companies moving abroad because information and communications technologies allow low-cost real-time steering of global value chains.

In contrast to these expectations, after the financial crisis, productivity growth performed particularly poorly in the United States. Puzzlingly, low productivity figures from the United States are even interpreted as a result of the economy's dependence on Silicon Valley companies' innovations. It turned out that tech firms run highly profitable business models but only through securing a high level of market power in winner-takes-it-all platform markets. Today, the tech giants hold huge cash reserves and hoard highly qualified employees in a way that is tantamount to creating implicit barriers to market entry. In this sense, large tech corporates create a two-speed economy where normal companies cannot compete at arm's length at the technology frontier, but instead focus on standard products requiring lower risks and investments. Additionally, the new information and communications technology companies are less dependent on geographical production sites than the old manufacturing industries. For taxing authorities, this provides a major challenge as it becomes more difficult to prevent profit shifting and enforce a level playing field.

However, the domination of new platform corporations in monopolistic or oligopolistic markets is not the only game in town. A country-wide and long-established business model that has recently proven fruitful for productivity progress can be found in the Germany. In contrast to the presumably secular trend of deindustrialization and in the face of demographic change, medium-sized German high-tech *Mittelstand* companies from rural areas keep dominating global niche markets with their highly innovative manufacturing goods. Manufacturing still accounts for 23 percent of German value added (and only 12 percent in the United States, 11 percent in France, and 10 percent in the United Kingdom). During the past few years, these companies have managed to integrate customer-specific services such as servicing or consulting into their goods. This joint production accounts for another 9 percent of the German economy. As a result, productivity progress is not limited to a few shining stars but distributed much more inclusively. Due to the integrated value chains in Germany, service sector innovations spill over into manufacturing faster than in the United States,

where the economy is more characterized by stand-alone companies. It seems obvious that if we want to master the challenges of the future—climate change, demographic change, and globalization—in a socially acceptable way, we need more productivity progress and we need it to be distributed throughout the entire economy. This seems to work better through the well-known manufacturing business model. Total factor productivity contributions to the reasonable GDP growth in Germany between 2011 and 2018 ranged around 0.6 percent yearly—far ahead of comparable economies.

After introducing "Industrie 4.0" technologies, the German business model will shift even more strongly to the integration of services into the manufacturing sector. Hence, incentivizing manufacturing investment and research and development activity as well as enabling employees through adequate on-the-job training is going to accelerate productivity in Germany on a broader scale. By contrast, triggering productivity growth in the United States depends much more on fostering inter-company technology spillovers and creating a level playing field for competitors in platform markets.

Slower global productivity growth is due to a decline in new disruptive innovations and a lack of diffusion of new technologies.

STEFFEN ELSTNER
Senior Economist, RWI, and former Deputy Secretary General, German Council of Economic Experts

Since at least the mid-2000s, many advanced economies have experienced low productivity growth. This development is often related to declining productivity gains in the United States, often considered as the global technology frontier. Several studies show that the U.S. economy represents the technology frontier in finance, business, and personal services, whereas Germany for example represents the technology frontier in manufacturing.

Research concerning U.S. productivity spillovers on other industrial economies is primarily informed by the work of Wolfgang Keller, who documented that for most countries, foreign sources of technology are estimated to account for around 90 percent of domestic productivity growth. Furthermore, new technologies originate from a small number of countries that determine the pattern of worldwide technology transmission.

Since the United States is commonly regarded as the world technology frontier, my coauthor Svetlana Rujin and I tried to analyze the spillover effects of changes in U.S. technology on the aggregate productivity level in other advanced economies. Productivity is hereby defined as labor productivity, which means output per working hour.

Overall, we find positive but small spillover effects of U.S. productivity changes on other economies. The recent U.S. productivity slowdown, therefore, seemed to have a limited effect on productivity developments in advanced economies. Our research further suggests that institutional factors are not able to explain cross-country differences in the size of the productivity spillover effects. If any, regulation of the service sector seems to play a role. The latter finding nevertheless has some policy implications as, in particular, the German economy is characterized by a high degree of regulation in the service sector.

To understand why we have seen this contemporaneous decline in productivity growth despite low U.S. productivity spillovers, we studied more in detail the productivity development in Germany. Despite massive digitization efforts, the German economy has experienced a marked slowdown in its productivity growth. A major factor for this decline is the turnaround of the German labor market that commenced around 2005. The successful integration of five million predominantly low-productivity workers into the labor market induced an attenuating effect on productivity growth. This does not explain the slowdown entirely, however. As a potentially important countervailing force, technological advances associated with digitization would have had the potential to lift productivity growth more strongly, but they frequently translated into employment growth instead.

Often the point is made that the current innovations in the digital economy are poorly measured in the official national account statistics. This prominent explanation of measurement error that systematically underrepresents genuine productivity growth was analyzed by several studies focused on the U.S. economy. Measurement errors could arise for three reasons: First, quality changes aggravate price measurement, especially for information and communication technologies. Yet a study by David Byrne of the Federal Reserve Board of Governors, John Fernald of the Federal Reserve Bank of San Francisco, and Marshall Reinsdorf of the International Monetary Fund finds little evidence that such mismeasurement is driving the deceleration in estimated U.S. productivity growth. The information and communication technology sector is simply too small to create massive real productivity gains due to falling prices.

Second, recent productivity growth does not capture the costless services provided by large information and communication technology firms such as Facebook, which increases consumer benefits in a way not included in GDP. The University of Chicago's Chad Syverson argues, however, that these benefits are by far too small to explain the missing productivity gains since the mid-2000s.

Third, it is difficult to measure value-added in a large part of the economy comprising health care, education, financial services, and professional services. This point seems to be valid and it is difficult to argue against it.

Overall, a large part of the literature suggests that the slower pace of global productivity growth since around 2000 is due to two reasons. The first is a decline in the number of new disruptive innovations and hence a slower pace of growth of the productivity frontier. The second is a lack of diffusion of new technologies in all parts of the economy. The latter point is often associated with missing business dynamism and the effects of aging populations.

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