The impact of technology on long-term potential economic growth

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IN BRIEF

- Technological change is advancing with unprecedented speed, scope and scale - and with potentially far-reaching effects across economies and societies. Amid explosive growth in processing power and machine learning, a world where artificial intelligence (AI) eventually rivals human intelligence can no longer be dismissed as science fiction, with profound implications for economic growth and the labor force.
- Technology will affect economic growth rates and capital market returns in ways that are difficult to foresee. Workforce automation and AI have the potential to deliver significant overall productivity gains, and some nations facing growth challenges from aging populations could see an additional boost to trend growth rates. This suggests a possible increase to the current Long-Term Capital Market Assumptions (LTCMA) estimate of trend GDP growth in developed economies of 1% to 1.5%, while narrowing the growth spread among them.
- However, the latent power of automation has also raised fears of substantial job losses. Historically, fears of technological unemployment have not materialised, but, given the nature of the current wave of innovation, we cannot take historical patterns entirely for granted. If displaced workers are not efficiently re-employed, it could weigh on consumption and economic growth. Therefore, the above numbers represent a reasonable upper bound to potential growth forecasts provided displaced labor is rapidly reabsorbed.
- Recent backlashes against globalisation point to the social and political strains that must be addressed to fully harness the benefits of technology. We envision a changing role for governments in helping workers and the broader economy adapt to technological change. Protecting the purchasing power of consumers will be critical.
- This paper identifies five areas where the early effects of technological change on the world economy are believed to be investible today: cloud computing; the Internet of Things; artificial intelligence; robotics; and, blockchain technology.

INTRODUCTION

Amara's law states that "we tend to overestimate the effect of technology in the short run and underestimate the effect in the long run".[1] Over the last few years, the media have been saturated with articles, papers, books and videos exploring how technology will change our lives. Some scenarios describe a fundamental transformation of society, the workforce and, indeed, the world order that would rival even the most fanciful science fiction.

Among many groundbreaking technologies[2] on the horizon, the focus of this paper is on automation and artificial intelligence. Exponential growth in these technologies will profoundly change economies and societies, and in ways we have not yet imagined. The impact of these changes is expected to accrue gradually at first and that Amara's law will be proven once more. Nevertheless, the authors believe that early effects of technology on economic growth, labor, policy and trade will begin to be felt over the 10- to 15-year investment horizon and that the early implications of those effects should influence investment choices now.

The following pages examine how technological change - particularly automation and AI - might affect the way economies grow. The analysis is structured as follows:

- First, "Why now?" What is it about the nature of prevailing technological advances and the shape of today's global economy that pose unique challenges? Specifically, this paper looks at how the current situation may differ from previous technological revolutions in its speed, scope and scale.
- How technology may affect growth in productivity and, ultimately, real GDP.
- The challenges to the labor force, consumption and government policy that will arise from automation and AI.
- The implications of technological change for the authors' LTCMAs.
- Separately, current investment opportunities related to automation and AI.

The current wave of technological change, the authors conclude, is unlike any that has come before. Its unprecedented speed, scope and scale will profoundly, and simultaneously, impact many sectors of the economy. In the industrial revolutions of the past 200 years, the economy and labor force adapted positively to disruptive technology. But, we cannot assume that today's (and tomorrow's) workers displaced by technology will be rapidly or easily redeployed in new functions. While technology could boost productivity significantly, it is unclear whether a modern economy that is rapidly adopting automation and AI can deliver rising wages and rising productivity simultaneously. This creates complications in estimating the potential boost to trend GDP and in harnessing the positive - and mitigating the negative - effects across economies and societies. While we are probably a long way from a world in which artificial intelligence rivals human intelligence, the authors expect today's technological revolution to spark far-reaching economic, social and geopolitical changes - perhaps eventually redefining the role of human labor in the workforce.

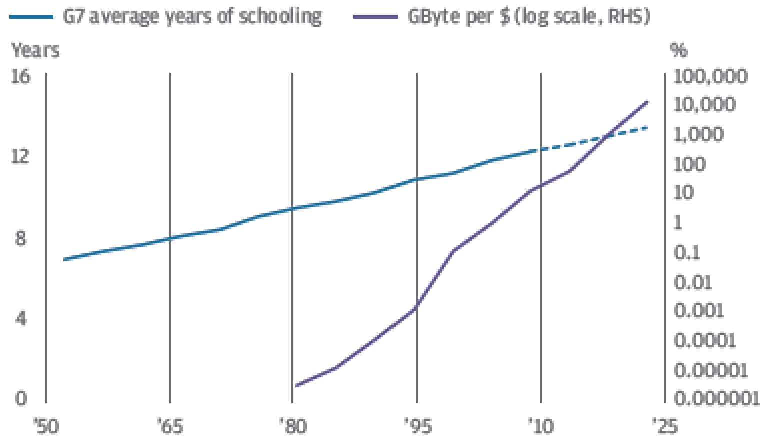
WHY NOW?

Any analysis of the potentially disruptive impact of technology quickly runs into the question "Why now?" There are many who - quite rightly - point out that the economy and labor force proved remarkably good at adapting to disruptive technology over the last 200 years. The first two industrial revolutions took the world from an era reliant on human and animal power to execute physical tasks into an era in which machines powered by natural resources provided the physical power and humans increasingly added value with their minds. New industries and functions arose to demand labor, such that productivity and real wages grew in tandem. But, the disruptive potential of today's automation and AI is, in the authors' view, something altogether new. Put simply, technology is now automating brains as well as brawn.

The speed of this technological progress is well characterised by Moore's law[3] whose spirit is alive and well today in the continued exponential growth in processing speed, data storage capacity and connectivity relative to cost. For example, a 2017 smartphone has more processing power than Cray-2, the world's most advanced supercomputer in 1985 - a time when just two of the popular contemporary video game consoles were together more powerful than the computers that put man on the moon in 1969. Moreover, the capacity for data storage has reached a critical level and continues to grow exponentially, even as human education and skills development remain linear (Figure 1 and 2). In the authors' view, data is to the information economy rather like oil is to the industrial economy - thus, the cheap, widespread and instantaneous availability of data, and the power to process it, are critical enablers of the growth in automation and AI.

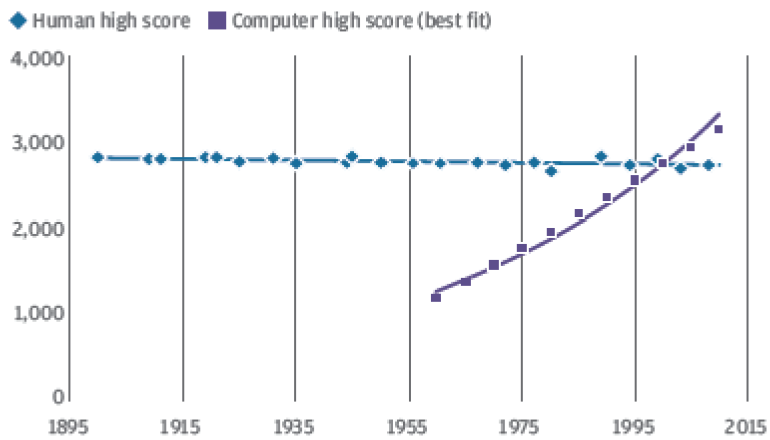
Human development and education follow a linear progression, while both data availability (proxied by storage costs) and the processing capabilities of machines (proxied by leading computer chess scores) are increasing exponentially.

Figure 1: G7 average years of schooling vs. data storage costs (Gigabyte per $1.00)



Source: Barro and Lee (2013), "A new data set of educational attainment in the world, 1950-2010," *Journal of Development Economics*; statisticbrain.com. Data to December 2016; trends extrapolated for forward estimates.

Figure 2: Average scores, human chess grandmasters vs. computer chess programs

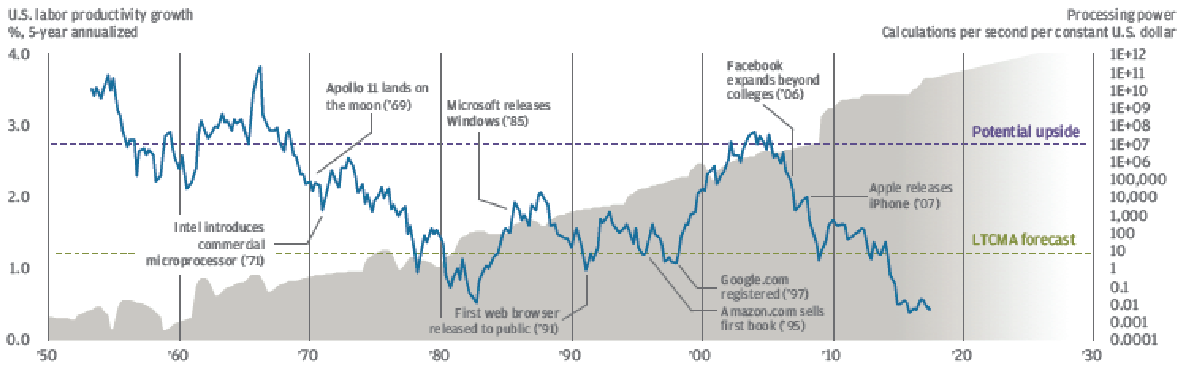


Source: Chessmetrics, L. Muehlhauser, Wikipedia.

Despite promising advances across a range of new technologies, productivity growth seems to have stalled in the aftermath of the financial crisis, leading many experts to reduce their optimism for future productivity growth and thus GDP growth - a topic explored in the 2017 edition of the LTCMAs. The authors agree that productivity growth is not guaranteed by some "magic force," but disagree with the idea that the heydays of productivity growth are past. That view is likely to be overly pessimistic. Historically, productivity growth has come in fits and starts, often but not always coinciding with the widespread adoption of specific previous breakthroughs - some of which have greater impacts on productivity than others (Figure 3).

Throughout history, U.S. productivity growth has alternately surged and stalled, as the persistent and exponential growth in processing power has overlapped with both peaks and troughs in productivity - suggesting we should not extrapolate recent weakness in productivity data.

Figure 3: U.S. labor productivity growth, 1950-present, and selected notable technology developments



Source: Bureau of Labor Statistics, Goldman Sachs, Singularity.com; data as of August 2017.

In many cases, the impact of new technology on productivity might have been foreseen in advance, with technologies in the pipeline for some time before they had a measurable effect. For instance, Ford's Model T was introduced in 1908, but it would be about 20 more years before 50% of American households owned an automobile. The automobile, of course, had profound and measurable impacts on productivity.

By contrast, in the past decade many technological advances, from social media to the streaming of films and music, have resulted in large consumer benefits far exceeding the amounts paid, and their impact therefore has probably not been fully captured in GDP. In the authors' view, the innovations in today's pipeline suggest meaningful opportunities to boost growth and GDP, as explored in the next section. Nevertheless, the potential upside from new technology brings with it concerns about labor displacement - an echo of fears raised at technological turning points throughout history. Previous technological advancements were absorbed to the benefit of capital owners and the labor force alike, but the speed, scale and scope of automation and AI create the unique policy challenge of optimising both the level and spread of the economic gains.

ESTIMATING THE POTENTIAL UPSIDE FOR GROWTH

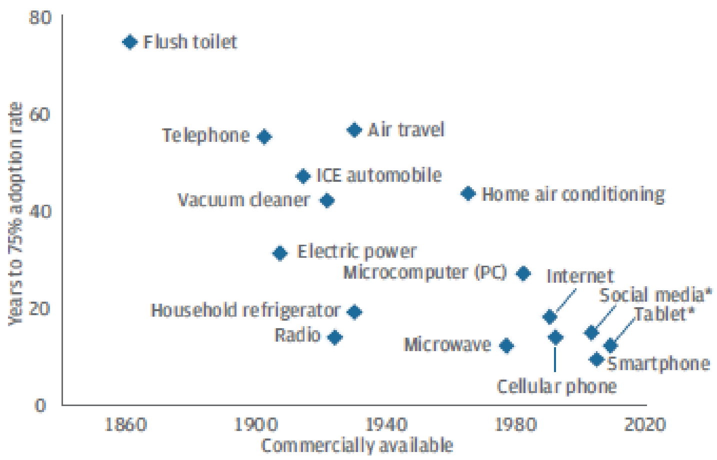
In the past, technological innovation transformed society and increased labor productivity in three key ways: **replacing** existing workers with machines and thus producing at least the same output with fewer workers (e.g., refrigeration vs. the iceman); **complementing** existing workers' jobs, boosting output per worker by automating some of their tasks (e.g., power tools); or, **creating** entirely new, higher productivity industries (e.g., computer software engineering), offsetting the displacement of workers by machines or replacing altogether industries that had been made obsolete.

Many commentators focus on labor replacement, as it may be the most directly measurable impact of new technology - not to mention the subject of intense media attention and public debate. Driverless vehicles are a prominent example, offering a large potential upside to aggregate economic output from redeploying the nearly five million U.S. employees operating trucks, taxis and other ground transportation. If just half of these jobs were automated over the next 20 years and, critically, displaced workers were efficiently re-employed elsewhere at average productivity, the incremental boost to GDP from driverless car automation alone would be almost 0.1%. It is also plausible that transportation volumes would increase, given lower costs. Of course, the assumption that labor is redeployed is central to the positive case - and some skeptics question whether this is possible when other comparably skilled jobs are also being automated. But ignore this for one moment and extend the replacement concept across the whole U.S. economy. If we assume the most extreme estimates of automation - such as Frey and Osborne's projection that 47% of jobs are computerised[4] - and make the exceedingly optimistic assumption that all of these individuals are redeployed into the workforce at average productivity, it would imply as much as a 3.5% per annum boost to GDP growth over 20 years. More moderate estimates - for example, studies from the McKinsey Global Institute and PwC - suggest GDP gains from automation of approximately 1% to 1.5%.[5]

These calculations apply primarily to replacing labor rather than complementing existing jobs or creating entirely new ones. Other technologies known to be in development - including advances in nanotechnology and bioengineering - could precipitate an entirely new wave of even greater productivity gains and potentially deeper disruption, including through these two channels. They may also create new opportunities for displaced labor, particularly as the pace of adoption of new technologies today is much faster than historically (Figure 4).

The pace of adoption of recent technological innovations is speeding up compared with history, offering potential for new job functions to emerge.

Figure 4: U.S. technology, rate of adoption (%)



Source: Asymco, compiled from various sources with support of the Clayton Christensen Institute. Note: Estimated from current adoption trends.

RELATIVE WINNERS AND LOSERS, AND GROWTH ACCOUNTING

This paper turns now to a discussion of the authors' Long-Term Capital Market Assumptions. At the heart of the LTCMA process are 10- to 15- year real GDP forecasts for major economies, based on a growth accounting framework (discussed below) that estimates potential growth over long periods by focusing on the supply side of the economy - that is, productive potential. That potential is divided into two components: total hours worked; and, labor productivity. Labor productivity is further subdivided into capital, skills and a residual total factor productivity (TFP).[6] Technological progress drives GDP growth in developed economies most directly through TFP. In the LTCMAs, it is assumed that all developed market (DM) economies are operating at the "technological frontier", with the latest business practices and technology, such that TFP advances at roughly the same pace across all the DM economies. Emerging market (EM) economies, in contrast, are still catching up to the technological frontier and thus should experience faster TFP growth.

Automation: The great leveler?

In the growth accounting framework, the key challenge facing most developed markets is the decline in labor force growth due to aging and reduced birthrates. The most extreme example[7] is Japan, where population decline subtracts 0.25% per annum from the long-term growth estimate (visible in the example calculation in Figure 5 as the product of 0.4% assumed shrinkage in the labor force and the 60% labor share in the economy).[8]

Automation is a clear boost to total factor productivity growth, but the related labor impact must also be taken into account in estimating trend growth rates.

Figure 4: Potential impact of technology on GDP growth, trend growth estimates, next 15 years

	U.S	EMU	HP	EM
Capital input	1.7	1.5	0.8	5.3
Assumed labor offset from automation		+0.2	+0.6	
Labor input	0.7	0.5	-0.3	1.8
Labor force growth	0.5	-0.1	-0.4	0.6
Hours	0.0	0.2	-0.1	0.0
Human capital (skills)	0.2	0.4	0.2	1.3
TFP	0.6	0.5	0.5	1.0
Assumed TFP boost from automation	1.0	1.0	1.0	1.0
Labor share	0.6	0.6	0.6	0.5
Capital share	0.4	0.4	0.4	0.5
Original trend	**1.7**	**1.4**	**0.6**	**4.4**
Trend with TFP and labor impact	**2.7**	**2.5**	**1.9**	**5.4**

Source: J.P. Morgan Asset Management.

In contrast, labor force growth in the U.S. adds 0.3 percentage point (ppt) per annum (again, assuming a 60% labor share in the economy). Simply put, just over half - nearly 0.6% - of the 1.1% differential between the Japan and U.S. GDP growth assumptions is explained by the different trajectories of labor force growth. In aggregate, emerging markets are not expected to suffer labor force shrinkage over the LTCMA time horizon, but there are wide divergences among specific EM nations - for example, between India's fast-growing labor force and Russia's rapidly shrinking one.

Automation has the potential to narrow these growth differences, offsetting shrinkage in the labor force. Thinking of technology in this way - as a means of making up the drop in labor force from population aging - would imply narrowing the spread in growth rates across developed economies. The calculation in Figure 5 simply assumes that increased automation exactly offsets the impact of any negative labor growth numbers,[9] thereby shrinking resulting GDP growth differences. Clearly, this is somewhat speculative, and in reality there is no reason this could not go further. And while this would certainly be a boon to the affected economies, it would also raise the capital share in the economy at the expense of labor, an issue discussed in a later section, "Challenges for labor and consumers, and a changing role for government?".

Automation: The end of the cheap labor advantage for emerging markets?

What is the impact of automation on emerging economies? Note that globalisation has substantially benefited emerging markets, as the outsourcing of manufacturing from developed markets has offered a means to accumulate productive capital and develop a skilled workforce. Relatively cheap EM labor has sparked and sustained much of that outsourcing, but if factory automation reduces its appeal by reducing developed economies' domestic production costs, current and future generations of EM economies might have to find new sources of economic growth. Additionally, emerging markets are also likely to receive relatively less of a productivity boost from automation, given that their still relatively lower labor costs diminish their incentive to automate.

Overall, then, at least over the LTCMA horizon, the authors think automation will lead to a leveling of growth differences within both EM and DM economies, but also perhaps a small narrowing of the EM vs. DM growth advantage.

GROWTH ASSUMPTIONS

The more clear-cut impact of automation within the LTCMA growth accounting framework is to boost total factor productivity growth, analogous to faster technological progress. For simplicity's sake, in the numerical example in Figure 5 this is represented this by just conservatively adding 1.0%, the bottom end of the range of most studies of the likely productivity impact from automation. While in this simple example, everyone benefits by the same total amount from the boost to TFP, clearly a 1.0% gain will feel much more meaningful in an economy with 0.5% trend growth than in one with 2% trend growth. However, implementing new technologies - such as investing in robots on the production line - might also be expected to appear in capital deepening.[10] Further, to compete with automation, the human jobs of tomorrow will require increased education and thus skills deepening. Of these latter two factors, for simplicity in the numerical example, it only includes the impact from potential labor force replacement into faster capital growth.

The overall impact on growth from these two aspects is as a leveler of differences. Picking the two extreme ends of the DM spectrum, in the example, the U.S. economy would go from growing almost three times as fast as Japan to growing slightly less than one-and-a-half times as fast. Similarly, the relative advantage of emerging markets over developed markets shrinks.

Many of the effects described above reflect the potential upside to trend growth and paint a picture of an upper bound to the growth projections if all goes smoothly. However, the timing and extent of any economic boost is difficult to predict, and while optimistic that at least some of these gains will be realised, the authors are also keen to find tangible investing opportunities today around this theme.

Where is technology most investible today?

In an investing process founded on fundamental research, analysis is divided into key themes that focus on the dynamics that will be important drivers of asset prices over the medium term. Among those themes is the widespread adoption of existing and emerging technologies. Understanding how these key technologies impact industries and the economy may offer the greatest investment potential in the current environment:

- **Cloud computing** is offering ubiquitous, flexible and on-demand access to a shared pool of computing resources. While delivering substantial cost savings, cloud computing is also fuelling a wave of start-ups ready to disrupt incumbent companies in the software industry.
- **The Internet of Things** - the connection of non-computer devices, such as sensors, control systems, white goods and cars to the internet - will increase connectedness among people, processes and physical things, generating new business models, such as usage-based pricing in the insurance, telecommunications and energy sectors, as well as improving inventory control.
- **Artificial intelligence** will enable machines to perform a wider range of tasks, from autonomous driving in commercial transportation to computer-assisted diagnosis in health care to robo-advising in the financial services sector.
- **Robotics** will result in widespread automation and lead to increased productivity and competitiveness. Industrial companies will “re-shore” their manufacturing base, while retailers will fully automate the store experience with self-checkout and drone deliveries.
- **Blockchain** technology could completely disintermediate the settlement and recordkeeping of transactions. Blockchain-enabled “smart contracts” will facilitate, verify and enforce the execution of contracts and reduce transaction costs. Central banks have flooded the streets with money. As economies recover and financial systems mend, this torrent could turn into a trickle.

CHALLENGES FOR LABOR AND CONSUMERS, AND A CHANGING ROLE FOR GOVERNMENT?

Reskilling the labor supply

The growth accounting framework described above estimates potential growth over long periods by focusing on the supply side of the economy - that is, its productive potential. Embedded in that framework is the implicit assumption that displaced labor is smoothly redeployed, generally maintaining something close to full employment. However, one significant worry surrounding near-term technological advancement is the reduction in the number of human jobs available in the economy. Such concerns date back at least as far as the first industrial revolution. From the automation of textile manufacturing in the 19th century[11] to the recent digitisation of music and film,[12] new technology has sparked fears of job destruction - fears that have mainly proved unfounded.

The base case is that this historical pattern will hold - at least over the 10- to 15-year forecast horizon - and that the labor force will continue to adapt. But this outcome depends crucially on human skills keeping pace with technological advancement. Many past episodes of technological advancement were disruptive to specific industries or processes, in particular highly manual or labor-intensive activities. Reskilling or redeploying labor into other functions - or, indeed, new functions explicitly created with the new technology - generally prevented mass labor displacement and eventually boosted low skilled worker productivity.

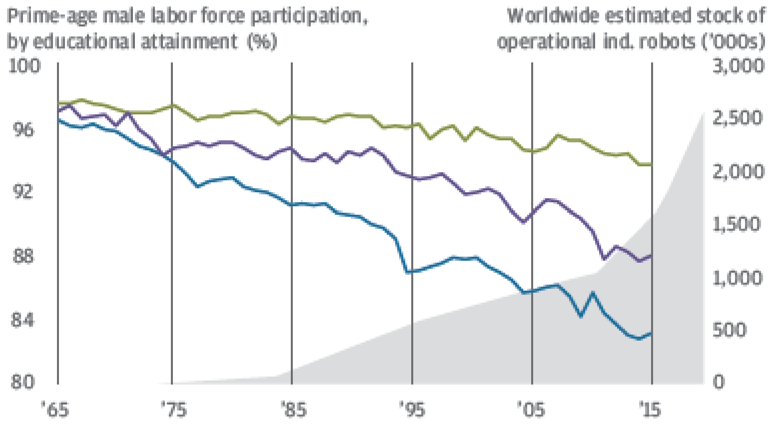
However, the impact of the current wave of automation has so far been skills-biased. That is, it has enhanced the productivity of highly skilled workers while undercutting the prospects for low skilled workers. The functions at greatest risk are still likely to be routine physical jobs that can be fully automated. These collectively account for 13% of U.S. wages and 18% of time spent in all U.S. occupations[13] - affecting industries such as accommodation/food services and manufacturing. Going forward, the data computing and processing powers of emerging technologies will put many routine, non-physical jobs at risk, including white collar administrative functions that span industries. The jobs least vulnerable to technological disruption are likely to be non-physical and non-routine and generally include functions that require interpersonal skills and expertise—a core human element in many sales, communications, artistic, cultural, health care or management jobs.

All of the above only serves to emphasise the importance of skills deepening through education and retraining (Figure 6 overpage). In the past, this has allowed workers to benefit from technological innovation. Further, it has made it possible for economies and the labor force to flourish through successive episodes of disruptive technology, from Jethro Tull's[14] seed drill to the internet. The future needn't be dominated by machines or humans; in an optimal world, machine and human will productively coexist. Case in point - chess players and chess supercomputers. In *The Second Machine Age*, McAfee and Brynjolfsson note that although even chess grandmasters now have no realistic hope of beating the best chess supercomputers, an average chess player in combination with an average chess program can still prevail. Training displaced workers to function in combination with technology seems an obvious step in skills deepening. But, paradoxically, urging human workers to be more human might also enable them to keep their grip on functions that will probably remain beyond the scope of automation and AI - at least, in the intermediate term.

Government will play an important role in providing skills, training and education, but its track record in this area has been patchy, at least in part because it is difficult to keep educational content relevant in a fast-changing global economy. Given companies' role as the driving force of many of these changes, there is scope for innovation around tax structure and other incentives - such as the accounting treatment of corporate investment in human skills - to motivate companies to promote skills deepening and help optimise processes that combine human and machine labor.

In the past, skills deepening through education and retraining allowed workers to benefit from technology, but widespread automation across many sectors at once creates a challenge to lower skilled workers that is already apparent in labor data.

Figure 6: Labor force participation by educational attainment vs. number of industrial robots



Source: Bureau of Labor Statistics Current Population Survey; Council of Economic Advisers calculations as of June 2016; International Federation of Robotics as of August 2017.

Maintaining consumer demand

Prior sections of this paper have focused on technology's impact on the supply side of the economy. It now shifts perspective to a consideration of the economy's demand side.

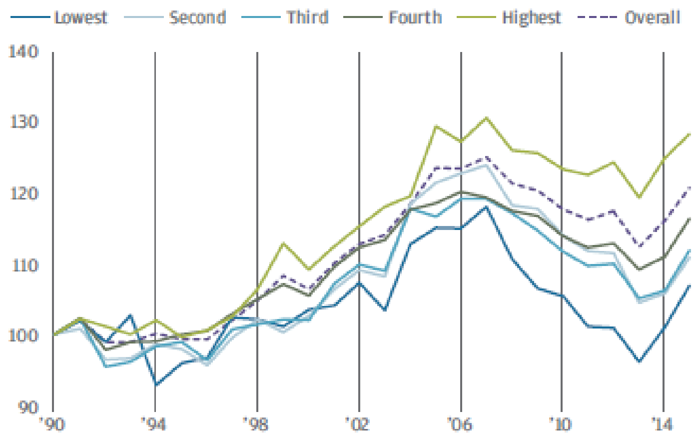
One of the main threats from workforce automation is that a greater share of output, all else equal, is likely to accrue to a concentrated group of capital holders rather than more evenly to labor as wages. This risks increasing inequality and may weigh on consumer demand (Figures 7 and 8).[15] From an individual firm's perspective, it might be profitable to replace a human worker with a robot, but that robot will not need the shampoo, coffee, mortgage advice and myriad other consumer goods and services that its displaced human equivalent once did. Simply put, looking at the economy in aggregate, we must acknowledge that one sector's displaced labor may be another's disenfranchised consumers.

The notion that economic demand, especially consumption, will keep pace with the potential levels of production that automation might allow cannot be taken for granted if those consumers have fewer jobs or lower salaries. For this reason, we believe that the policy debate will focus on two key areas: first, the new roles and responsibilities government may need to assume in maintaining the purchasing power of consumers, and by extension the demand side of the economy; and second, incentivizing education and reskilling the broad workforce to rapidly adapt to new technologies and fulfill new job functions. As we explain in the following section, proactive policies to prepare the labor force for emerging technologies are set to be important in maintaining social and political stability as automation and AI become more widespread.

This potential threat to demand is not the only contentious subject for governments, as it relates to a declining labor share of income. Even if the workforce doesn't face imminent decline - and with employment statistics[16] showing quite the opposite, this isn't an immediate risk - the level of real wages and the labor share of the economy are already displaying worrying trends. In particular, real wage stagnation, growing inequality and a diminished range of job opportunities appear to be stoking resentment in some quarters. The recent rise in populism across developed economies - the vote share for populist fringe political parties is at its highest point since the 1930s[17] - points to challenges that a disaffected labor force might create. Thus far, anger has been directed mostly at the forces of globalization, especially corporate outsourcing (often decried as "sending jobs overseas").We have yet to see a wave of 21st-century Luddism directed at automation, but should the object of populist ire shift that way, it will create a significant policy challenge of maximising the positive impact of technology and minimising its potentially disruptive effects.

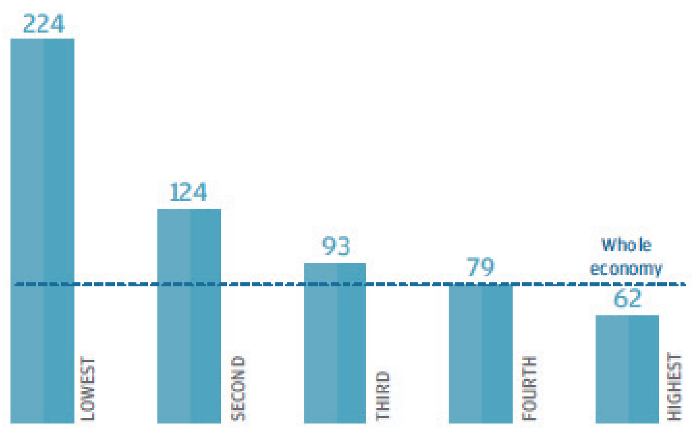
The level of real wages and the labor share of the economy are already displaying worrying trends, particularly given that the lowest income brackets spend the greatest share of their income on consumption.

Figure 7: U.S. pre-tax income by income quintile
(Index, 1990=100)



Source: Bureau of Labor Statistics Consumer Expenditure Survey; data as of Aug 2017.

Figure 8: Marginal propensity to consume by income quintile*



Source: Bureau of Labor Statistics Consumer Expenditure Survey; data as of Aug 2017. *Marginal propensity to consume = avg expenditure / pre-tax income.

The history of technological progress shows that productivity gains have typically raised the demand for labor, not destroyed it. However, the scale and speed of today's technological changes mean we can't take a repeat of this outcome for granted, and that policymakers have a role to play to encourage a continuation of this trend. Economies operate most efficiently when incentives are aligned and capital and labor are in equilibrium. Extreme policy in any direction will likely fail - a pure laissez-faire approach risks persistent wage pressure and swelling populism, while excessive redistribution risks capital flight. The authors expect governments to avoid both extremes and play a generally positive role, deploying a range of policies to help ensure that the economic benefits of automation and AI are widely spread.

The precise policy prescription will ultimately depend on how emerging technologies reshape the labor market. Where automation augments human labor, the policy imperatives are likely to be reskilling and retooling labor. But if automation substitutes for human labor, then the policy imperatives might shift more to redistribution in order to keep capital and labor in balance and, more crucially, to prevent a drop in demand. Figure 9 presents upside and downside scenarios of the economic impact of automation.

Productivity gains have historically raised the demand for labor. But the scale and speed of today's technological changes mean we can't take a repeat of this outcome for granted

Figure 9: Upside and downside scenarios of the economic impact of automation

	DEVELOPED MARKETS	EMERGING MARKETS
UPSIDE	• Automation fills labor force shortfalls, boosting supply side potential of developed markets with aging populations • Automation boosts total factor productivity growth • Net share of displaced workers is reskilled or subsidized for a time, maintaining purchasing power; wage gap and inequality trends subside • Faster absolute growth; spread of growth rates across developed markets narrows	• Automation boost to productivity growth muted relative to developed markets, given lower wages, but impactful in "last mover advantaged" scenarios • Displaced workers magnified given developed markets' reliance on emerging markets for low skilled tasks, but net share of displaced workers reskilled or subsidized to maintain purchasing power • Faster absolute growth, but emerging markets' growth advantage over developed markets may narrow
DOWNSIDE	• Failure of public policy to react means net share of displaced workers lose purchasing power • Wage gap and inequality trends magnify, depressing demand and risking populist backlash • Political uncertainty weighs on market confidence, leading to the growth boost from technology undershooting potential • Demand shortfall negates growth boost and creates structurally depressed interest and inflation rates	• Automation boost to productivity growth muted relative to developed markets, given lower wages. Displaced labor impact is magnified, given developed markets' reliance on emerging markets for low skilled tasks, but policy fails to react • Cross-regional wage gap and inequality trends magnify, depressing demand and risking political instability • Developed market service providers use improved global communications network to fill DM job needs with cheaper EM workers, depriving local EM markets of key higher skilled workers, while also suppressing DM wages and growth potential

Source: Richard Baldwin, *The Great Convergence: Information Technology and the New Globalization*, Harvard University Press, 2016; J.P. Morgan Asset Management.

IMPLICATIONS FOR THE LTCMA FORECASTS

Technological change - especially automation and AI - is likely to have profound effects on the global economy over the long term. We are often struck by how rapidly new technology is being developed and adopted. The early effects - at least over the 10- to 15-year forecast horizon of the LTCMAs - will probably accrue slowly. Nevertheless, the groundwork for more substantial changes to the economy will be laid. If automation and AI provide the kind of productivity boost suggested by a range of studies, including those from PwC and the McKinsey Global Institute, of 1%-1.5%, and technology also essentially offsets population decline in some developed nations, then annualised DM growth and equity returns could be more than a full percentage point higher than currently assumed. Moreover, the dispersion in equity return between developed and emerging markets has scope to narrow meaningfully.

The effect on equilibrium interest rates, however, may be more nuanced. While higher productivity and better growth might increase equilibrium yields, at the same time reduced labor bargaining power would likely keep inflation in check, which could reduce equilibrium yields. On balance, the baseline assumption is that these forces will roughly offset, so equilibrium rates are expected to be little changed. But even then, the 1% to 1.5% boost to potential equity returns could meaningfully increase 60/40 returns as automation and AI become more widespread in the next 10 to 15 years.

This is, of course, a rosy view, but it does set a reasonable upper bound to the impact of technology on the economy and asset returns over the forecast horizon. By contrast, should automation and AI start to displace labor and reduce wage growth, it would potentially offset some of the boost from productivity - in turn, weighing on nominal growth forecasts and equilibrium interest rates, and bringing equity returns back down toward, or even below, the base case estimates.

Ultimately, modeling the impact of technology on productivity, the labor force, the economy and government policy is an issue of extraordinary complexity. Paradoxically, we might need to wait for a sufficiently advanced level of artificial intelligence to truly understand it.

ENDNOTES

1. Roy Amara, scientist and futurist (1925–2007).

2. To name but a few others: biotechnology, nanotechnology, alternative energy.

3. Moore's law is the empirical observation that the number of transistors in an integrated circuit - closely related to computational performance - has for several decades doubled approximately every two years.

4. Carl Frey and Michael Osborne, University of Oxford, "The future of employment: How susceptible are jobs to computerisation?" (September 17, 2013).

5. The McKinsey Global Institute estimates 0.8% to 1.4%; PwC sees a 14% boost to world GDP by 2030, approximately 1.5% per annum.

6. This framework is analogous to the widely used Cobb-Douglas production function, which represents output given two or more inputs (e.g., capital, labor).

7. Europe is also challenged, but to a much smaller degree over the LTCMA time frame.

8. The impact is also negative in the euro area, but much smaller.

9. Therefore, this only affects Japan and the euro area in the example. Note that given the 60/40 labor-to-capital shares in the economy, the boost to capital growth required to offset a given labor shrinkage is 1.5x larger.

10. Increased capital per worker.

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11. The Luddite rebellion of 1811-13 was driven by fears that new weaving machines would lead to mass unemployment of textile workers.

12. CD sales fell from almost 800 million in 2000 to just 150 million in 2016 as music streaming took over from conventional album sales (gloriousnoise.com, Nielsen music via Billboard).

13. McKinsey Global Institute, "A future that works: Automation, employment, and productivity."

14. Viscount Jethro Tull developed the seed drill in 1701; it is credited as the first major automation in agriculture.

15. The important subject of income inequality is beyond the scope of this paper.

16. Prevailing labor data in the U.S. show the lowest level of unemployment since 2001 and robust demand for labor in most industries.

17. Bridgewater Associates and Lombard Street Research.

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John Bilton, CFA, is Head of Global Multi-Asset Strategy, Multi-Asset Solutions with JP Morgan Asset Management. Shrenick Shah is Portfolio Manager, Multi-Asset Solutions; Patrik Schowitz, CFA, is Global Strategist, Multi-Asset Solutions; Michael Albrecht, CFA is Global Strategist, Multi-Asset Solutions; and Brian Bovino is Associate, Multi-Asset Solutions.