GROUP OF TWENTY

Technology and the Future of Work

Prepared by Staff of the

I N T E R N A T I O N A L M O N E T A R Y F U N D*

* The background note does not necessarily reflect the views of the IMF Executive Board.

CONTENTS

EXECUTIVE SUMMARY

Historically, technology has enabled an unprecedented growth in labor income, but has also been a source of disruption. Technology has boosted productivity, which, in turn, has driven strong per-capita GDP growth and has been associated with expanding employment. However, the gains in employment and income can come in spurts and tend to favor different sectors over time. This forces deep and sometimes painful structural adjustment, with jobs changing or disappearing in some areas while new jobs are being created elsewhere. Moreover, while there are many reasons for the decline in labor income shares over the last three decades, technological progress in capital goods has played a role. Finally, the distribution of labor income itself has become more unequal as some skills—particularly those associated with more routine tasks—have become redundant, leading to a polarization of income gains favoring high-skilled and disadvantaging low-skilled labor.

Technological advances are likely to have a similar impact in the future. Two interrelated factors that have been driving the impact of technology in the past are expected to continue to do so going forward: i) automation or, more broadly, an increase in the extent to which capital can technically substitute for labor; and ii) the falling relative prices of capital goods (which encourage the replacement of labor for a given degree of substitutability). Automation could allow machines to perform cognitive but routine tasks now handled by humans. This would put particular pressure on low-skilled labor doing routine work. Illustrative model simulations indicate that the more easily capital will substitute for labor, the more productivity and overall income growth will pick up, but the more this is likely to increase inequality by favoring income from capital and higher-skilled work. A decline in capital goods prices is also likely to benefit the high-skilled vis-à-vis the low-skilled.

Transitions can be costly. An advance of automation and falling relative prices of capital goods can be expected to entail similar labor market disruptions as technological progress in the past: skill mismatches will have to be overcome; investment in human capital will have to be financed in the presence of credit constraints, especially for low-income households; and some workers could be dropping out of the labor force altogether. While a significant shift in technology requires adjustment across all skill levels, adjustment will likely be more difficult and costly for the low-skilled.

And technology will have repercussions beyond labor market adjustment. Technology and global economic integration are intertwined, and affect cross-country income convergence. For instance, new technologies could increase concentration in product markets and reduce labor shares. They can also redefine the boundaries of firms and the role of employees, potentially fissuring the workplace.

Policies can change the impact of technological change. Depending on societies' preferences for growth versus income equality, governments may want to distribute the gains from technology more evenly. Certain policies, if well designed, could mitigate the trade-off between both objectives. For example, illustrative model simulations show that higher education spending would not only allow low-skilled workers to participate in the gains of technological change, it would also increase output; this holds even when taking into account that higher spending will require higher rates of taxation. More generally, while the use of the tax/benefit system to redistribute the gains from technological advances tends to come with some loss in efficiency, the resulting loss in output tends to be relatively small. Other relevant policies include stronger and portable social safety nets centered on empowering and protecting workers (rather than preserving jobs). Competition policies might have a role to play as well—e.g., in response to more market concentration driven by digitalization—but will have to be mindful of the complex relationship between market power and the creation and diffusion of new technologies.

I. INTRODUCTION

1. Technological progress boosts living standards, but can be a source of disruption. Technological advances can raise overall productivity and income. But they can also lead to structural change, creating new jobs and sectors while displacing and changing others, with major repercussions for some parts of the population.

2. Anxiety about the adverse impact of new technologies on jobs and incomes is not new. It dates back at least to the Luddites movement at the outset of the Industrial Revolution (Mokyr, 2015) and has been a recurring theme. For instance, John Maynard Keynes (1930) warned about the possibility of "technological unemployment." Anxiety re-emerged in the 1960s following a period of particularly high productivity growth post-World War II (National Commission on Technology, Automation and Economic Progress, 1966) and in the 1980s at the outset of the Information and communication technologies (ICT) revolution (National Academy of Sciences, 1987).

3. Is this time different? Fears have recently been rekindled, partly reflecting that the latest wave of technological innovation has come at a time of already timid growth of real wages and a falling share of labor in national income, particularly for low-skilled workers. Looking forward, new technological advances—when they diffuse more widely—may be even more disruptive, especially from automation and falling capital goods prices. In assessing the opportunities and challenges of innovation, this note will focus on two underlying trends that will play a key role in shaping the future of labor markets and technology:

- ***Machines can perform an increasing range of tasks reserved for humans in the past…*** ICT have eliminated many office jobs performing routine tasks, and progress in robotics has changed manufacturing. But technological advances powered by the rise in Artificial Intelligence (AI) have the potential to transform work in a more fundamental way: as robots get more productive, more tasks in the future could be performed by a combination of machines and AI instead of labor.

- ***… and they have become cheaper relative to labor.*** The diffusion of ICT led to advances in innovation and invention of new and increasingly cheaper capital goods and production processes. These have incentivized firms to substitute machines for routine tasks, contributing to falling labor shares and income polarization (IMF, 2017a). Further declines in capital goods—driven by productivity gains in ICT—may have similar effects, even without fundamental changes in how machines and labor are used for production.

4. Is there a role for policies? Based on simulated paths for these trends, this note argues that technological advances offer prospects for higher productivity and stronger growth, but also bring with them risks of increased income polarization and a need to deal with the difficulties of adjustment. In the first instance, reforms to lift growth are critical (see, for example, IMF (2017b)). But, historically, policies to spread the gains from growth more widely were an important part of the way economies transformed in the wake of technological change (Acemoglu and Robinson, 2002). This suggests a focus on policies to enable countries to harness technological change for a broad group of their populations, tailored to their social preferences. Indeed, the note shows that such policies, if well designed, could even further boost growth. For instance, investment in human capital is key to allow low-skilled workers reap the gains of technological change. Redistributive policies, such as differentiated income tax cuts, can also help reallocate gains (though come with efficiency losses). At the same time, policymakers need to get ready to facilitate the process of adjustment, as technological advances change individual jobs, whole professions, and potentially the sectoral makeup of economies.

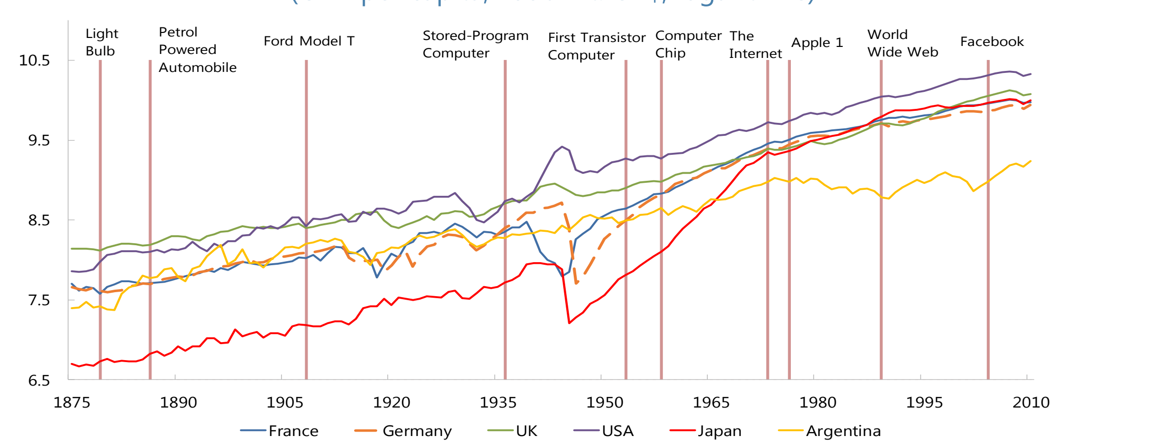
5. **Scope for further work.** This note identifies key channels through which technological change may affect labor and highlights broad policy tradeoffs. Further work is needed to add more granularity to policy responses tailored to country-specific circumstances, and to assess how technological change could expand or constrain policy options (e.g., how digitalization could affect taxes). Furthermore, several factors that are potentially related to new technologies—such as growing market concentration and more flexible work arrangements—deserve more scrutiny and, in some instances, might require novel policy approaches. The Fund is planning to look into these areas in collaboration with external partners.

II. TRENDS

A. Technology as an Engine of Growth and a Source of Disruption

6. **Innovation has been a driver of growth.** While the time lags between particular inventions and their eventual broad diffusion can be, long and change over time, technology has been key to productivity growth since the first industrial revolution, which, in turn, has underpinned strong per-capita GDP growth (Figure 1). A series of significant innovations such as the steam engine, railway, electricity, and the combustion engine, as well as improvements in production methods, infrastructure, health outcomes, and educational attainment supported productivity growth throughout the 19th and 20th century, resulting in vast gains in living standards. The ICT revolution boosted productivity again at the turn of the 21st century.

Figure 1. Technological Innovation has Underpinned the Rise in Living Standards
(GDP per capita, 1990 Int. GK$, logarithms)

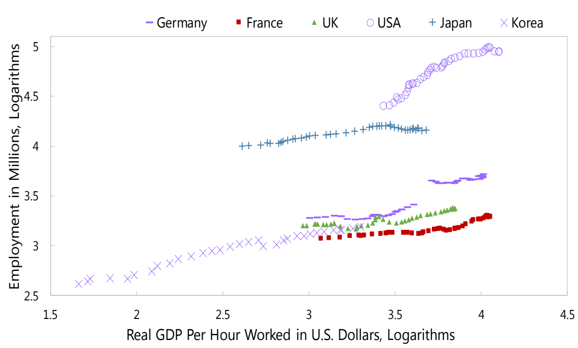


Source: Maddison Project and IMF Staff Calculations.
Notes: GK$ refers to the Geary–Khamis dollar, more commonly known as the international dollar.

7. Historically, concerns about 'technological' unemployment proved unwarranted… Notwithstanding a trend toward shorter working hours (and shorter-term fluctuations in labor force participation and unemployment rates), there is no evidence of a persistent negative impact of new technologies on the overall demand for labor. New technologies displaced some jobs, but created complementary new tasks. And the associated rise in productivity contributed to higher incomes and aggregate demand, supporting job creation (Figure 2; Autor and Solomons, 2017).

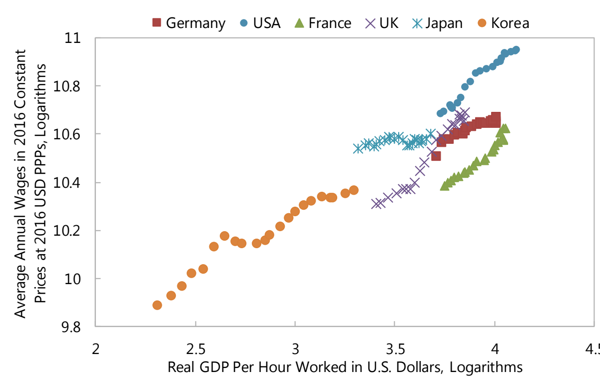
8. …and real wages increased rather than declined. Trends in real wages followed those in productivity, which resulted in an unprecedented growth in labor income since the start of the Industrial Revolution (even though the share of gains from productivity advances accruing to workers has fluctuated over time (Figure 3).

Figure 2. Productivity Associated with more Employment…
(1970–2011)



Source: U.S. Bureau of Labor Statistics.

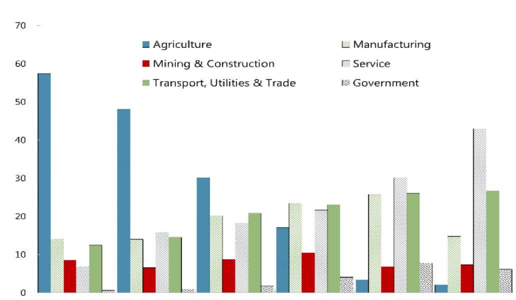
Figure 3. …and Higher Wages
(1990–2011)



Source: OECD; U.S. Bureau of Labor Statistics; and IMF Staff Calculations.

9. Adjustment to change has often been difficult, and gains have been spread unevenly, particularly in recent decades. Technological change has eliminated some jobs and transformed others. Over time, new jobs have been created, as reflected in growing aggregate employment. But changes have been dramatic, as illustrated in shifts in the sectoral composition of employment over time, for instance from agriculture to manufacturing, and more recently from manufacturing to services (Figure 4 demonstrates the process for the U.S., but similar shifts have occurred in other

Figure 4. Technological Change has Contributed to Sectoral Reallocation within the U.S. Economy
(percent of labor force)

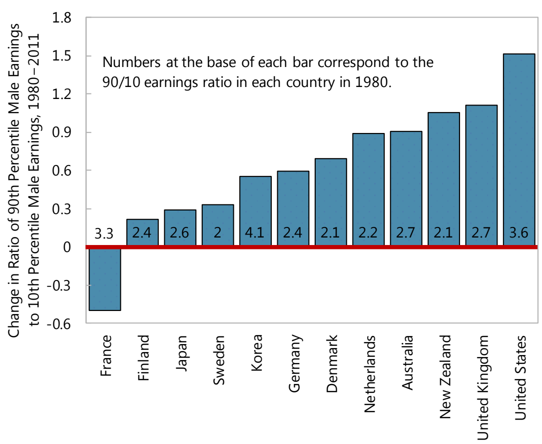


Source: U.S. Census Bureau and IMF Staff Calculations.
Notes: In the 1850-1910 samples, the industry of employment was inferred from the reported occupation.

advanced economies (AEs) and Emerging Market and Developing Economies (EMDEs); see Gruen (2017)). Not surprisingly, shifts on such a scale have led to painful adjustments for many:

- ***Some skills have become redundant, impacting employment and skill premia.*** Demand for some skills has declined with new technologies (for instance, ICT eliminated many routine office jobs). For some, this led to a move to less skill-intensive and lower-paying jobs; and, while this has not systematically impacted aggregate unemployment and labor force participation rates, others became unemployed or dropped from the labor force altogether. In contrast, demand for skills complementary to new technologies has increased. Taken together, this contributed to a hollowing out of middle-skilled jobs in many AEs in the past three decades. It also led to a polarization of income gains—favoring high-skilled and disadvantaging low-skilled labor, which has been an important factor behind the rise in inequality in the past three decades (Figure 5). High-skilled jobs required increasingly higher educational achievements, in some countries driving educational wage premia fueled by slower labor supply adjustment (Figure 6).[1]

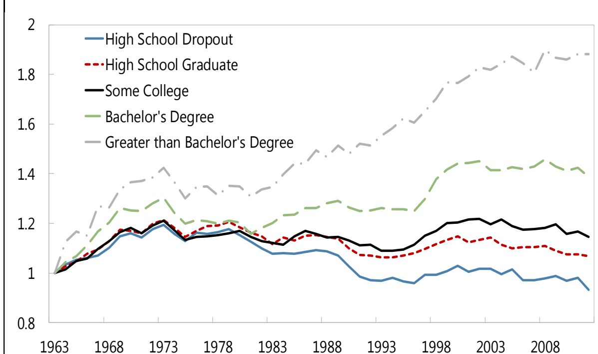
Figure 5. Earnings Polarization Accompanied by…



Source: Autor (2014).

Figure 6. … an Increasing Educational Wage Premia in Some Economies

(real wage level of full time U.S. male workers relative to 1963)

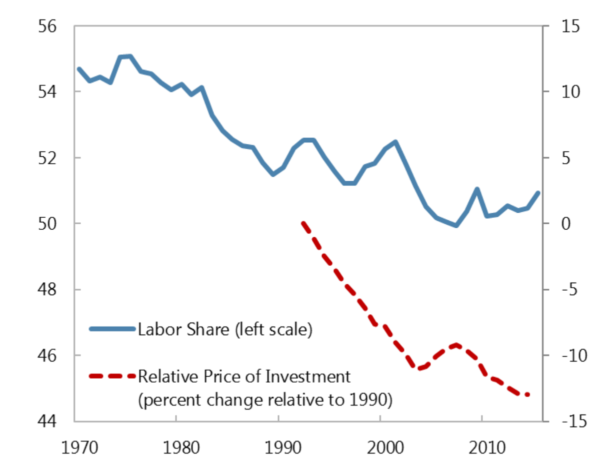


Source: Autor (2014).

[1] The dynamics of educational wage premia depends on the supply and demand for skills, as well as on labor market institutions. The increase was most prominent in the U.S., but observable—albeit to a lesser degree—in other economies (Katz and Autor, 1999). Since the Global Financial Crisis, there has been a flattening of the skill premia in the U.S., likely reflecting a supply response (an increasing number of workers with college and higher education).

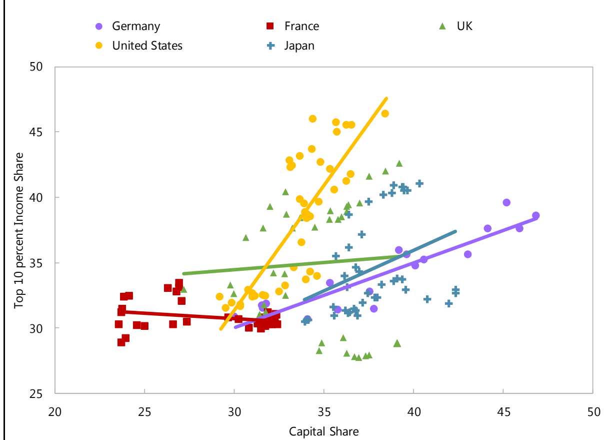
- ***The labor share of income has declined now and again.*** Declines in labor shares—or shifts in the distribution of national income away from labor—have occurred in the past, most notably in periods of fast technological change. For instance, in many AEs a downward trend in labor shares between 1980s and the late 2000s has been associated with a move toward more capital-intensive production methods, which in turn has been linked to falling prices of capital goods (Figure 7; IMF, 2017a). However, other factors have been at work as well, with some observers pointing to globalization (Elsby, Hobjin and Sahin, 2013) and others to growing market power of companies (Barkai, 2016; Autor et al., 2017). Fluctuations in the share of income accruing to capital have also been correlated with shifts in within-country inequality (Figure 8).

Figure 7. Declining Labor Shares Associated with Falling Capital Goods Prices in Advanced Economies
(percent)



Source: April 2017 WEO.

Figure 8. Income Inequality Correlated with Capital Shares
(percent, 1970–2010)



Source: Bengtsson and Waldenstrom (2017).
Notes: "Capital share" denotes the aggregate share in national value added going to capital and "Top income share" denotes the top decile's share of total income in the personal income distribution.

10. The Global Financial Crisis brought adjustment challenges to the fore. The demand shock affected jobs, as reflected in initially higher unemployment, a fall in the labor force participation rate, and involuntary part-time employment. At the same time, as production and investment slowed, productivity growth dropped to historical lows despite further advances in ICT, most notably the rise of the digital economy. Indeed, the legacy of the crisis has been linked in part to less productivity-enhancing investment, including in ICT and intangibles (IMF, 2017b), slowing the diffusion of new technologies.[2] As in the past, potential mismeasurements of new goods and

[2] More broadly, Brynjolfsson et al. (2017) explains the paradox of rapid technological advances and slow productivity growth largely by implementation lags, as new technologies have not yet diffused widely. Others argue that research productivity has been falling in many fields (Bloom et al., 2017) and that overall productivity growth has been in long-run decline (Gordon, 2015). But there is historical evidence of sluggish productivity growth followed by an

(continued)

services in the digital economy could have played a role, but appear less critical (Box 1). The impact on inequality is more complex. On the one hand, the slowdown in the implementation of new technologies and drop in income derived from wealth and assets seem to have supported a stabilization of the adverse trends in the labor share and inequality. On the other hand, historical and econometric evidence suggests that the slowdown in productivity ultimately translates to lower wage and employment growth (IMF, 2017c).

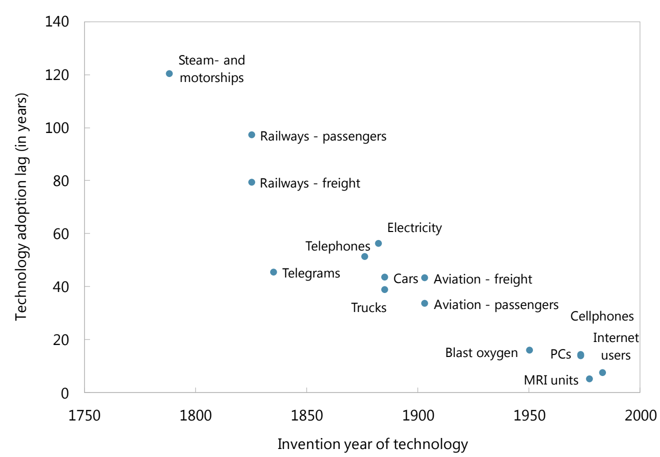
B. Technology and Economic Integration

11. Technological change and global economic integration are intertwined.

- ***Technology fosters economic and financial integration…*** Falling transportation costs due to the widespread use of containers, and, more recently, the ICT revolution are both examples of technological progress driving integration via cross-border trade and financial flows. Global efficiency gains have expanded the variety of available goods and services at lower prices, enabling further integration. Advances in communications technologies were particularly important for financial integration (Garbade and Silber, 1978).

- ***and integration facilitates technological diffusion.*** Trade and financial integration supported innovation, investment, and diffusion of knowledge across the world. In AEs, efficiency gains from global integration contributed to productivity growth, and, for firms close to the technology frontier, global competition has been shown to increase innovation incentives (Aghion et al., 2015). For EMDEs, investments by local affiliates of multinational companies and technology embedded in imported goods (the share of imported high-tech products in GDP has risen by more than half since the mid-1990s) allowed easier access to foreign know-how. As a result, cross-country lags in the adoption of new technologies have been reduced from almost 100 years in the 1800s, to 20 years today (Figure 9; Comin and Hobijn, 2010).

Figure 9. Technology Adoption Lags have Decreased Over Time



Source: Comin and Hobijn (2010).

Notes: Technology adoption lag is a mean estimated lag in cross-country technology diffusion.

acceleration, particularly in the case of advances in general purpose technologies (where productivity gains can be realized only after complementary innovations are developed and implemented; see Jovanovic and Rousseau (2005)).

- ***Both technology and integration impact growth and the way it is shared.*** Increasing integration boosted growth in EMDEs, contributing to a reduction in poverty and cross-country convergence. And during the fifteen years prior to the Global Financial Crisis the integration of China into global trading system alone may have accounted for over a tenth of total factor productivity gains in AEs (Ahn and Duval, 2017). But employment effects have been uneven across industries and groups of workers (Autor, Dorn and Hanson, 2016); for instance, AE manufacturing jobs have shifted to lower-wage EM economies. Some regions pulled ahead (e.g., as large companies created positive spillovers from technological and organizational know-how, see Andrews et al., 2015), while others lagged, with aging populations and welfare systems possibly hampering the movement of people (Schleicher, 2017).

III. POSSIBLE FUTURES

12. What drives current labor market trends? IMF (2017a) and several other studies have identified a number of factors affecting the decline in the labor share and the rise in wage premia.

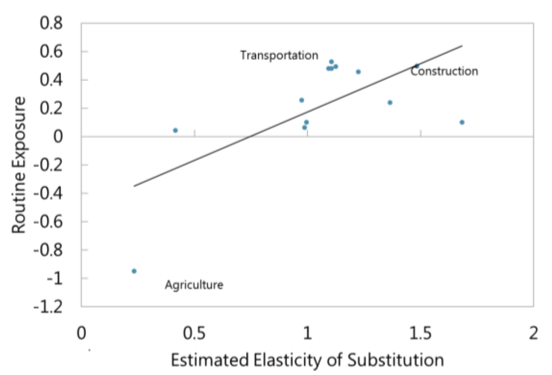
- ***Automation and cheaper capital goods.*** Automation and the falling prices of capital goods are interrelated factors that drive technological advances and productivity growth. They have also been linked to the decline in labor shares and income polarization as: (i) the automation of tasks routinely performed by labor affect substitutability between capital and labor; and (ii) the falling relative prices of investment goods encourage substitution away from labor. A higher degree of routine tasks is typically associated with a larger elasticity of substitution between capital and labor, and therefore with a greater job replacement risk if the price of capital goods falls (Figure 10). IMF (2017a) finds this mechanism to be a leading explanation behind the fall in the labor share for AEs, where middle-skilled workers performing routine tasks have been most susceptible to automation (Figure 11). The impact has been smaller for EMDEs, which have had so far relatively fewer jobs exposed to automation.[3]

- ***Global integration and other factors.*** The ICT revolution has made the global economy more connected, contributing to outsourcing and spreading manufacturing production through global value chains (Baldwin, 2016), as well as to financial integration. This boosted efficiency but also inequality. For instance, IMF (2017a) finds that participation in global value chains has been one of the factors behind the decline in labor shares: it has been associated with offshoring tasks that are labor-intensive for AEs, but capital-intensive for EMDEs. Elsby, Hobjin and Sahin (2013) similarly show that labor share decline in the U.S. was deeper in industries more affected by increasing imports. There is also an ongoing academic discussion about the impact of new

[3] Some studies question the role of declining capital good prices in explaining the dynamics of the labor share. For these declines to have an impact, the elasticity of substitution between capital and labor must be higher than typically found in empirical studies (Autor et al., 2017). IMF (2017a) shows that, due to higher routine exposure, the elasticity of substitution in AEs is sufficiently high for the decline in capital goods prices to have a negative impact on labor shares. Moreover, the importance of this channel may increase if new technologies lead to more substitutability between labor and capital. The estimated elasticity of substitution is lower for EMDEs, and capital deepening could therefore result in an increase in labor shares for these countries.

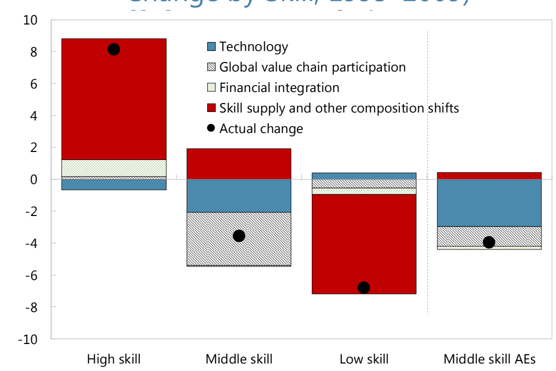
technologies on workers through other channels, such as changes in the structure of product markets (e.g., digitalization may increase market concentration (Guellec and Paunov, 2017)) and labor markets (e.g., 'search and matching' platforms may make work arrangements more flexible (Katz and Krueger, 2016)). Additionally, demographic changes can interact with technology and economic integration.

Figure 10. Elasticity of Substitution Correlated with Degree of Task Routinization
(by sector, 1992–2014)



Source: April 2017 WEO.
Notes: Routine exposure is measured by aggregate routine task intensity index (Autor and Dorn, 2013); smaller number reflects lower exposure to "routinizability."

Figure 11. Technological Change and Global Value Chains Contributed to Integration
(Contributions to Aggregate Labor Share Change by Skill, 1995–2009)



Source: April 2017 WEO.
Notes: Decompositions are derived from aggregate labor share regressions by skill group. Middle-skill advanced economies refers to the decomposition of the aggregate middle-skilled labor share, using only the advanced economy subsample in the regression. Contribution of skill supply and other shifts in composition is the combined effect of educational composition and the regression constant.

13. What will shape jobs in the future? This note focuses on automation and falling prices of capital goods as the key factors potentially affecting future growth and developments in inequality. It employs economic modeling to illustrate their impact on both. The impact of global integration and other factors is more uncertain, and the note highlights potential channels and interactions between them.

A. Automation

14. The trend toward automation will likely continue or even accelerate. For instance, advances in AI and robotics could make more cognitive tasks replaceable by machines, increasing substitutability between some forms of capital (for simplicity called 'robots') and humans.

- ***Many jobs could be affected, particularly in AEs.*** McKinsey (2017) estimates that 375 million workers globally (14 percent of the global workforce) may be at the risk of job losses by 2030 in their baseline scenario. The risk is seen as higher for workers in AEs, with about 23 percent of jobs potentially affected in the U.S. (and up to 44 percent in a fast-automation scenario, which is broadly consistent with 47 percent estimated by Frey and Osborne (2017)). Estimates for EMDEs are considerably lower (e.g., about 13 percent for Mexico, 9 percent for India, and 16 percent for China), which reflects differences in the sectoral composition of production. Other studies find smaller impacts.[4]

- ***Automatability may decrease with the level of education.*** There is consensus that high-skilled occupations are the least susceptible to automation.[5] The impact on low- and middle-skilled jobs is less certain. McKinsey (2017) estimates that the hollowing-out of the middle class will continue, with automation disproportionally affecting middle-income workers. In contrast, Frey and Osborne (2017) and Arntz et al. (2016) suggest a break in this trend, with automation mainly substituting for low-skilled jobs. New, yet unknown activities may boost demand for different skills in the future, amplifying this uncertainty.

15. A dynamic model simulation illustrates the potential tradeoff between growth and inequality. The approach focuses on the substitution channel, and, as the depth of penetration of new technologies is uncertain, it features two automation scenarios where the advance of robots allows substituting labor to different degrees (Box 2).[6] Relative to a no-robots baseline, GDP growth is higher under both scenarios, but this is at the cost of higher inequality: the more easily robots substitute for routine labor, the more productivity and overall income growth will pick up, but the more strongly inequality will likely increase.

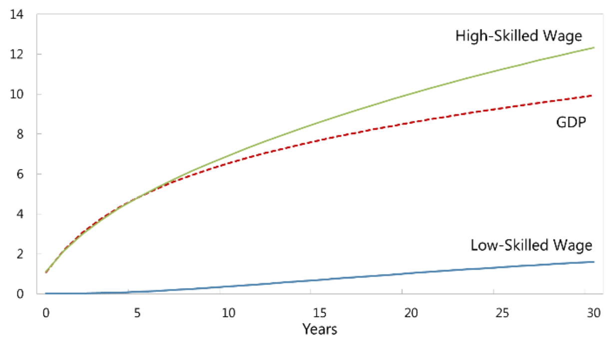
- ***What if the substitutability between robots and labor is relatively low?*** At the start of this scenario, it is assumed that technological progress introduces robots into the economy. This allows firms to replace routine, low-skilled labor to some limited degree. Relative to the no-robots baseline, GDP increases by about 10 percentage points over the longer term—taken to be 30 years in this case—and wages rise for all workers, albeit significantly more so for the high-skilled. The overall labor income share changes little, even though the low-skilled income share falls by about 2 percent of GDP. The high-skilled profit directly from the introduction of robots (which makes them more productive), while the low-skilled benefit only indirectly and more slowly through the resulting increase in investment in traditional, i.e., non-robot, capital.

[4] Arntz et al. (2016) predict that only 9 percent of jobs in OECD countries are automatable, based on a methodology distinguishing between jobs (which may survive, though in a different form as automation progresses) and their constituent tasks (which may become automatable). Using the same methodology, Ahmed and Chen (2017) estimate automatability at 1 percent for Vietnam.

[5] Substitutability', though, is not always correlated with the degree of formal education. For instance, Frey and Osborne (2017) suggest that kindergarten teachers are less "computerizable" than paralegals.

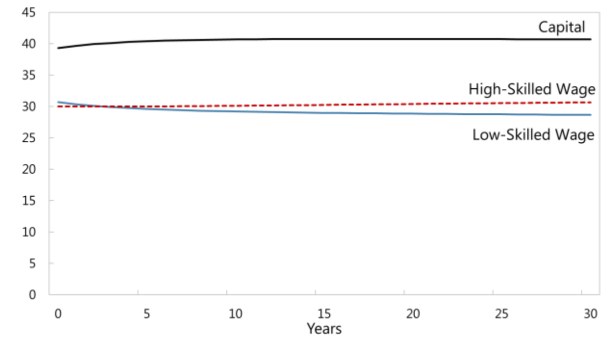
[6] To focus the discussion on the substitution mechanism, this model aggregates low- and middle-skilled groups (called low-skilled for simplicity). The next section will look into the differences in impact across skill groups using a different modeling approach.

Figure 12. With Limited Substitutability, Low-Skilled Wages Increase…
(percent change from the baseline)



Source: IMF Staff Calculations.

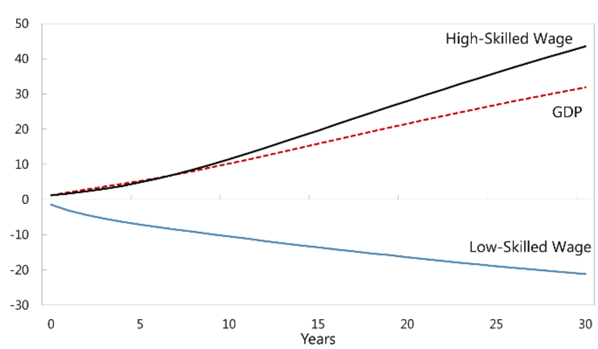
Figure 13. …and Income Shares are Broadly Unchanged
(percent)



Source: IMF Staff Calculations.

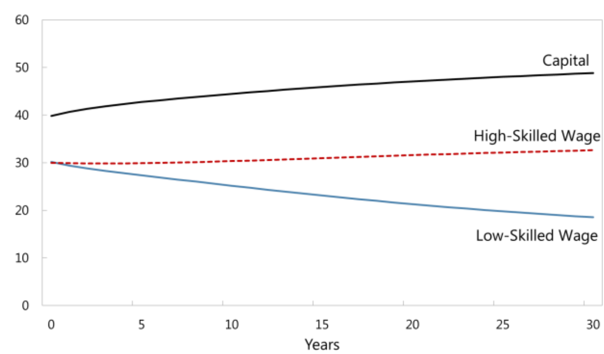
- ***What if the substitutability is higher?*** By assuming more low-skilled tasks are replaceable, new technologies produce a more fundamental shift in substitutability between robots and low-skilled workers. On one hand, this means that output increases by about 30 percent over 30 years, significantly more than in the low-substitutability scenario. On the other hand, there is also a larger rise in income inequality. The wage of low-skilled workers falls and the decline is substantial and persistent—by over 20 percent in real terms after 30 years—reflecting more intense competition with robots (as it is more productive to combine traditional capital with robots rather than with low-skilled labor, traditional capital accumulation provides now only a limited offset for the low-skilled). Furthermore, the share of income going to capital (robots and traditional capital) increases from 40 to about 50 percent in the long term. Because little income from capital goes to low-skilled workers, this increases overall inequality.

Figure 14. With Higher Substitutability, High-Skilled Wages Increase and Low-Skilled Wages Decline…
(percent change from the baseline)



Source: IMF Staff Calculations.

Figure 15. …while Low-Skilled Income Share Plummets
(percent)



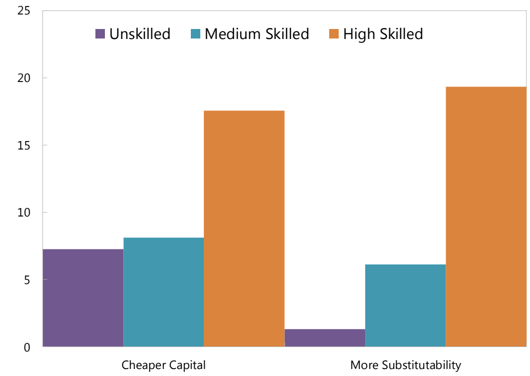
Source: IMF Staff Calculations.

B. Falling Prices of Capital Goods

16. Just like automation, further declines in capital goods prices will likely increase GDP but benefit disproportionately the higher-skilled. A downward trend in the real price of capital goods observed for AEs will probably continue as technological advances in ICT improve the design and production efficiency for investment goods. It is easy to imagine a scenario where, for a given degree of substitutability of labor by capital, making capital more affordable for firms will yield broadly the same effects as automation—over time, firms will increase capital and use more machines and fewer workers producing greater output. In general, it will be low-skilled labor that is most easily replaced by capital while the demand for high-skilled workers might go up—for example, because they develop or otherwise complement production capacities. As a consequence, and depending on the size of the price drop for capital, we would expect relative wages to develop broadly along the same trajectory as under the automation scenarios discussed above.

Figure 16. Cheaper Capital has Less Distributional Impact Than Substitutability

(percent change of income from the baseline)



Source: IMF Staff Calculations.

17. A second set of model simulations incorporating both capital goods prices and automation confirms this hypothesis.

- The question is addressed with the help of a heterogenous agent general equilibrium model calibrated to fit the U.S. as a benchmark economy.[7] While this static framework abstracts from transition dynamics to focus only on the long term (the “steady state” where the economy has adjusted to all changes), it allows for a more detailed discussion of both capital goods prices and automation, as well as their impact on workers of different skill levels (low, middle, and high). As such, it is also more suitable for a broad range of policy simulations (see below).
- Assuming a 20 percent drop in the relative price of capital goods, which is broadly consistent with the pace of decline observed in the U.S. since the 1980s, GDP rises by 14½ percent over the long term compared with the baseline, but—since higher-skilled labor is considered to be complementary to capital—higher-skilled workers generally benefit more than the low-skilled. Specifically, cheaper capital goods increase income by 16 percent for high-skilled workers, and by about 7 percent for both low- and middle-skilled workers.
- To assess the difference between the impact of cheaper capital goods and automation (considered earlier), the model also simulates a 10 percent increase in the elasticity of

[7] The model assumes that capital is a substitute for (an aggregate of) middle- and low-skilled labor with an elasticity of 1.5, while capital and high-skilled labor are complements. The distribution of skills is exogenous and constant (the implications of shifts in this distribution—driven, for instance, by education policies—are discussed in Section IV).

substitution between capital and labor. This produces the same 14½ percent increase in GDP and is broadly consistent with the more benign of the dynamic simulation scenarios that assumes relatively low substitutability. In the static model higher substitutability between capital and labor generates more inequality than the decline in capital goods prices, producing little or no benefit to low-skilled workers, while high-skilled workers' consumption increases by almost 20 percent (Figure 16).

C. Transition

18. The transition to the long term comes with adjustment costs, particularly for people with lower skills.

- ***Even the moderate automation scenario sees low-skill income rising only slowly***. All simulations produce a significant increase in inequality, but, in the case of relatively low substitutability between labor and robots, there is no loss of income for the low-skilled in the longer term or new steady-state equilibrium. However, the dynamic simulation suggests that the transition to even this mediocre (from the point of view of low-skilled workers) outcome takes time to materialize, as wages for the low-skilled remain stagnant in the first decade after the introduction of robots (Figure 12). The reason is that their wage gains are the result of productivity gains from investment in traditional (non-robot) capital, which is slow to materialize.
- ***And skill mismatches are likely to produce frictional unemployment.*** As automation proceeds and the price of capital falls, not only wages of different skill groups adjust, but also significant labor reallocations occur that could lead to frictional unemployment—a transition cost ignored in the simulations above. Such reallocations may take place within skill categories (i.e., low-skilled labor finding different low-skilled occupations) or across. Of course, skill acquisition could change the composition of labor force and mitigate the distributional impact of technological change—indeed, an active strategy to upgrade human capital is among the policy options considered below. But the transition process is likely to be difficult, with skill mismatches leading to frictional unemployment, human capital investment being costly and difficult to finance in the presence of credit constraints, especially for low-income households, and some workers dropping out of the labor force. While a significant shift in technology requires adjustment across all skill levels, adjustment is more costly for the low-skilled.

D. Other Related Drivers

19. The impact of other technology-related factors on jobs and inequality is more difficult to assess.

- ***Economic integration.*** More automation could reduce incentives to outsource routine tasks from AEs to EMDEs. This could have an impact on income convergence (traditionally driven by manufacturing) by either reducing outsourcing or, more likely, changing its nature and criteria for becoming an attractive production location (Hallward-Driemeier and Nayyar, 2017). At the same time, new technologies could reduce barriers to integration for less developed economies. For instance, issues associated with the lack of trust or weak property rights could be partly overcome with distributed ledger technology (DLT), and fintech could improve access to financing and lower transactions costs (IMF, 2017d).[8] That said, how countries' workers integrate into the global economy ultimately depends on global demand for different types of labor, which in turn depends on progress in automation (which itself may be affected by easier access to the pool of cheap labor).

- ***Market concentration.*** There is an ongoing academic discussion about the role of market concentration in driving the dynamics of labor shares, and whether technological advances could further increase the market power of leading firms (Box 3). Empirically, there is evidence suggesting that a rise in concentration has been correlated with soaring corporate profits (above a 'normal' rate of return measured as the product of the interest rate and the capital stock), which are a mirror image of the decline in labor shares. The increase in concentration could arise from demand- and supply-side economies of scale in high-tech industries, but could also reflect barriers to entry (which may be changing because of technology, being lowered in some cases and increasing in others, especially where emergence of large closed networks reduces opportunities for competition (IMF, 2017d)). Welfare implications potentially range from benign (concentration reflects economies of scale) to adverse (barriers to entry stifle innovation), and more work is needed to assess interactions with other sources of technological disruption.

- ***Fissuring of the workplace.*** Advances in ICT have redefined the boundaries of firms and the role of employees by splitting jobs into tasks and facilitating their outsourcing (Weil, 2014; Katz and Krueger, 2016). Some companies rely almost exclusively on external contractors (e.g., digital platforms such as Uber). The threat of outsourcing, in combination with factors discussed above, might have reduced the bargaining power of labor, likely also contributing to the lower labor share (Dube and Kaplan, 2010; Goldschmidt and Schmieder, 2017). This may produce efficiency gains by eliminating firm-specific wage premia (paid by high-wage employers to ordinary workers) and strengthening the correlation between individual wages and skills (Goldschmidt and Schmieder, 2017). But it could also mean less economic rent channeled to labor, less incentives for firms to invest in workers, and less learning-by-doing from exposure to co-workers with higher skillsets. On the other hand, the reduction in search costs and more flexibility in hiring and firing could increase employment opportunities for low-skilled (e.g., Berger et al. (2017) report a positive impact of the presence of Uber on local employment markets).

- ***Global demographics.*** Some regard the integration of China and Central and Eastern Europe into global labor supply as a key driver of wage dynamics (Goodhart and Pradhan, 2017). If so, population aging in these economies (and in AEs) could produce wage pressures, reverting the past decline in labor shares. This may, however, be counteracted by a potential expansion in the

[8] The need for trust remains. Rather than being replaced by technology, the focus of trust shifts from trust in traditional intermediaries (the "trusted third-parties") to trust in the network and underlying protocol.

(continued)

global labor force considered under the first bullet, or by technology-driven medical advances.[9] Demographic changes could also interact with the nature of technological change, with incentives for developing labor-saving technologies affected by the supply of labor, both domestic and global (Acemoglu and Restrepo, 2017).

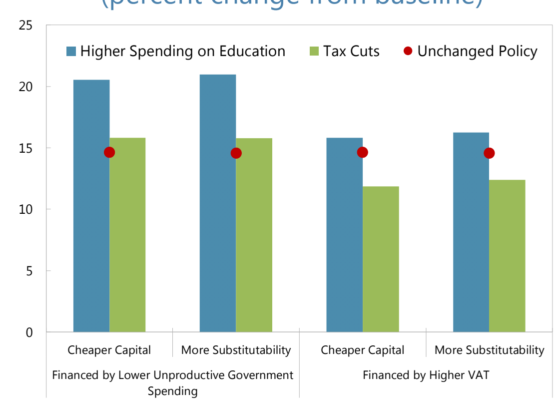
IV. POLICIES

20. This section looks into policies to better share gains from technology. The earlier scenarios illustrate the potential of technology to boost productivity and income growth. Where structural impediments stand in the way, harnessing this potential requires reforms to facilitate change and thus boost the growth potential (IMF, 2017b). But depending on societies' preferences with regard to the trade-off between equality and higher output, policies also have a role to ensure that the gains of growth are shared more equally. To that end governments can alter the distribution of market income through education and other human-capital formation policies (such as life-long learning), or they can adjust net incomes through the tax-benefit system.

21. Simulations illustrate gains and tradeoffs from policy responses. They are based on the same steady-state model discussed in the previous section and—for robustness—are conducted for both of the technology-driven growth scenarios considered earlier: a drop in the price of capital goods and an increase in the substitutability of capital for labor (in other words, the results from Section III.D function as the baseline).

22. Two policy responses are considered, along with two alternative financing assumptions (Box 4). First, increasing public spending on education to reduce the share of low-skilled workers in the economy and, second, a redistribution through differentiated income tax cuts that benefit primarily middle-income workers. Both policies are calibrated to cost about 2 percent of GDP, to be financed in two alternative ways. One type of financing posits a hypothetical cut in 'unproductive' government consumption, and another—

Figure 17. Spending on Education Boosts Income Gains; Gains After Tax Cut are Smaller but Sizeable
(percent change from baseline)



Source: IMF Staff Calculations.

[9] The impact of aging on the labor force has been cushioned by technological advances (in health, but also by facilitating female labor force participation, and reducing physical demands of work), making work possible beyond the official retirement age (Czaja and Moen, 2004).

perhaps more realistically—assumes financing through an increase in the VAT rate, which comes with efficiency losses for the economy.

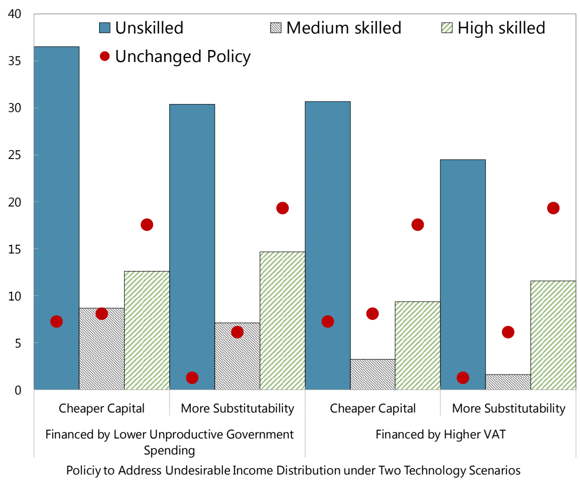
- ***Both policies maintain gains from the underlying advances in technology, while distributing them more evenly.*** As established earlier, either advance in technology raises the GDP level—by about 14½ per cent in the illustrative simulations presented earlier. If financed by cuts in unproductive public spending, higher education spending and income tax cuts amplify the gains from technology—bringing the rise in GDP levels to about 20½ and 16 percent, respectively (Figure 17). However, when redistributive income tax policies or human capital investment are financed through distortionary taxes, the implied efficiency loss could reduce growth. The simulations suggest that the negative impact is limited, leaving large income gains for all income groups.
- ***Education spending may be a particularly effective policy tool.*** In addition to raising the income of the low-skilled, it also lifts the level of GDP beyond the baseline by increasing the aggregate level of human capital in the economy. If it is financed by the increase in the VAT rate, low-skilled workers gain between 25 and 31 percent in income, depending on whether technological advances come in the form of lower capital goods prices or an increase in capital-labor substitutability (Figure 18). High-skilled workers' income increases between 9 and
- 12 percent in this case, while middle-skilled workers gain 2 to 3 percent (reflecting the tax incidence of the assumed VAT reform—higher education spending would be neutral for the middle-skilled if financed by cuts in unproductive spending). Of course, the simulation assumes that education spending is well targeted and enhances the human capital of the low skilled.[10]
- ***Taxation can help redistribute gains.*** Differentiated income tax cuts, by construction, are a readily available tool to help ensure that the gains from technological advances are shared more evenly. For instance, the simulations suggest that, following the middle-class-focused tax cut (of six percent for households with incomes close to the median, and decreasing to zero for those with incomes four times higher than the median), the gains of technological change would be shared more evenly across skill groups and roughly equally if the change is coming in the form of a drop in the price of capital goods (Figure 19).
- ***A combination of both could help minimize the risk associated with either.*** Skill investment tackles the root of the problem—equipping new generations of workers with the skills required to cope with technological advances, while shrinking the supply of increasingly redundant low-skilled labor. At the same time, the lasting effects of today's education policy decisions on the type of human capital future workers will be equipped with, combined with the uncertainty surrounding the type of skills future labor markets will actually need, mean that skill deficiencies may not be tackled effectively. Tax policies can provide some insurance against such risk by

[10] The impact of educational spending on students' outcomes have been extensively studied. Earlier literature questioned the efficiency of additional spending (e.g., Hanushek, 1986), but more recent studies indicate that increases in spending lead to higher wages and a reduction in the incidence of adult poverty (e.g., Jackson et al., 2015).

tilting the distribution of market income in favor of the relative losers from technological progress. As such, they can be a useful complement to education policies.

Figure 18. Human Capital Investment Disproportionally Benefits Low-Skilled Workers

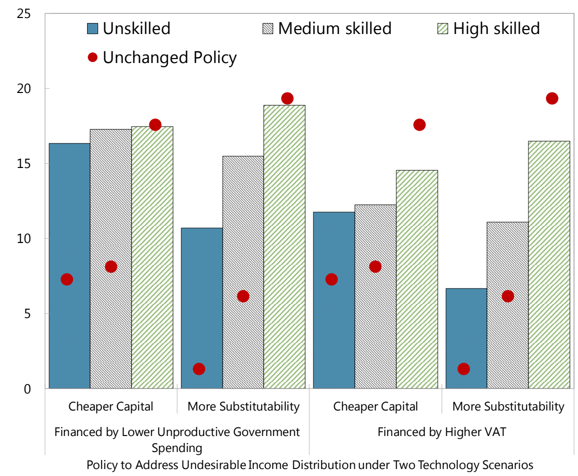
(percent change from the baseline)



Source: IMF Staff Calculations.

Figure 19. Taxes Redistribute Income Gains but not Equally

(percent change from the baseline)



Source: IMF Staff Calculations.

23. More work is needed to add further granularity to these policy approaches.

- ***Education policies.*** While spending matters, the quality and adaptability of education will make the difference in preparing workers for change. There is no one-size-fits-all policy solution. Given the high uncertainty about which skills are needed at any point in time, educational systems need to be flexible in responding to market demands. For instance, to equip future workers with skills to shift across occupations more easily, general education may need to re-focus on problem-solving and emphasize social skills, while new approaches could be necessary to provide and certify specific job skills, which will need to be replenished frequently. To facilitate transitions for those already in labor force, some countries have taken steps in promoting pre-emptive acquisition of new skills ("life-long learning") while overcoming credit constraints. For example, Singapore offers unconditional grants to all adults for training throughout their working lives. Moreover, labor force participation could be encouraged by changing norms related to gender roles, for instance by getting more women to enter STEM fields (science, technology, engineering, and math) (World Bank, 2012).

- ***Other forms of redistribution.*** In general, redistribution policies should be carefully designed to facilitate mobility and adjustment while minimizing the adverse effect on efficiency. In this context, Universal Basic Income (UBI) has received growing attention, seen as an instrument for addressing income declines and uncertainty generated by the broad impact of technological change on jobs across qualifications. However, a UBI would, by design, cover higher-income groups, generating important fiscal costs. Furthermore, if a UBI was to replace existing social benefit systems, then the impact on lower-income households should be carefully assessed, especially where current systems are progressive as is the case in many advanced economies. Regarding taxation, policies could consider increases in capital income taxes, in countries where they or some of their components (e.g., capital gains) are taxed very lightly, although the optimal rate may remain below the one on labor income. Consumption taxes, such as VAT will maintain their role as efficient sources of revenue. While the VAT should be kept simple with a single rate, excises on luxury goods can be used to increase the progressivity of the tax system, especially should the taxation of labor become more difficult. Property taxes, especially on real estate, could also be raised where they are currently low, improving progressivity while being very efficient, as levied on an immobile base.

- **Policies to facilitate change.** Given potentially costly transitions, 'enabling' policies should focus on reducing adjustment costs by (1) facilitating labor reallocation (e.g. through easier employment protection legislation (EPL) together with a stronger, but temporary, unemployment safety net), and (2) shortening periods during which labor remains idle (options could include making social benefits more portable, well-designed active labor market policies, minimum income payments and relocation grants for those willing to move within countries to areas with greater employment opportunities).

24. Complementary policies can provide additional benefit. This is especially important if technology is driven by other factors than those captured in the scenarios described above. For instance, the acquisition of skills may do less for the distribution of gains if these gains, at least in part, come from growing market concentration.

- ***Economic integration.*** Despite advances in technologies such as DLT, sound policies will continue to be critical for fast income convergence, including transparency and good governance, supporting openness and competition, protection of property rights, and investment in human capital. More generally, there are clear benefits from improving market access through connectivity and mobility, and a general strengthening of educational institutions (Hallward-Driemeier and Nayyar, 2017).
- ***Market concentration.*** In general, competition policies such as product market entry regulation and anti-trust enforcement will need to strike a balance between incentivizing innovation and exploiting efficiency gains. For example, if restrictions to the access of consumer data turned out to create new barriers to entry in some segments of the economy, strengthening property rights to personal data (or making them portable across digital platforms) could help reduce and redistribute the associated rents. In general, different sources of excess market concentration must be addressed by different policies. While network effects may create rents and redistribute gains away from labor, total welfare may be higher than if a network industry is broken up and network benefits are no longer available (Economides, 2006).

- ***Fissuring of the workplace.*** More flexible forms of employment promoted by 'search and matching' technologies could amplify the distributional impact of other factors reducing the bargaining power of labor (such as automation or economic integration). But flexibility could also be beneficial as it may facilitate low-skilled employment. Therefore, government interventions needed to ensure that these opportunities become decent jobs should be carefully evaluated in light of this tradeoff.[11] Related to this, less stable employment relations put a premium on social safety nets and educational opportunities centered on workers rather than jobs. While many elements of the social safety nets in AEs are already de-linked from jobs, this is not the case universally. Finally, employer-provided training may need to be replaced or substituted by other schemes, with implications for active labor market policies.

V. IMF WORK ON TECHNOLOGICAL CHANGE

25. There is a wide array of IMF work related to the economic impact of technological change. The flagship reports have looked at the impact on jobs, including on labor income shares (IMF, 2017a) and wage dynamics (IMF, 2017c). As technological change affects income inequality, the IMF's broader work on inclusion and its link with growth is also highly relevant (IMF, 2014). Moreover, IMF (2017e) considers policy options to address inequality in the context of technological change, including for redistribution and better access to health and education. And the IMF has been working on the impact of digitalization on statistics (IMF, 2017f; IMF, 2018a) fiscal policy (Gupta et al. 2017; IMF, 2018c; IMF, 2018d), and the implications of emerging technologies for financial stability, regulation and central banking (Fintech) (IMF, 2016; IMF, 2017d; IMF, 2018b). This analytical work feeds into the Fund's support for its members through surveillance, lending, as well as capacity development, such as training (on inclusive growth and fiscal policies) and technical assistance (such as on tax policy and income redistribution).

26. Going forward, more work is needed to better understand challenges from technological advances and develop appropriate policy responses. The impact of technological change raises a host of macro-relevant issues, which staff will be exploring, including in collaboration with external partners. The Fund will continue current work streams, including further work on the digitalization and fiscal policies (IMF 2018d; IMF 2018c), the impact of fintech, including on financial inclusion (IMF 2018b), and regional work (e.g. the future of work in Africa will be discussed in the Fall Regional Economic Outlook). In addition, the impact of less-understood technological drivers demands further attention. In this context, IMF staff is working on the assessment of the impact of firm market power on innovation and productivity, and on the assessment of the impact of labor market institutions on labor shares. More broadly, staff is also working on a strategy to assess the global economic implications of rapid digitalization, aiming to draw implications for the Fund's work and the steps needed to fulfil its mandate. This work will feed into multilateral and country surveillance to guide policy recommendations.

[11] Lordan and Neumark (2017) find that increasing the minimum wage decreases significantly the share of automatable employment held by low-skilled workers, and increases the likelihood that low-skilled workers in automatable jobs become unemployed. Cette et al. (2017) find that strengthening employment protection legislation result in more capital-to-labor substitution in OECD economies.

Box 1. Measurement of Growth and Productivity in a Digital Economy

Digitalization has disrupted traditional ways of doing business and given consumers access to free, low-cost, or time-saving alternatives. It has also expanded their access to product varieties and information and allowed self-service to replace tasks formerly done by market producers. These changes have raised questions about whether growth and productivity are being correctly measured and about whether additional indicators of welfare gains are needed. Another question is whether price measures for ICT goods and services are capturing the quality improvements made possible by advances in digital technology.

Research by the IMF and the OECD on the measurement controversies sparked by digitalization finds that many of the criticisms of GDP statistics reflect misunderstandings of what GDP is supposed to measure, or involve effects that are small. The market output concept covered by GDP is well-suited to key uses of GDP (such as understanding conditions affecting employment, investment and government revenue), but it should not be interpreted as a broad measure of welfare. Thus, if growth of welfare from consumption linked to digital goods and services has outstripped GDP growth, this would not necessarily mean that the growth statistics are wrong. Furthermore, experimental measures of values of the free media and free smartphone apps show that they amount to at most a small fraction of household final consumption.

Adjustments to deflators for ICT products to better measure quality improvements may add up to 0.2 percentage points per year to GDP growth rates of advanced economies, raising the estimate of the maximum potential effect of measurement errors related to digitalization on GDP and labor productivity growth to perhaps 0.3 percentage points. Although an upward adjustment of 0.2-0.3 percentage points would be significant in a slow growth environment, it could not explain the productivity slowdown because similar measurement errors were present before the slowdown began. Furthermore, the effect of mis-measured deflators on total factor productivity (TFP) is smaller than their effect on labor productivity because corrections to the deflators for ICT goods and services would affect the growth rate of inputs of capital services (which are a subtraction in the calculation of TFP).

Multinational enterprises active in the digital economy sometimes domicile their intellectual property in tax-advantaged offshore jurisdictions, and attribute much of their global production to the affiliates that own the intellectual property. This could cause underestimation of GDP in high tax jurisdictions, and, relatedly, underestimation of the weights on ICT activities in GDP deflators (making it difficult to correct those deflators to take better account of quality improvements).

The IMF and the OECD are continuing joint research on issues related to the measurement of the digital economy in macro-economic statistics. One topic being looked at is the sensitivity of measures of inflation and consumption growth to possible adjustments for substitution to lower-cost and improved digital economy products. The IMF is also participating in OECD expert groups on national accounts for a digitalized economy and on balance of payments statistics on digital trade.

Box 2. Substitutability Between Robots and Humans—Impact on Income Distribution

A dynamic CGE model illustrates how the use of robots can impact the income distribution. Two scenarios illustrate outcomes under less and more substitutability between humans and robots.[1]

The model aims to capture some macroeconomic effects of new technologies. It does not make specific quantitative predictions, because the range of uncertainty is too large. Rather, the model's goal is to explore some of the implications of incorporating robots in a standard growth model, in particular the implication of technologies that may be able to substitute for humans across a wide range of activities—physical and mental, routine, and not-so-routine.

Robots are modeled as a new capital that is a close substitute for labor. This approach supposes that a new industrial revolution introduces a new type of capital—robots—into a growth model in which output is a function of labor and capital. The critical feature of this robot capital is that it is a close substitute for labor; in other words firms can readily replace humans with robots.

Some skills will be more replaceable than others. Realistically, there will remain tasks in which robots cannot replace humans at all. For simplicity, workers that robots can replace are labeled as "low-skilled," and those whose productivity is rather enhanced by robots are labeled as "high-skilled."

Two scenarios consider less and more substitutability. The baseline assumes that production requires combining traditional capital and high-skilled labor with robots and low-skilled labor (e.g., a warehouse and a supervisor, combined with warehouse workers and robots). In addition, robots and low-skilled labor are substitutable, but the degree to which this is the case is difficult to pin down. In light of this uncertainty, we consider alternative scenarios that illustrate the main forces at work—one where robots are not a very close substitute for labor and one where they are.

The main finding is that robots are good news for growth and bad news for income inequality. The more robots substitute for low-skilled labor, the more they boost economic growth but the more they increase income inequality—possibly even leading to sustained (absolute) income losses for the low-skilled:

Relatively low substitutability. In a scenario where robots can replace labor only to some degree, the model assumes that a 1 percent increase in the wage of low-skilled workers would lead businesses to increase the ratio of robots to low-skilled labor by 1½ percent (for a given level of output and holding other factors constant). (Note: This is at the high end of the range of available estimates for traditional capital.) The growth model can then be calibrated to ask what happens when robots become cheap and effective enough to compete with low-skilled labor.

1/ See Berg et al. (2018) for the discussion of the model and additional simulations.

Box 2. Substitutability Between Robots and Humans—Impact on Income Distribution (concluded)

- **GDP growth benefits all workers, but the less skilled gain less.** Within 30 years, GDP it about 10 percent higher relative to a no-robots baseline. Wages rise for both workers, but the increase is significantly higher for the high-skilled. Because the competition between robots and low-skilled labor is not too fierce, the higher productivity of robots and resulting increase in the supply of traditional capital leads to a small increase in the real wage of low-skilled workers. The wage of high-skilled workers goes up by a lot more because they benefit directly from the availability of robots. As a result, the overall labor income share is broadly constant and it shrinks modestly—by about 2 percent of GDP—for the low-skilled.
- **Why do robots not create a bigger boom in this scenario?** Robots are potentially pro-growth because they can replace workers, in effect adding to the total stock of available labor. Capital can be built without limit. Therefore, robots lead to more capital of all sorts, and more output per worker. Because the ability of robots to replace workers is limited, it is ultimately the supply of workers that determines overall growth.

Higher substitutability. An alternative scenario assumes that a 1 percent increase in the wage of low-skilled workers would lead businesses to increase the ratio of robots to low-skilled labor by 4 and half percent, enabling a much more aggressive replacement of workers.

- **Growth is higher, but at the expense of a large rise in income inequality.** Robots raise the productivity of both traditional capital and high-skilled labor (for the warehouse example, robots in the warehouse make the warehouse itself and its manager more productive and hence more valuable). Investors respond by building more traditional capital as well. All this raises output by about 30 percent over 30 years in this simulation and the wage of high-skilled workers by even more. However, the wage of low-skilled workers *falls* substantially and persistently, by over 20 percent in real terms after 30 years. There is a direct effect as competition with the robots drives down their wage. Indirect effects stemming from faster traditional capital accumulation do help, but provide only a small offset.
- **Why are low-skilled so adversely affected?** With traditional technological change, improvements in technology make capital more productive, and the higher capital stock increases the productivity and demand for all workers, such that the wage eventually rises. Here, direct competition with robots overwhelms this channel. Furthermore, as robots compete effectively with labor, the overall share of income going to capital (robots and traditional capital) increases—from 40 to about 50 percent after 30 years. If little income from capital (robot or traditional) goes to unskilled workers, overall inequality thus goes up substantially

Box 3. Technology and Market Concentration

Growing market concentration—one of the possible factors behind the fall in labor share of income—can be driven by technology. Its welfare implications can be benign or adverse.

Several studies attribute the decline in the labor share to growing market concentration. Barkai (2016), Autor et al. (2017), and De Loecker and Eeckhout (2017) attribute the decline primarily to firms' growing market power, translating to higher markups. For instance, Autor et al. (2017) report that a rise in sales concentration in most U.S. industries is correlated with declines in labor shares (as more profitable firms—with lower labor shares—increasingly dominate the industries). They also link the decline in the labor share to globalization and technological change, which can provide an advantage to the most productive firms in each industry. These patterns are also observed in other OECD countries (Autor et al. (2017)).

Technology can drive concentration. Many tech industries are characterized by both demand-side economies of scale (known as "network externalities" or "network effects") and supply-side economies of scale arising from large fixed costs and small (or even zero) marginal costs (Guellec and Paunov, 2017). This combination creates a 'concentration feedback loop,' as more sales lead to lower unit costs and more appeal to new customers. Moreover, switching costs (i.e., changing software) are often high for consumers, and data gathered by incumbent firms allow them to better analyze consumer behavior, maximize profits through price discrimination, and ward off competitors.

Welfare implications range from benign… Concentration can be driven by an increase in product market competition, which allows higher-productivity firms capture a larger share of the market (Autor et al. (2017)). Dominant firms can also be swiftly replaced by others in a neo-Schumpeterian model of creative destruction (Aghion and Howitt, 1992). And dominant incumbents are sometimes more likely to innovate than entrants (Gilbert and Newbery, 1982; Acemoglu and Hildebrand, 2017).

…to adverse. Higher concentration could arise when incumbents are protected by barriers to entry, for instance with a weakening of anti-trust enforcement or stricter occupational licensing (Kleiner and Krueger, 2013) and there is evidence that distortions inhibiting competition play a role in driving concentration (Gutierrez and Philippon (2016) and Gutierrez and Philippon (2017)). And while Autor et el. (2017) find that industries that are becoming more concentrated are those with faster technological progress—which suggests that they are legitimately competing on the merits of their innovations or superior efficiency—they could imaginably use their market and lobbying powers to erect barriers to entry to protect their position in the future.

Box 4. Policy Options

Model-based simulations illustrate how adverse distributional impacts of technological change can be mitigated by policy responses.[1]

Two kinds of technological change. As discussed in the Section III.B, the model, based on (Lizarazo Ruiz et al. 2017), analyzes steady-state impacts of two possible sources of technological change: A further decline in the relative price of investment; and an increase in the elasticity of substitution between capital and labor. Simulations show a positive impact on aggregate income, but it disproportionally benefits the high-skilled, particularly when there is higher substitutability of capital and labor.

Policies. Two alternative policies are considered for each scenario to spread the GDP gains more evenly: Redistribution through higher education spending leading to improvements in human capital for low-skilled workers; and differentiated income tax cuts. For simplicity and to better understand the underlying mechanisms at work, the model assumes that these policy interventions are financed either by reducing unproductive government consumption, or by an increase in the VAT rate (the latter has an efficiency cost):

- **Higher education spending.** The model assumes a 4 percentage points reduction in the share of low-skilled workers, 2 percentage points of which become medium-skilled and the other 2 become high-skilled. Based on data on education costs in the U.S.—the economy used here to calibrate the model, the cost of such a change can range from 1 to 3 percent of U.S. GDP. We use a mid-point estimate of 2 percent of GDP. This calibration implies that financing this policy requires an increase of 2.5 percentage points in the VAT rate relative to a no-education-policy-response baseline.
- **Tax cuts.** We assume a reduction in effective income tax rates of 6 percentage points for households with incomes close to the median, and gradual but rapidly declining cuts for households with higher incomes (a cut of 2 percentage points for households with three times the median income and no cut for households with incomes above 4 times the median). The revenue cost of this measure is equivalent to about 2 percent of GDP (so also equivalent to 2.5 percentage point increase in the VAT rate).

Both policies maintain (or even boost) income gains from technological advances. When financed through cuts in unproductive public spending, the improvement in human capital boosts GDP gains from 14½ percent (impact of technological change alone) to 20½-21 percent (combining the impact of technological and policy changes), while the tax cut results in GDP gains of about 16 percent. Financing these policies by an increase in the VAT rate—given its efficiency cost—reduces the gains to about 16 percent for human capital improvement, and to 12-12½ percent for tax cuts.

Higher education spending is a more efficient policy option. Adding to the human capital of low-skilled workers allows them to profit from technological progress. It also makes low-skilled workers more scarce, boosting their wages. The tax cuts, by construction, help

redistribute asymmetric gains, spreading them roughly equal across skill groups. This policy is less efficient, changing the income distribution ex-post.

While indicative of potential gains, the results must be interpreted with caution. This is because the model is relatively simple and simulations illustrate only two potential paths for technological change.

1/ See Lizarazo, Peralta-Alva, and Puy (2017) for the description of the model.

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