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The future of work: how G20 countries can leverage digital-industrial innovations into stronger high-quality jobs growth

Marco Annunziata and Hendrik Bourgeois

Abstract

The wave of digital-industrial innovation which begins to disrupt vast sectors of the global economy has fueled fear of a potential adverse impact on jobs and wages. This paper argues that digital-industrial innovations make human capital more important than ever and the focus needs to shift to the complementarity between new technologies and human abilities. In particular, more effort should be devoted to (i) understanding what new skills will be needed, and how existing jobs will change; (ii) upgrading education and professional training schemes; (iii) reforming labor market institutions to support a future where a larger share of workers will change jobs and employers more frequently; (iv) reforming social benefits systems and bolstering social safety nets to smooth the economic transition and cushion the impact on the worst-affected workers. This paper presents an analysis of the challenges, addresses the key areas of action, and puts forward specific proposals, including policy actions, industry initiatives, and further research projects. The authors argue that the G20 could and should champion a comprehensive approach to leverage digital-industrial innovations for faster job creation and growth, with initiatives to re-align demand and supply of skills, labor market reforms, redesigned social safety nets, measures to promote digital innovation and facilitate the adoption of skills-augmenting technologies, and strengthened private sector training programs.

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Authors

Marco Annunziata, Annunziata + Desai Advisors, annunziata.sf@gmail.com
Hendrik Bourgeois, Cargill

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Introduction

The global macroeconomic environment today seems characterized by greater uncertainty than ever before. The massive disruption of the Global Financial Crisis has been followed by an unprecedented monetary stimulus by major central banks—extraordinary in its size, shape and duration. The normalization of monetary policy has just begun, and has already started to send waves of volatility through financial markets. Rapid economic growth in emerging markets has brought about a significant rebalancing in the global economy, upsetting traditional equilibria, displacing workers in some advanced economies industries, and fueling protectionist pressures. Technological innovation has accelerated, disrupting a growing number of industries, while at the same time productivity growth decelerated sharply across OECD economies. Prominent economists have questioned the validity of long-standing theoretical frameworks and policy tools.

This also carries unprecedented uncertainty for labor markets across the globe. Many governments have achieved a remarkable degree of success in boosting employment levels following the Global Financial Crisis: the US and Japan are back at full employment—in fact, in the U.S. there are now fears of overheating, unemployment rates have declined substantially across Europe, though they remain elevated in some countries, and large emerging markets keep creating employment opportunities for their fast-growing populations.

This success, however, has been accompanied by growing concern about the quality and sustainability of job creation. Even as labor markets tightened, the pace of wage growth has remained muted, fueling fears that a rising share of new jobs might be "low-quality" service sector occupations providing only low incomes and limited career opportunities. More recently, we have seen some first signs of stronger wage growth in the U.S., but not in itself sufficient to quell concerns about the quality of new jobs.

At the same time, the accelerated pace of innovation brings a new set of challenges. In advanced economies, technological change has already displaced some sections of the workforce, though global competition and, in some cases, market rigidities have also played an important role. In emerging markets, the possibility of automation poses a rising threat to low-cost, low-skill workers. The potentially disruptive impact of technology on jobs features prominently in the media, most often with alarmist headlines, and contributes to feed insecurity in the workforce, particularly among those categories of workers who have experienced very slow wage increases so far. In addition, technology driven impacts on labor markets are fueling populist political reactions, prone to blame and oppose liberalization, trade, immigration, and free markets.

Fear that technology will create massive unemployment is not new. In the early 19th century, workers in France would throw their wooden shoes, called "sabots" (clogs) in the newly introduced textile machines to break them so to preserve their employment. Allegedly, this practice lies at the origin of the word 'sabotage'. In the coming years, however, technological innovation is likely to have a much more significant impact on the workforce. We are in the early stage of a digital-industrial revolution, as new digital technologies are beginning to transform industries: traditional industrial assets become intelligent interconnected devices, new

production techniques like additive manufacturing revolutionize the way we design and build products, the widespread use of sensors and big data transforms the way that work is carried out on factory floors and in many other sectors of the economy, including the services and agricultural sectors for instance . Advances in robotics and artificial intelligence will further propel this transformation.

These changes have already fueled concerns that innovation will cause permanent mass unemployment and a significant further widening of income inequality. Bill Gates recently argued that it might be desirable to slow the pace of innovation;[1] others have advocated the adoption of Universal Basic Income schemes. In 2016, the European Parliament proposed a report which considered the need to introduce corporate reporting requirements on the extent and proportion of the contribution of robotics and AI to the economic results of a company for the purpose of taxation and social security contributions (European Parliament 2016).

Yet the evidence runs counter to the prevailing narrative that new technologies are already causing job losses on a massive scale. As mentioned above, employment levels have risen strongly, while labor productivity growth has slowed to a near stand-still across the OECD since the financial crisis, the opposite of what the simplistic automation narrative would suggest.
The risk that new technologies will displace jobs, and potentially eliminate some of the current categories of employment, has to be taken seriously. There is in fact a very high probability that technological unemployment will rise in the coming decades. In addition, we do have to consider the risk that –even as new jobs are created—technological displacement might result in a *net* loss of jobs for a period of time. More importantly, the nature of many occupations, the way in which many jobs are performed, is likely to change significantly. We argue that more attention and study need to be devoted to the way in which jobs are likely to change, and to what steps can be taken to facilitate the transition and to build the right supply of skills. This includes addressing the current demand for skills, and trying to build a bridge to the future and different skills demand.

The U.S. manufacturing sector provides significant evidence of a skills mismatch: there are numerous reports of companies struggling to find qualified employees for specific skilled factory floor positions (Mutikani 2017), and the aggregate data show a widening gap between job openings and hires in manufacturing. Similar challenges have emerged in Australia and other countries (Burgess 2017). This suggests that the main risk is not widespread automation and rising unemployment, but rather a growing mis-match between the skills demanded by a rapidly evolving economy and those supplied by an education system that struggles to keep pace. Automation and skills-mismatch are closely intertwined: the automation of some tasks often requires workers to acquire new skills as the content of their jobs changes; and companies unable to find enough workers with the right skills will have a greater incentive to invest in automation.

We argue that throwing sands in the wheels of innovation would be misguided and counterproductive. Innovation remains the key to sustained economic growth and rising living standards. We also argue that technological change will ultimately result in more and better

[1] https://qz.com/911968/bill-gates-the-robot-that-takes-your-job-should-pay-taxes/

jobs—as it always has in the past. Accordingly, rather than slowing it down, we should continue fostering and enabling innovation, and stay ahead of the curve by anticipating technological changes that are bound to occur. This time, however, it will be even more important to manage the transition effectively, because this new digital dimension promises to make innovation in industry faster and more disruptive than in the past. This will require action on two fronts: (a) measures to enable the employment- and wealth-creating potential of new technologies; and (b) measures to cushion the social impact of inevitable transitory disruptions.

The digital-industrial revolution is already changing the demand for skills that the workforce needs to succeed in manufacturing and other areas of economic activity. Moreover, to capitalize on this revolution and turn it into a competitive advantage, it is important to better prepare the workforce to promote the quick absorption of this new technology in the economy. The challenge ahead is to understand this evolving trend and design a system of education and training able to endow workers with the necessary abilities, and to equip our economies with the appropriate flexibility and support mechanisms to allow companies, workers and societies to adapt quickly and successfully to the faster and deeper changes in front of us.

Technology's impact on jobs: understanding the challenge

During the past 10–15 years, a number of academics and practitioners have analyzed the impact of technology on jobs. Research on the topic has made significant inroads, notably in documenting how technology can lead to the automation of a growing number of tasks across a wide range of occupations, and showing that while the overall number of jobs that can be totally automated is probably smaller than feared, there will be a deeper and broader transformation in the nature of many jobs, resulting in a growing skills mismatch. However, more research is needed to better understand how the growing skills mismatch will manifest itself, and what actions can be taken by individuals, firms and governments to better manage the transition. This should include a better understanding of how new technologies can augment workers skills and help to both make some existing jobs more productive and create new jobs.

Most of the academic literature begins by focusing on the concept of "task" – recognizing that jobs involve the combination of a number of different activities. A first strand of the literature divides task in "routine" and "non-routine". Routine tasks are defined as activities that can be well described by a codified set of instructions. By their nature, these are more likely to be successfully executed by a computer—in the case of "cognitive" tasks—or by a robot—in the case of "manual" tasks.

Autor et al. (2003) show how a decline in jobs involving routine manual and cognitive tasks became apparent in the 1980s and had continued since. They also note a stabilization in the number of jobs involving non-routine manual tasks, that is jobs that require interpersonal interaction, situational awareness and the need to respond flexibly and rapidly to changes in the environment. Autor and Price (2013) confirm an increase in these jobs starting about 2000. Both studies also show a stabilization in the number of non-routine cognitive tasks, those requiring

managerial or analytical skills; though Autor and Price note a marginal decline between 2000 and 2006, followed by a modest rebound through 2009.

These studies and others confirm an intuitive insight: computers and other machines are usually better than humans at repetitive tasks in a controlled environment; when we can, we tend to delegate those tasks to the machines.

Frey and Osborne (2017) take the argument one step further. They note that thanks to advances in Artificial Intelligence (AI) and Machine Learning (ML), machines no longer need to be given step-by-step instructions in order to perform a task—they can learn by themselves just by absorbing enormous amounts of data on how a task is performed. Frey and Osborne cite self-driving cars as a case in point. The task of driving a car in varying conditions is way too complex to be described by a set of instructions, and self-driving cars were once considered science fiction. Today they are a reality.

Artificial Intelligence could therefore greatly expand the range of tasks that will be taken over by machines. Frey and Osborne take a detailed look at the universe of existing jobs in the U.S., based on the Bureau of Labor Statistics classification. They assume that advances in AI and ML will proceed at the same pace as in the recent past, and from there infer which tasks are likely to be automated in the coming years (Frey and Osborne do not give a definite time scale, but a couple of decades is seen as a plausible horizon). They conclude that 47% of existing U.S. jobs are at high probability of becoming automated (where high is defined as 70% or higher).

The Frey and Osborne study is probably the most widely quoted, but it is not the only one to give a dismal picture of future employment trends: A recent PwC study (Berriman and Hawksworth 2017) estimates that 38% of U.S. jobs are at high risk of automation; other advanced economies fare little better, with 35% of jobs at risk in Germany, 30% in the U.K. and 21% in Japan. The World Bank's 2016 World Development Report estimates that 57% of jobs in OECD countries could be automated in the next two decades. Taken together and at face value, these studies paint an alarming picture, and media reports have often jumped to the conclusion that between one-third and one-half of existing jobs across advanced economies will be eliminated by technology within a fairly short time span.

Acemoglu and Restrepo (2017) develop a model where robots and humans compete, and compute a measure of "exposure to robots" to estimate the impact on employment and wages in different industries and commuting zones. They estimate that robots have displaced between 360,000 and 670,000 U.S. jobs between 1990 and 2007. While this number was immediately picked up in alarmist tones by the press, the data show that over the same period the U.S. economy created on a net basis about forty times the top-range estimate of those taken by robots. Aware of this, Acemoglu and Restrepo concede that "…the number of jobs lost due to robots has been limited so far…" but argue that this is because "…there are relatively few robots in the U.S. economy…" and that a plausible scenario would see both the number of robots and the number of jobs lost accelerate significantly in the future. Robotics provide an especially powerful example of how digital innovation can power mechanical technology advancements across industries.

Other research, however, points to a different conclusion. A recent paper by Graetz and Michaels (2017) analyzes the impact of robots on jobs across a sample of seventeen countries;

they find no evidence of a negative impact on overall employment levels, though they do find an adverse effect on low-skilled workers. Building on their analysis and dataset, Andes and Muro (2015) point out that countries that use robots more intensively appear to have suffered a smaller loss of manufacturing jobs than less robot-intensive countries.

The assessment of the impact of technology on jobs is complicated by the fact that labor markets in the U.S. and other advanced economies have been impacted by other concomitant shocks, most importantly an acceleration in global trade flows with increased competition from China and other emerging markets. A parallel strand of the academic literature has endeavored to assess the impact of trade on jobs.

Autor et al. (2013) analyze U.S. commuting zones to assess the effect of exposure to Chinese imports; they estimate that competition from Chinese imports accounts for 44% of the decline in U.S. manufacturing employment between 1990 and 2007; in the more recent part of the sample, 2000–2007, they estimate that 55% of manufacturing jobs lost were displaced by Chinese imports. They find that local labor markets more exposed to China's competition also experienced a decline in labor force participation as well as an increase in disability benefits and other transfers over the 2000–2007 period. Caliendo et al. (2015) estimate that nearly one third of the U.S. manufacturing jobs lost between 2000 and 2007 (800,000 out of about 3 million) were displaced by competition from Chinese exports to the U.S. (though they also note that cheaper imports of Chinese intermediate inputs and consumer goods were instrumental in fueling a similarly-sized jobs growth in other sectors of the economy).

This review of the literature suggests that we are far from a fully satisfactory understanding of the impact of new technologies on jobs. The main takeaways, in our view, are:

- The evidence available to date supports the idea that innovation will lead to stronger overall job creation in the long run, by boosting economic growth and purchasing power and enabling the rise of new jobs. This is consistent with the historical experience of the past two centuries.
- Some categories of jobs have already been displaced, however, and others are at risk (truckdrivers threatened by autonomous vehicles are an obvious example). Wider sections of the workforce will be impacted as technology changes the way that their jobs are carried out and the tasks they involve.
- Innovation will continue to change the distribution of available jobs across industries, the types of jobs available and the skills required. This disruption is set to accelerate with the faster adoption of robotics, artificial intelligence, and additive manufacturing—just to name three prominent new technologies impacting industry, all driven by digital innovation.

An increasing number of *tasks* will be automated or modified by new technologies; this holds the key to a better understanding of how jobs will change. Too often the public debate is dominated by fears that innovation will cause a sharp rise in unemployment, equating a job's share of tasks that are at risk of automation with the probability that the entire job will be

automated. This generates dramatic media headlines, but misses the more complex and nuanced relationship between human abilities and technological capabilities:

- There will be jobs where over 50% of the tasks can be automated, but the minority share of tasks that cannot be automated is crucial to the nature of the job itself; this could lead to a situation where the worker keeps the job, outsources some of the tasks to the technology, and takes on additional—in some cases more interesting and rewarding—tasks that become part of the reconfigured job description in a way that need not imply any job loss.
- In other cases, the automation of a share of the tasks might instead lead to a consolidation of responsibilities and a reduction in the number of jobs. To take a simple example, suppose a situation where two-thirds of the tasks in a job are automated and a worker is then able to perform the work previously carried out by three workers. This could lead to a direct reduction in headcount by two-thirds; which could however be compensated by the attendant improvement in competitiveness generating additional demand.

Moreover, to put these fears of mass unemployment in perspective, consider that (1) these new technologies have already been gaining traction for several years; and (2) researchers have been drawing attention to its impact for nearly twenty years now. The job-displacing impact of new technologies should therefore be already visible. Yet, as we noted above, employment levels have risen across a wide range of countries, including those closest to the technology frontier.

The McKinsey Global Institute has recently published two in-depth studies (Manyika 2017a, Manyika 2017b; see also Chui et al. 2016) that assess how technological innovation will impact overall employment, the mix of jobs and the structure of individual jobs. The studies strive to estimate both the job-destroying impact of innovations (through automation) and the job-creating impact (spawning new activities or raising the productivity of existing ones), in line with past experience: they note, for example, that the advent of computer technology has eliminated many data collection and inputing jobs, but has created many more jobs for financial analysts, business analysts and others, given the greater opportunity to convert data into insights. The studies also consider how ongoing economic growth will continue to raise demand for goods and services—and therefore labor—as well as the potential impact of additional investment in infrastructure and energy sustainability.

The McKinsey studies find that on balance affected economies should be able to maintain full employment, as job-creating forces balance job-destroying automation; they warn, however, that the magnitude of the labor market disruption ahead is substantial, on a par with the first industrial revolution. It is worth highlighting in this context a few key findings of their analysis:

- The greatest impact will come through the transformation of jobs rather than the elimination: the studies estimate that less than 5% of existing jobs could be entirely automated, but for 60% of existing jobs one-third of the tasks could be automated;

- The speed of this disruption is highly uncertain, and will depend, among other factors, on how quickly new technologies are deployed across industries;
- For advanced economies, the studies predict a continued decline in routine manual and cognitive tasks, and an increase in jobs that require interpersonal or managerial skills, or creativity, broadly in line with Autor et al. (2003) and Autor and Price (2013). For the U.S. and other advanced economies, this should imply a decline in jobs that require only secondary education or less, and will increase the risk of further polarization in the income distribution. In emerging markets, conversely, the studies find that strong growth in demand for goods and services from a burgeoning middle class should fuel a sustained rise in middle-skill jobs requiring at most a secondary education.
- The studies emphasize that to facilitate the transition it will be extremely important to fuel strong economic growth, ensure labor markets are flexible and dynamic, and invest more in education and training, to accelerate the reskilling and redeployment of workers displaced by innovation.

A strategy to cope with this challenge, we believe, should be guided by a collaborative research effort involving not just universities, think tanks, and government research institutions, but also companies drawn from different areas of technology, manufacturing and services, as well as national and international policy institutions. Further research needs to go down "into the trenches", to understand how existing job functions are already changing; which technologies are proving most helpful to workers on the factory floors, and what individual characteristics or training programs make workers more or less successful at adapting to the new technologies.

This research could help improve awareness and provide both companies and governments with a common baseline to share best practices, laying the ground for a coordinated—and therefore more effective—policy and awareness effort. G20 policymakers could play an important driving role. At the policy level, this could also help promote common standards in the measures to adopt to benefit from new technological developments ensuring interoperability across markets where needed. These new technologies are based on platforms, ecosystems and collaboration frameworks—international cooperation, standards harmonization and interoperability will be essential to maximize the benefits and minimize the disruptions. It could also provide the basis for a more constructive public awareness campaign, steering the public debate away from sterile alarmism while equipping students and workers with tools to better understand the challenge ahead and prepare for it.

Human capital as the crucial resource

The focus in both the research and the public debate tends to be on the threat that new technologies will displace human labor, overall or for individual tasks—and as we argued above, this risk needs to be taken seriously. But the faster pace of innovation also places human

capital front and center of corporate strategies, as companies will face new and changing requirements for human capital:

- Some of these technology changes require new skills because they result in the convergence of different disciplines: digital-industrial innovations will require a mix of traditional mechanical skills and new software skills.
- Some of the new manufacturing techniques require a new way of thinking: additive manufacturing can bring maximum benefit only if products are designed in new ways. This can often be best achieved by product designers whose thinking has not been shaped by the traditional manufacturing methods.
- Since changes in technology and business models are reshaping the competitive landscape, companies can now benefit from 'cross-over talent': people who have work experience across a variety of different fields
- As changes in technology and business models become faster and less predictable, companies need greater flexibility in tapping and deploying human capital.

This is happening at the same time as technology breakthroughs show the potential to alleviate the constraints on some traditional resources, such as energy. And at the same time as some industries face the challenge of an aging workforce, with large cohorts of experienced workers set to retire in the next decade; while education and training systems struggle to keep up with innovation.

Human capital will therefore be the scarce resource of the future, and the ability to tap and deploy workers with the right skills will be a key factor of success.

Skills-augmenting technologies

While the public debate has focused on the risk of technologies displacing workers, on the "race against the machine" view, innovation has already generated a number of new skills-augmenting technologies that can augment the efficacy and productivity—as well as the safety—of workers at different levels of the skills distribution; and they can facilitate and accelerate the learning of new skills on the job as well as the transmission of knowledge and expertise across the workforce.

An especially powerful example is the development of upskilling technologies: portable and wearable digital devices that can augment the abilities of workers at different levels of the skill distribution, and that are already being deployed on factory floors. For example, augmented-reality smart glasses can be used in manufacturing and field services to provide workers with just-in-time step-by-step instructions on how to perform specific procedures. Such devices can give workers instant on-the-job training, and allow them to tap the support and accumulated expertise of their colleagues.

These upskilling devices have already been deployed by industrial companies, for example by General Electric in its Renewable Energy and Healthcare divisions. Abraham and Annunziata (2017) show that the use cases so far have demonstrated an average productivity improvement of over 30%; and the improvement can be realized already from the first use and with almost no need for prior training.

These upskilling tools are especially powerful when combined with software analytics able to provide a much more sophisticated view of the functioning of industrial equipment—from an individual electricity generation turbine to an entire power plant—and advise technicians and management in real time on alternative courses of action. Artificial Intelligence tools will prove increasingly powerful in providing clear information on the technical and economic trade-offs of specific decisions (for example the intensity of use of a piece of power generation equipment at a precise point in time based on demand and supply on the grid as well as overall market pricing).

As the discussion above suggests, the interaction between new technologies and skills will be multifaceted. In some cases, new technologies can make workers more efficient and productive with the same set of skills. Consider for example a specialized technician assembling a new model of wind turbines: the technician already posses the technical skills needed, but she has no experience with the new equipment. Augmented-reality glasses can help guide her through the necessary steps in real time, obviating the need to interrupt the work to consult manuals or colleagues. In other cases, new skills will be necessary: an energy plant manager who now has at her disposal an AI-powered system to help her guide the plant's operations will need to be able to operate the (hopefully intuitive) system interface, understanding the key parameters involved and being able to interpret the information and choices provided by the AI interface.

As upskilling technologies such as these develop and advance, policymakers should devote increasing attention to their efficacy, and to their impact on employment and wages; they should also analyze the feasibility and desirability of measures targeted to incentivize and accelerate the adoption of skills-enhancing technologies; this could speed up the integration of new technologies in a way that would benefit both workers and overall productivity. A coordinated approach to these measures would help not only to promote best practices, but also to offset the risk that they might fuel international tensions in the current environment of rising protectionist pressures. At the same time, companies will need to review and update their operational and management practices, in order to exploit the full potential of the new technologies; they will also need to rethink their human capital strategy, around a better understanding of the evolving skills and talent needs, and redesigning strategies to attract, train and retrain workers.

Welfare-enhancing digital technologies

Other striking examples of welfare-enhancing digital technologies can be found in many sectors, including the agricultural sector, with the introduction of software that can identify cows by their hide patterns and faces, and track key data such as food and water intake, heat

detection and behavior patterns; the software then delivers analytics that drive on-farm decisions that can not only positively impact farmers' tasks, milk production, reproduction management, but also overall animal health.

These innovations are part of a broader wave of digital innovations in manufacturing, which includes the concept of a "digital thread", the ability to link workers and equipment through sensors and analytics, and to link the manufacturing floor to supply chains and distribution networks. This results in a greater ability to predict and to react to changes in market conditions. It can yield significant increases not only in efficiency and productivity, but also in workplace safety and other benefits.

We are not suggesting that these technologies can enhance the welfare of all workers in all circumstances; their impact will be multifaceted and will depend on how the new technologies are implemented:

- Some upskilling technologies can raise productivity for workers at all levels of the skills distribution, including for lower-skills workers. Greater productivity gains would then enable faster wage growth for relatively low-skills workers, mitigating wage and income inequality;
- Depending on demand conditions, greater productivity could imply that the company will need fewer workers in a specific job; this could put pressure on some of the workers to acquire new skills and take on different tasks, or face the risk of displacement;

Therefore, while upskilling technologies will provide new opportunities and help level the playing field, their net impact on overall employment and wage distributions will depend on other factors as well, including demand conditions.

Education and training

As we discussed in the previous sections, we need to gain a better understanding of how technology will continue to change existing jobs, and of the new jobs it will create. As the picture becomes more detailed, we can better understand what skills will be best suited for the new economy. Just as in the case of robotics and automation, the public debate on education and skills often veers towards extreme positions:

- some argue that the future will only have jobs for computer and data scientists, and that education should therefore be heavily skewed towards Science, Technology, Engineering and Math (STEM);
- others say the future calls for a new breed of highly creative "Renaissance Man", and that education should emphasize creativity and problem—solving skills.

Both ideas hold an important grain of truth, but both seem to take it to an unrealistic and possibly counterproductive extreme. It is worth remembering, for instance, that not every citizen of Renaissance Florence was a polymath—most held regular jobs as bakers, merchants or accountants. There is little doubt, however, that the education system is proving increasingly inadequate to keep pace with the accelerating economic transformation.

Building the right skills for the future will certainly require greater emphasis on STEM. As we have argued above, workers stand to benefit from the introduction of new technologies in the workplace. An increasing number of new opportunities, however, will hinge on workers' abilities to understand and interact with new technologies. This does not imply that most workers will need degrees in engineering or computer science, or will all have to be coders—upskilling technologies will be increasingly accessible thanks also to improvements in user interfaces. But it does mean that workers will need to acquire a greater degree of familiarity and comfort with new technologies. *The bar on scientific and digital literacy needs to be raised.* We should think of scientific and technological literacy as the new basic literacy. In most countries, the idea that every individual should be equipped with basic reading and writing skills has long been accepted. It should now be extended to include basic knowledge of science and technology.

While young people's attitudes to science cannot be changed overnight, governments should urgently take concrete measures to ensure that a greater proportion of the workforce is equipped with STEM skills. These measures could include:

a) implementing decisive curriculum reforms,
b) creating strong fiscal incentives for companies to partner with schools and universities,
c) developing active labor market policies with training for unemployed to tackle STEM shortages, accompanied by more Vocational Education Training in STEM.

The education system should also renew its efforts to nurture creativity, critical thinking and problem-solving abilities:

- across industry and other economic sectors, decision-making is becoming increasingly data-driven; advanced analytics and Artificial Intelligence provide workers and managers at most levels of the organization additional powerful tools; it becomes all the more important for workers to be able to fully leverage the potential of these new tools, and this requires the ability to correctly frame the problem and the most effective approach to a solution. Similarly, managers need to think about how to address problems and develop strategies in light of the new information made available by digital technologies, and the insights that can gleamed from these data.
- Creativity and critical thinking are emerging as characteristics that have a very high degree of complementarity to the most advanced technologies in robotics, AI and others. High performance in these dimensions would therefore allow workers to display high productivity, which would be reflected in higher compensation.

As we discussed earlier in the paper, the bulk of the disruption in the labor market will come not from the jobs that will disappear or that will be created *ex novo*; it will come from the transformation of existing jobs. This implies that a number of existing skills will remain relevant for the foreseeable future; this is especially true in manufacturing and across other industrial sectors. Therefore, *countries also need to redouble their efforts to increase the supply of traditional manufacturing skills. Vocational education, apprenticeships, and company-provided training programs can all play an important role*. This is especially important because of evidence that even as employment levels remain lower than desired, companies in a number of countries are having difficulties filling job vacancies for lack of qualified candidates. In the U.S., for example, this "skills gap" is highlighted by the growing divergence between the number of job openings and the number of hires (Figure 1):

> In a 2012 McKinsey survey, only 43% of surveyed employers said they were able to find enough appropriately qualified workers, and 39% said that a shortage of skills was a main reason for persistent entry-level vacancies (Barton et al., 2013).
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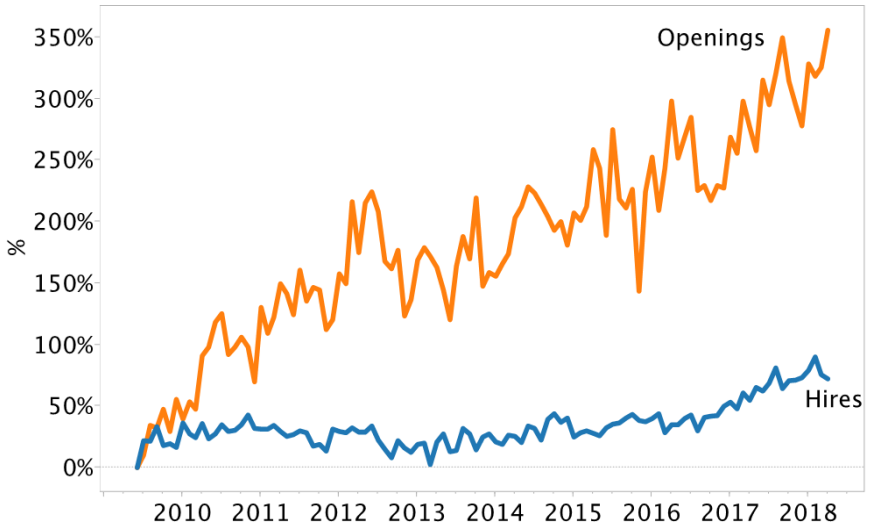
> A 2015 report by the US Manufacturing Institute and Deloitte projects that as many as 2 million US manufacturing jobs will remain unfilled in the coming decade due to an insufficient availability of skills (Giffi 2015).
>
> This skills gap is set to widen because of demographic trends. In a number of important industrial sectors, ranging across oil and gas, transportation, electricity generation and distribution, and others, large cohorts of senior and experienced technicians are due to retire within the next decade, and there is no comparable pipeline of younger workers ready to take their place. This might be due in part to the fact that students are increasingly attracted to new industries, notably in the technology sector, considering also the physical hardships of some specific industrial professions.
>
> Many operators in these sectors consider this to be one of their key strategic challenges. This challenge could be met in part with new technologies that can upskill workers, automate the hardest and most dangerous tasks, and make it easier for younger and less experienced workers to tap the reservoir of experience created by their senior colleagues: for example by creating easily accessible online libraries of instructions and how-to videos that can rapidly guide workers through complex procedures that they have not encountered before. This, however, can only be a partial and temporary solution; it cannot substitute for a broader adaptation of the workforce. Industry leaders need to see that the required supply of skills is gradually being rebuilt. Unless these remedial actions are put in place, companies operating in these sectors might face an overpowering incentive to develop and adopt technologies that will replace the existing workforce, eliminating attractive job opportunities.
>
> Addressing this problem requires acknowledging that traditional technical abilities in, among others, electrical and mechanical skills remain of fundamental importance even as new digital technologies transform the work environment. Encouraging a closer

Figure 1: Manufacturing openings & hires in the U.S.
(cumulative % change since June 2009)



Source: U.S. Bureau of Labor Statistics, Job Openings and Labor Turnover Survey (JOLTS), https://www.bls.gov/jlt/

dialogue and cooperation between the education system and the world of industry can play a fundamental role, helping to shape a system of vocational education and apprenticeships that provides a rapid and targeted path to high quality jobs. The German system already provides valuable examples in this respect. G20 governments could pool their efforts and share best practices on how to improve the communication and cooperation between education and industry. This should ideally include a more transparent way to inform students about the prospective careers and likelihood of employment for different educational paths.

While experimentation at the national and local level will help identify the most effective education models and strategies, this is an area that could benefit from an internationally coordinated effort to**:**

i. *Set common standards for STEM curricula* that can guide individual governments' education reforms efforts; convergence towards common standards would also facilitate the mutual recognition of skills that could in turn enable better worker mobility.

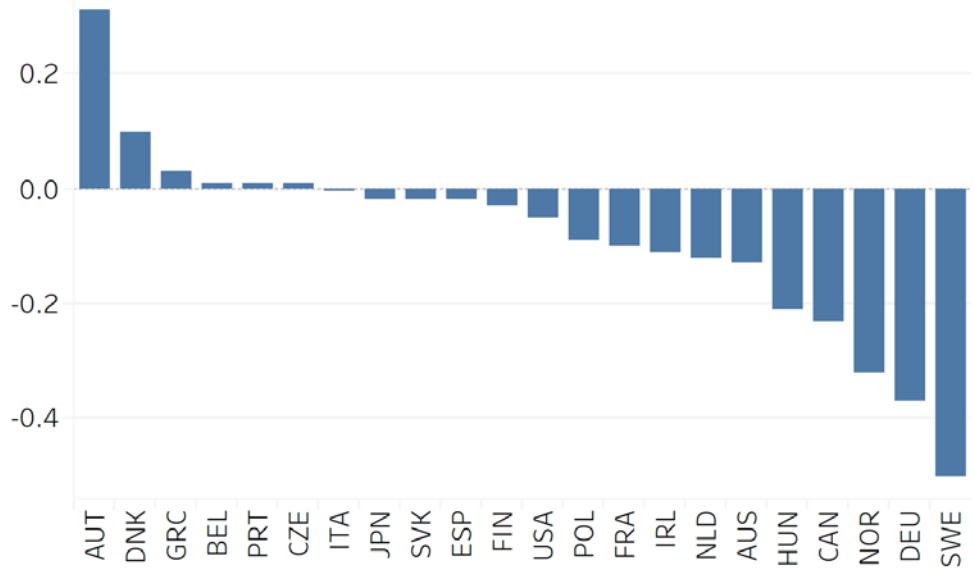
ii. *Coordinate a cross-country analysis of the existing gaps in traditional manufacturing skills.* In most countries, evidence of skills gaps remains anecdotal. It would be greatly beneficial to have a coordinated effort to understand the true extent of the existing need for both engineering and non-college educated technical skills. This could then inform education reform efforts.

iii. *Commission an assessment of the efficacy of vocational and apprenticeship programs implemented* in key countries, with the intent of identifying best practices as well as possible further improvements. Individual governments would then be able to adopt the programs best suited to their individual challenges.

Governments should prepare to invest additional resources in workers training efforts. In this regard, we find it somewhat alarming that the trend over the last 20–25 years has been in the opposite direction: as the chart below shows, between 1993 and 2015 most OECD governments have reduced their spending on workers training (Figure 2).

Private sector companies should not stay on the sidelines, and can act both through increased investment in training programs and with efforts to improve gender balance and promote more women in engineering and technical roles. Improving the gender balance, especially in technical roles, can have substantial benefits in terms of better performance and competitiveness for individual companies, and faster economic growth and job creation at the macroeconomic level. Annunziata and Chase (2017) highlight these benefits and argue that improving the gender balance will be fundamental to realize the full growth-enhancing potential of new digital-industrial innovations.

Figure 2: Change in public spending on training, 1993–2015 (% GDP)



Source: OECD

Labor market policies, life-long learning and social safety nets

The existing skills mismatch limits employment opportunities, especially for younger workers. The rapid pace of innovation risks widening the skills mismatch, with a broader disruptive impact on labor markets. In the previous section we have argued that education and training can play a key role in addressing this challenge, providing the right mix of skills to cope with the disruption and helping create new jobs.

Labor market policies will play an equally important role, however. In a number of countries, labor markets remain characterized by structural rigidities, with a high cost for companies to attract talent. These countries already suffer from relatively high unemployment levels. Unless these labor market rigidities are addressed, these countries will not be able to leverage the full job-creating potential of new technologies, and may in fact suffer disproportionately from technological disruption.

It is worth noting in this respect that the EU countries suffering from the highest youth unemployment rates are not the ones experiencing faster rates of technological development and adoption. Moreover, youth unemployment rates in these countries have remained at extremely high levels for the last forty years, as shown in Annunziata (2012); this suggests that in these countries at least, structural rigidities play a much larger role than technology in reducing job opportunities and preventing younger generations from accessing jobs and career opportunities. There is evidence that in these countries, for example Italy, Greece, Spain, France and Portugal, institutional labor market features have resulted in a two-tier labor market where many young workers remain 'trapped' in temporary contracts with limited benefits that thwart their opportunities to build skills and experience, as discussed in European Commission (2010) and in Juan Dolado (2015). Eliminating these rigidities should be a priority; left unaddressed they would render ineffective all other efforts to boost employment.

More entrepreneurial and flexible forms of work that will be increasingly enabled by new technologies will likely play a very important role in improving the functioning of labor markets. Digital-industrial innovations lower the threshold for becoming self-employed and engaging in entrepreneurship. At the same time, new technologies allow for more flexible and agile work because more people are now better connected and can be set up for digital work through home offices. These new forms of employment offer a real answer to unemployment, and can open up a new set of opportunities especially for younger workers. Access to this type of work should be encouraged and facilitated, rather than regarded as a threat or a last resort. New manufacturing technologies such as Additive Manufacturing (or '3D printing') could open the way for a new generation of 'hardware startups' and a new sector of high-tech artisan activities, similarly to what we have seen already in the software space. Affordable 3D printers could play the same democratizing role as affordable personal computers.

The rapid pace of technological change also implies that workers are likely to face two new trends:

First, the tasks composition of jobs and the skills required to perform them are likely to keep evolving at a faster pace than in previous decades; if that is the case, workers will have to

update their skills and familiarize themselves with new technologies and applications at a higher frequency than in the past—even as they remain in the same job.

Second, both the changing nature of jobs and the more pervasive disruption of industries imply that workers mobility will probably increase, with a higher share of workers changing jobs and employers with higher frequency, and more people working independently in a crowdsourcing or gig-economy framework. Indeed *the last decade has already witnessed a significant rise in the share of non-traditional work arrangements*. A recent study by Larry Katz of Harvard and Alan Krueger of Princeton (Katz and Krueger 2016) finds that the number of contingent workers has increased by about one half over the past ten years, to 16% of the U.S. workforce by 2015. The increase is equivalent to the entire net rise in employment over that period. On a broader definition, the Fed Board's Enterprising and Informal Work Activity Survey (EIWA) finds that over one third of the U.S. adult population relied on informal paid work as a complement or substitute for traditional work arrangements (Robles and McGee 2016). The McKinsey Global Institute estimates that 20–30% of the working age population in both the U.S. and Europe engages in "independent work", defined as work with a high degree of autonomy, based on a short-term relationship, and compensated by task, assignment or sales (Manyika et al. 2016).

Gig-style work arrangements allow a wider range of people to find work opportunities that can match their personal preferences and the constraints of their personal lives. They can therefore improve labor force participation—as noted by Fed Board Governor Lael Brainard—bringing a wider range of talent into play (Brainard 2016). (Hall and Krueger 2017), for example, found that three-quarters of Uber drivers reported the greater flexibility and control over their schedules as a significant benefit of the work arrangement.)

Non-traditional work arrangements are only starting to spread to manufacturing: Katz and Krueger find that the manufacturing sector accounts for a mere 6% of the employees engaged in alternative work. But they are likely to account for a growing share of manufacturing employment in the decades ahead.

Adapting to this new reality will require a number of actions on the part of policy makers, industry and the education sector:

Countries should strive to develop more robust frameworks for life-long learning. These might in principle include (i) ongoing in-house training programs run by individual companies to keep their workers up to speed with the new technologies being deployed and facilitate the transition of workers to different opportunities within the company, where possible; (ii) professional training programs organized by educational institutions to allow workers to upgrade their skills or acquire new skills either when they are in between jobs or while they are engaged in full-time or part-time employment; (iii) training and education programs run jointly by consortia of companies—either in the same industry or cutting across industries; this would allow different companies to contribute a wider set of expertise, while at the same time forming a pool of workers that the entire consortium could then tap into.

In other words, the changes afoot will likely call on companies to look at human capital as both a joint resource and a joint responsibility. Policymakers have an equally important role to play:

This should be complemented by a system of sufficiently robust, flexible and portable social benefit systems. In some countries, notably in the U.S., this would require a fundamental rethinking of the existing social benefits system setup.

Employment legislation should also better reflect the rapidly changing nature of the world of work. International policy institutions could design recommended guidelines to help national governments adapt labor market and other legislation and rules that were originally designed for a completely different phase of industrial and economic development. Allowing businesses to better adapt to shifting demand will in turn further promote innovation and entrepreneurship and provide increased employment opportunities, particularly for young people.

Labor market reforms should be complemented by national and international-level efforts to facilitate the flow of workers across countries. While this seems to run counter to the current political climate, a sufficient degree of labor mobility is essential to enable the efficient allocation of human capital, allowing countries to more easily and quickly address skills gap, and allowing workers to seek the best job opportunities and to pursue training and career development opportunities.

EU Member State governments could take the lead on this front, and set the example by working together to eliminate barriers and adopt measures to promote the flow of workers across the EU. These include

a) providing for equivalence in national social security and pension programs, and
b) adopting programs that incentivize young workers to seek employment outside of their home country.

A greater degree of international labor mobility could be fostered through specific measures, which could include:

i. Mutual recognition of educational and professional qualifications meeting internationally recognized standards
ii. Points-based visa systems for highly qualified workers
iii. Permanent and time-bound visa and work permit programs for low-skilled workers

Stronger education and training policies will equip workers with the right skills needed to keep pace with new technologies; and more flexible and open labor markets would help workers to more quickly identify and secure the job opportunities best suited to their abilities and personal circumstances and priorities. But they will not be able to negate the adverse transitional impact of technological disruption. In the short term, some jobs will be automated; some workers will see their skills become obsolete; some companies will be disrupted by new competitors and forced to downsize or exit the market outright. Workers will be impacted. And what economists can define as “short term” in the context of an overall economic transformation can be a very long term for an individual whose livelihood and place in society are put at risk.

It will therefore be imperative to rethink, redesign and strengthen social safety nets to better cope with faster and more profound technological transformations. A stronger social safety net will make it easier for displaced workers to retrain and re-skill more rapidly; this will not only reduce personal hardship, but also improve a country's overall human capital, contributing to economic growth. A stronger social safety net will also make it easier for individuals to take more risk in their education and employment choices, in an environment characterized by greater uncertainty and where individuals will need to exercise greater entrepreneurship in shaping their careers. Moreover, by cushioning the adverse impact of innovation on the workforce, a stronger social safety net will buttress social and political stability and reduce the risk of a fierce backlash against technology—similar to the backlash against globalization that has already affected economic policy decisions in a number of countries.

Designing better social safety nets should start with a better understanding of how workforce disruption will most likely manifest itself. While there is no scarcity of research on the impact of automation and digitization on employment, there is as yet limited clarity on which sections of the population are most likely to be affected—beyond the broad insight that low-skilled workers in routine jobs are most at risk. A better understanding of where the impact is likely to be most severe, in terms of both social groups and geographies, would help design more targeted cushioning measures, but also anticipate the potential political backlash and the attendant impact on policy-making efforts.

It would be highly desirable for international policy institutions to coordinate an international study mapping the potential impact of technology on jobs onto different socio-demographic characteristics of the populations, so as to better understand the socio-economic ramifications, which are likely to extend well beyond job losses. This study would provide the basis to design upgraded targeted mitigating measures; these could include:

a) Retraining and career-counseling programs, designed so as to be targeted at the most at risk segments of the population;
b) Time-bound unemployment benefits programs, fine-tuned to yield the right combination of support and incentive for a rapid re-entry into the labor force;
c) Long-term income support mechanisms for workers who might find it prohibitively hard to re-enter the labor force—notably specialized workers disrupted at a later stage in their careers;
d) Support measures for small and medium sized companies and their employees, to enable them to access retraining measures otherwise limited to large companies.

Here as well, EU countries could play a leading role: the European continent has a long tradition of strong social safety nets, and this uniquely positions Europe to ensure that particularly the short term social cost to technology advance are managed effectively. Europe's multi-layered political structure could also provide a useful testing ground to design and deliver policies at the appropriate level—central, regional or local.

New financing strategies to enable R&D

Last but not least, an important challenge in many countries is to design and promote new-generation funding programs for digital-industrial innovative projects. Many countries with a robust level of fundamental research activity are nonetheless lagging behind in developing products and solutions that digitize manufacturing assets and increase manufacturing productivity. Europe is a case in point. One notable exception is France, that has since some time successfully operated an attractive system of tax credit towards investments in R&D. G20 countries and the EU overall should resolutely opt for increased resources in their R&D funding programs, both as a percentage of the total budget and in absolute figures.

Allocating sufficient public funds is only part of the challenge. Equally important is designing programs that can

i. leverage additional funding sources, with private sector participation, including possibly new forms such as crowdfunding, and enacting legislation that can facilitate the creation of venture capital investment
ii. identify appropriate targeting strategies that can ensure funds are efficiently allocated to the best opportunities.

These programs should recognize that innovation projects will be subject to a higher degree of risk than traditional public infrastructure projects. Funding programs should therefore be designed with a view to allow for a 'natural' rate of project failure, but in such a way that failures can be identified at an early stage, reducing the capital expense. Private sector best practices would provide a useful blueprint in this respect.

Conclusion

In this paper we have argued against the current dominant focus on the threat that new technologies pose to jobs and wages, suggesting instead that these same innovations are making human capital ever more important in companies' strategies, and that we need to give greater emphasis to understanding and leveraging the new complementarities between technology and human skills. A combined effort by governments, private companies and education institutions —informed by additional research—could not only ensure that innovation will once again ultimately result in more and better jobs, but also smooth the transition and cushion the impact on the most affected sectors of the workforce. This paper represents an effort to identify the key areas for action and suggest some initial specific measures and initiatives. It underscores that G20 countries and policymakers are well-positioned to play a crucial driving role in this transformation.

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