Emerging Technologies and Preparing for the Future Labor Market

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A wave of new technologies appears to be emerging that many speculate will not only boost productivity but also increase rates of labor market disruption. While past waves of technological innovation have had enormous positive impacts, including on per-capita GDP growth, all have had some disruptive impacts, including on incumbent firms, workers, and communities. While it is not the role of governments to protect businesses from innovative competitors, it is their role to help workers and communities make effective transitions.

This paper provides a description of the various technologies encompassing the next production revolution (NPR) and G7 policies to spur NPR innovation. It then provides an analysis of the likely labor force impacts of the technologies, including on jobs and unemployment and on particular demographic groups and types of places. It then offers key principles to guide G7 policies, and lists specific policy ideas in four areas: spurring the development of NPR technologies, spurring their adoption, easing labor market transitions, and shaping policies related to common approaches to AI. The report closes with a brief discussion of key points G7 partners might make in common.

SUMMARY POINTS

Findings

- A set of new and improving technologies that promise to boost productivity growth rates is emerging.
- It could be a decade or more before this technology wave is fully reflected in GDP growth.
- This technology wave is not unprecedented, and likely to be of the same order of magnitude as the waves of the 1890s and 1900s, 1950s and 1960s, and 1990s and early 2000s.
- If policymakers do not give in to reactionary, anti-innovation forces, this wave could increase annual labor-productivity growth rates up to approximately 3 percent per year (up from the current average 1 percent).

- Current and historical evidence, as well as economic theory and research, strongly indicates this next innovation wave is highly unlikely to lead to a massive loss or shortage of jobs. However, it will likely increase labor-market and occupational disruption, albeit from its current lowest point in a generation.
- While the last wave had a disproportionate impact on the productivity of middle-wage and middle-skill jobs, the next wave is expected to similarly affect lower-skill and lower-wage jobs, whose workers are on average less well equipped to successfully make labor market transitions. On the other hand, this impact is likely to result in G7 labor markets having a larger share of better and higher paying jobs than at present.

Transformative Technology Firm/Society Recommendations

- G7 nations are taking steps to support the development of the next wave of technologies. But more can be done, including supporting pre-competitive research partnerships (public-private partnerships focused on early-stage R&D) to support the development of automation technologies, especially advanced robotics.
- Many of these technologies can play important roles in helping particular socio-economic groups. Toward that end G7 nations should support research and share findings on the development and application of these technologies aimed at helping underrepresented groups such as women, youth, the elderly, and people with disabilities.
- Since it appears that the AI impacts on productivity-driven job displacement are more likely to be greater for lower-skilled and lower-income workers, G7 nations should collaborate on best practices for both skill development and work transition practices to support lower-skilled workers.

Artificial Intelligence/Data Recommendations

- The NPR, particularly in the area artificial intelligence, will depend on data. To maximize AI innovation and adoption, nations will need privacy regimes that enable the use and reuse of data. While national privacy rules do not need to be harmonized as they mainly travel with data, this heightens the need for interoperability between regimes so as to facilitate the ease of doing business.
- Binding international rules regarding NPR technologies, including AI, are generally not needed because national regulatory regimes are adequate to address policy concerns. However, G7 nations should work cooperatively to limit restrictions on cross border data flows.
- G7 policy makers should work to ensure that data-protection regulations do not inadvertently limit AI innovation. In particular, privacy laws and other regulations that apply restrictive standards to automated decisions that would not apply to human decisions would raise costs and limit AI innovation, as well as force a trade-off with the accuracy and sophistication of AI systems.
- To help limit harmful or inaccurate results from AI applications, policymakers should pursue efforts to ensure algorithmic accountability (e.g., steps to ensure

that algorithms do what they are intended to do). Requiring algorithmic transparency, especially requirements that source code and detailed explanations of how the algorithm work be exposed to some degree of public scrutiny, will limit AI innovation.

Government Programming Recommendations

- G7 nations should cooperate on the development of sector- and system-based strategies for the widespread adoption of NPR technologies, including in key sectors such as construction, finance, health care, utilities, transportation and governments (e.g. smart cities).
- To the extent G7 nations focus on regulatory frameworks for the NPR, these should be grounded on the "innovation principle," rather than the "precautionary principle." NPR technology is in its infancy and its impact on society is only just starting to be understood.

Skills for the Future Labor Force Recommendations

- G7 nations will need to do more to ensure that workers displaced by NPR technologies have stronger capabilities and tools to make successful transitions. Policymakers should consider approaches that support employers' need for a flexible workforce while also supporting workers so they can make successful transitions.
- Education reform should be focused on enabling workers to get better skills and other competencies, particularly "21st century generic skills" and more technical skills. This will require significant, sometimes disruptive, reforms, particularly to high school and post-secondary institutions.
- More will need to be done to encourage employers to expand workforce training efforts, including wider use of portable skills credentialing, sector-wide training and development plans, industry-led skills alliances, apprenticeship programs, and portable training accounts.
- G7 nations should collaborate on how to better use information and communications technology to facilitate online skills assessment, career navigation, training, and workforce placement.

Going forward, there is little reason to believe historical patterns will not continue. Moreover, G7 economies will need the NPR to proceed at a robust pace. G7 productivity growth rates over the last decade have been lower than in the two decades prior, while the demographic challenges from an aging population are becoming more severe. Without faster rates of productivity growth, the only way for G7 economies to cope with increasing dependency ratios is to either decrease consumption by the elderly (through reduced benefits or delayed retirement) or increase taxes on workers. Greater productivity through technology—growing the proverbial pie—is the only way to allow both workers and retirees to see their living standards increase at reasonable rates. This can and should be done in ways that protect widely held values such as privacy and enable all individuals and groups to benefit.

Background on Technology and Employment

"The great enemy of the truth," President Kennedy once stated, "is very often not the lie—the deliberate, contrived, and dishonest—but the myth—persistent, persuasive, and unrealistic." "Few myths have been more persistent, persuasive, and unrealistic than those concerning automation and technological change." This sentence, it should be pointed out, was written by Charles Silberman, an editor for *Fortune* magazine, in his 1966 book *The Myths of Automation*. Much of what has been written about automation and job loss over the last few years is no different.

When looking at the history of the United States, three things should be clear about the process of technological innovation and jobs. First, "techno-panics" warning that technology is killing more jobs than can be created are anything but new. In 1927, U.S. Secretary of Labor "Puddler Jim" Davis wrote:

> In the long run, new types of industries have always absorbed the workers displaced by machinery, but of late, we have been developing new machinery at a faster rate than we have been developing new industries. … At the same time, we must ask ourselves, is automatic machinery going to leave on our hands a state of chronic and increasing unemployment? Is it giving us a permanent jobless class?

In 1955, the concern over automation leading to a rise of "push-button" factories was so great, the U.S. Congressional Joint Economic Committee held extended hearings on the matter. Looking back, it is clear that while advanced economies do fall into temporary recessions, they do not suffer from technologically-induced structural employment.

Second, labor-market churn, at least in the United States, was much higher in the past. When ITIF analyzed U.S. Bureau of Labor Statistics data to compare the rate of occupational churn (the rate of employment changes within occupations relative to the overall economy) from 1850 to 2015, it found that churn rates were significantly higher in prior periods than during the last 15 years. Moreover, the length of time it takes new technology to significantly disrupt occupations is considerable. For example, it was not until 77 years after the invention of the automatic elevator that the U.S. Census stopped counting the occupation of elevator operator. Because so much of this churn is driven by technological innovation that is broadly the same across G7 nations, it is likely the historical rates in those nations were similar.

There is no reason to believe things are different now. Although it is now widely assumed that the pace of innovation is accelerating, this does not appear to be the case. As David Moschella, an ICT expert with Leading Edge Forum writes:

> Technology is not accelerating. The time it takes for a new technology to be used in 50 percent of U.S. homes has long been used as a comparative adoption benchmark. By this standard, both radio and television were accepted faster than personal computers or mobile phones. More importantly, most Internet of Things (IoT) technologies—Fitbits, smart watches, 3D printers—are being adopted even more slowly.[1]

Likewise, MIT professor and roboticist Rodney Brooks notes that while the new Internet Protocol IPv6 was established in 1996, by 2017, less than 20 percent of Internet traffic was running on it—hardly a sign of rapid introduction.[2] Plus, if the pace of technological change were actually accelerating, the results would show increasing rates of productivity growth. Instead, productivity growth rates over the last decade in G7 nations have been at near historical lows.

Third, the scholarly economic research examining the relationship between technology-driven productivity and employment growth in developed nations around the world is virtually unanimous in the finding that higher productivity has not been associated with lower job growth or higher unemployment rates. This is because productivity growth creates additional income that is spent; in turn expanding demand for more goods and services and, hence, jobs.

Even though technological change does not lead to fewer jobs, some, including MIT economists Daron Acemoglu and Pascual Restrepo, assert it has led to lower wages and that policy makers should not press for rapid and widespread adoption of the NPR.[3] However, this is not in fact quite true. The last technology wave, which Acemoglu and Restrepo investigated, had a larger impact on the productivity of middle-wage jobs (e.g., manufacturing and information processing jobs) in the United States, thereby leading to a relative reduction of those jobs and a concomitant increase in both lower- and higher-wage jobs. But to contend that despite productivity growth, most workers were, on average, worse off is incorrect, when the majority were better off (including both the workers who moved to higher-wage jobs and the rest of the labor force that benefited from lower relative prices for goods and services). This is why technology-driven productivity has led to higher median per-capita incomes in the United States over the last three decades, despite what some researchers have asserted.[4] Even Acemoglu and Restrepo acknowledge this, writing that "automation increases overall welfare," as long as there are flexible labor markets, including policies and programs to help workers make successful employment transitions.[5]

THE NATURE OF TODAY'S DISRUPTIVE TECHNOLOGIES

This history of advanced economies is, at its core, the history of waves of technology innovations that disrupt existing production systems. Those who follow in the tradition of economist Joseph Schumpeter—who coined the term "creative destruction"—argue that economic change is driven by the emergence of "general purpose technologies" (GPTs) that transform industries and production systems. GPTs share several characteristics, including rapid declines in price and improvements in functionality; widespread use across different industries and production functions; and a significant, measurable impact on the macroeconomy. These technologies appear to come in waves, with periods of emergence and adoption characterized by rapid growth; and intervening periods between the exhaustion of one set of GPTs and the emergence of the next set characterized by slow economic growth.

Advanced economies have experienced five technology-powered waves: (1) the steam engine, starting in the 1780s and 1790s; (2) iron in the 1840s and 1850s; (3) steel and electricity in the 1890s and 1900s; (4) electromechanical and chemical technologies in the 1950s and 1960s; and (5) information and communications technologies of the 1990s and 2000s.[6]

Advanced economies appear to be in the midst of an intervening period of relative stagnation, wherein the existing GPT system (information and communication technology) has plateaued, making robust productivity gains difficult. While rapid improvements in operating systems, computer chips, broadband speeds, and smartphones were considered more significant a decade or two ago, today such changes are less impactful because the advances are more incremental and virtually all legacy IT systems are sufficient for most applications. This, more than any other factor, likely explains the slowdown over the last decade in both capital investment and productivity among G7 nations.[7]

If this periodization is correct, it suggests a sixth wave will emerge—likely grounded in artificial intelligence, more flexible and capable robotics, autonomous devices, and new materials. While these technologies are already in the marketplace, they are generally both too expensive and not powerful enough to drive economy-wide productivity. For example, despite the recent excitement over this new technology, "smart manufacturing" does not appear to have been embraced on a large scale, as evidenced in part by most manufacturers in G7 nations appearing to be in only the very early stages of adopting these systems. For example, from 1989 to 1994—a period of rapid improvement and adoption of the last wave of IT—U.S. manufacturing productivity increased 21 times faster than it did more recently between 2011 and 2016. Likewise, while there is considerable excitement about machine learning software systems, their current capabilities remain relatively limited, notwithstanding some promising early applications. And fully autonomous cars at a price point most consumers can afford are not likely to become available for at least another15 years.[8] Finally, fully dexterous robotic hands are not predicted to hit the market before 2030, or even 2040.[9] As Rodney Brooks notes, "Having ideas is easy. Turning them into reality is hard. Turning them into being deployed at scale is even harder."[10]

If this next wave of technologies—the next production revolution—follows prior technological trajectories, it will likely experience rapid price declines and significant performance improvements over the next decade. As this occurs, these technologies will be ready for, in the words of innovation scholar Carlota Perez, "widespread installation," providing enough of a compelling value proposition for a wide range of organizations to scrap existing technologies that have not been fully depreciated, and replace them with more productive new technology systems. If this happens on a widespread basis, robust growth will likely re-emerge in G7 nations.

There are at least seven technologies that look likely to comprise the next production revolution and have potentially significant positive impacts on productivity growth:

Artificial Intelligence: Artificial intelligence (AI) is a field of computer science devoted to creating computer systems that perform tasks much like a human, particularly those involving learning and decision-making.[11] AI has many functions, including but not limited to learning, understanding, reasoning, and interaction. There are two very distinct types of AI: narrow and strong. Narrow AI describes computer systems adept at performing specific tasks, such as Apple's virtual assistant, Siri, which interprets voice commands.[12] Strong AI, also referred to as artificial general intelligence (AGI), is a hypothetical type of AI that can meet or exceed human-level intelligence and apply its problem-solving ability to any type of issue.[13] Many of the fears about AI, such as it leading to most jobs being eliminated stem from the notion that AGI is feasible and imminent.[14] However, at least for the foreseeable future, computer systems that can fully mimic the human brain are only going to be found in Hollywood movie scripts—not in the labs in Silicon Valley.

The Internet of Things: The “Internet of Things” (IoT) refers to the concept that the Internet is no longer merely a global network wherein people communicate with one another using computers, but rather is also a platform for devices to communicate electronically with the world around them. The result is a world that is alive with information as data flow from one device to another and are shared and reused for a multitude of purposes, including analytics. A combination of technologies, including low-cost sensors, low-power processors, scalable cloud computing, and ubiquitous wireless connectivity, has enabled IoT. Companies are just beginning to use these technologies to embed intelligence and sensing capabilities in their machines and products, thereby allowing everyday objects to sense, learn from, and interact with their environment. In industry verticals, this is known as “smart x” (smart manufacturing, smart transportation, smart agriculture, etc.).

Blockchain: Blockchain is a digital-ledger technology in which immutable transactions are recorded digitally and made available across a network of computers, thereby enabling decentralized generation, storage, and transfer of information. While still in the early stages of development, blockchain technologies have been used for currency (e.g., Bitcoin); shipping and supply chain integration, including smart contracts; financial services; digital identification and certification; and public records.

Autonomous Devices: These are mechanical devices that have some ability to interact with their environment and change their physical actions in response. The most widely known autonomous device is the self-driving vehicle, which has the ability to navigate its surroundings partially or completely without human intervention. Although reliable fully autonomous devices, in large numbers and at affordable price points, are not expected to become available for some time, it is possible to envision many different autonomous applications, including tractors and other farm equipment; mining equipment; freight vehicles (trucks, rail, ships, cars, drones); passenger vehicles; delivery robots; and lawnmowers.

Robotics: As the number of different technologies that enable production processes to be automated continues to grow, so will the importance of robotics, in both services and goods production. While there is no single hard and fast definition of “robot,” the term generally refers to physical machines that can be programmed to perform a variety of different tasks, with some level of interaction with its environment, and limited or no input from an operator. Whether a robot looks like a human is immaterial to its being a robot. Overall, robots are getting cheaper, more flexible, and more autonomous, in part by incorporating machine learning systems.

New Materials: This is a catchall term that refers to innovations in physical materials. With breakthroughs in chemistry and improvements in nanotechnology, (the ability to manipulate matter at the atomic or molecular level), it is getting easier for engineers to design and mass produce materials with more innovative properties. For example, graphene is a form of carbon consisting of a single layer of atoms arranged into a hexagonal lattice that is also the strongest material ever tested. The European Commission estimates that in the near future, 70 percent of product innovation will be based on materials that have new or improved properties—with much of this innovation having important impacts on productivity, especially by extending the lifetime of products.[15] Such materials could be used to make products last much longer (e.g., roofing materials and paint that last 100 years); are energy efficient (e.g., windows that generate electricity); and that repair themselves (e.g., self-healing concrete). Related to this, biotechnological innovations, including genetic manipulation tool, like CRISPR (Clustered Regularly Interspaced Short Palindromic Repeats), could have significant implications for productivity, especially in curing diseases that currently require hundreds of billions of dollars in expenditures for medical treatment and care.[16]

Convergence: These technologies are not only being developed discretely, but their use is also converging. Autonomous devices and robots will increasingly rely on artificial intelligence, for example. Nanotechnology and data analytics are being combined with biological innovations to drive biotechnology advances. As such, just as many industries needed electromechanical capabilities after WWII—and then digital-hardware- and software-related capabilities in the 1980s and 1990s—going forward, many industries will need shared technological capabilities, such as AI and data analytics, robotics, autonomy, IoT, and other cyber-physical systems. And more skilled workers will be needed in these technical areas.

Perhaps the single most important economic question facing the G7 economies is what the likely economic growth impact from the NPR will be. Some, such as economist Robert Gordon, argue that G7 economies have picked virtually all the "low-hanging fruit," causing growth rates to be low for the foreseeable future. But Gordon and other pessimists may not fully appreciate the potential of the NPR to improve in price and quality, and therefore transform industries.[17] As one example, Gordon dismissed out of hand the productivity potential of autonomous vehicles (AVs), failing to understand that the reduction in accidents and increase in traffic throughput AVs will enable could generate an estimated $1 trillion in annual savings to the U.S. economy.[18]

Conversely, other experts, such as World Economic Forum leader Klaus Schwab, see the NPR as qualitatively different from past transformations, and believe the technology is advancing at an exponential rate. But such optimists appear to overstate the extent and pace of change because they may be basing their predictions on overoptimistic assumptions. For example, Moore's law (the doubling of computer power ever 18 to 24 months) has already slowed and is not likely to continue ad infinitum.[19] All general-purpose technologies have progressed along S-curves, meaning exponential growth has already stopped. As Sanjay Banerjee, director of the Microelectronics Research Center at University of Texas at Austin puts it, "No exponential is forever."[20] Moreover, new research by Nick Bloom and John van Reenen found the productivity of scientific and technological research has fallen significantly over the last half-century, as it has become increasingly difficult to wrench secrets from nature.[21]

Therefore, the most likely future technology trajectory appears to be one that will wend its way between the lowlands of techno-stagnation and the highlands of techno-exponentialism. In other words, the most likely scenario is the future following past technology wave trends, with a new wave of innovation emerging and powering a new wave of growth, not an unprecedented utopian (or dystopian, depending on one's view) epochal transformation. Thus, if G7 nations are fortunate, they will see a wave like those G7 nations experienced in the 1950s and1960s, and again in the 1990s and early 2000s.

Given precedent, it is not unreasonable to expect annual labor productivity growth rates in G7 economies to increase to perhaps 3 percent. Should G7 economies achieve these growth rates, it will mean significantly faster median-income growth, faster GDP growth, and with it, increased government revenues. This would also be true even if future growth rates were to maintain past trends in inequality; government revenues would continue to grow regardless of income distribution patterns. And as noted above, even with the growth of inequality in the United States over the last four decades, median income has grown at least 36 percent in real terms.[22] And it should be noted that G7 nations have enjoyed this level of productivity growth in the past without higher rates of structural unemployment.

G7 INNOVATION POLICIES TO SPUR INNOVATION

Because accelerating the transition to the NPR will provide G7 nations with significant economic benefits, including increased productivity and competitiveness, it is important that their governments help advance both the pace of NPR innovation and the speed and breadth of diffusion of NPR technologies to all sectors. There are an array of different policies the governments could adopt.

Increased Support for Research, Including Through Public-Private Research Partnerships: Accelerating scientific and engineering advancement in technologies related to the NPR is key to speeding the rate of innovation. To that end, G7 governments should focus their scientific research programs more on technologies that drive advancement in the underlying key technology areas, such as robotics, materials, and machine learning.

In addition, governments should work to support public-private research partnerships. There is considerable scholarly literature that shows companies typically underinvest in research—particularly riskier and precompetitive research. Although leading technology firms are conducting their own research in many of these areas, there remain a number of complex technological challenges yet to be solved, and few companies are focused on this earlier-stage, higher-risk research. Public-private research partnerships targeting technologies and industries can therefore be a key tool for overcoming this problem. For example, the U.S. Congress passed the Revitalize American Manufacturing and Innovation Act of 2013, which authorized the creation of a network of Manufacturing USA institutes. These 14 institutes are cooperative efforts between large and small firms and research universities, and focus on a variety of core technologies, including smart, additive, and composites manufacturing.

Under Prime Minister Trudeau's leadership, Canada has launched its Innovation Superclusters Initiative, which brings together firms, research universities, technical colleges, and entrepreneurs in clusters of business activity primarily focused on advanced technologies and industries, including artificial intelligence (where part of the initiative is to establish a system of AI research chairs at universities)—thereby creating superclusters. The United Kingdom's High Value Manufacturing Catapult program comprises a network of seven subcenters focused on various advanced technologies. France has established a similar network, the Carnot Institutes Network, as part of its Industrie du Futur initiative. And of course, many nations have modeled their efforts after Germany's long established and successful Fraunhofer Centers program.

Sector-Focused Initiatives: Nations are also establishing sector-focused initiatives. The main focus of Germany's Industry 4.0 plan to modernize its manufacturing sector is on sensors, software, and other Internet of Things (IoT) technologies. The country has devoted $221 million to support industry, academic, and government research and development efforts to advance smart-factory technologies ranging from sensor-embedded systems to artificial intelligence platforms that can help operate Internet-connected machinery. Likewise, Italy has funded its Intelligent Factories Cluster to support smart-manufacturing transformation.

Data Innovation: G7 nations are also helping to support data innovation and artificial intelligence by increasing access to government data. As ITIF has noted, all G7 nations have worked to release government data in open and machine-readable formats.[23]

Information and Communications Technology Deployment: Taking full advantage of the NPR will require many, if not most, economic sectors to be transformed by the technologies, and to that end, G7 nations are taking a variety of steps. Japan has dedicated itself to becoming the "world's most advanced IT nation," in part through a series of measures aimed at harnessing the Internet of Things to develop solutions in the areas of health care, disaster resilience, public safety, and infrastructure planning, as well as encouraging sensor-technology R&D. In 2015, the Japanese government announced plans to establish a council of public- and private-sector organizations that would support the development of specific Internet of Things technologies, including information-processing technologies that can analyze immense volumes of data collected from connected devices, and systems for safely disabling Internet-connected autonomous devices in the event of a safety or security risk, such as self-driving cars. Japan has also launched the Artificial Intelligence Technology Strategy Council in April 2016 to develop a roadmap for the development and commercialization of AI. Published in May 2017, this roadmap outlines priority areas for R&D, primarily focusing on the themes of productivity, mobility, and health. The strategy also encourages collaboration between industry, government, and academia to advance AI research, as well as stressing the need for Japan to develop the necessary human capital to work with AI.

In the United States in 2015, the White House launched a Smart Cities Initiative, which would allocate $160 million in new and ongoing R&D funding that went beyond just smart cities. The Smart Cities Initiative includes support for a range of programs including the National Institute of Standards and Technology's Global City Teams Challenge, which encourages the development of smart-city applications, Internet-connected vehicle pilots, and the establishment of IoT test beds. And in December 2015, the Department of Transportation launched the Smart City Challenge, which awarded $40 million to Columbus, Ohio, to implement connected technologies in order to reduce congestion, improve transportation safety, protect the environment, and support economic growth.

In March 2017, Canada launched the Pan-Canadian Artificial Intelligence Strategy, whose goal is to establish Canada as an international leader in AI research. The strategy has four goals: increasing the number of AI researchers and graduates; establishing three major AI research centers; developing global thought leadership on the economic, ethical, policy, and legal implications of advances in AI; and supporting the national AI research community.

The UK Digital Strategy, published in March 2017, recognizes AI as being key to growing the United Kingdom's digital economy. The United Kingdom's budget, published in November 2017, includes several provisions aimed at making the United Kingdom a world leader in AI, such as by establishing the Centre for Data Ethics and Innovation to promote the growth of AI, facilitating data access for AI through "data trusts," and funding upwards of 450 Ph.D. researchers working on AI.

ECONOMIC DISRUPTION AND SOCIETAL IMPACTS

Higher rates of innovation, especially when related to automation, increase not only living standards, but labor-market turbulence as well. As ITIF has shown, occupational churning (the decline and growth of jobs in various occupations) tends to fluctuate over time, trending higher when a technological innovation reaches the more vertical part of the S-curve, and lower once it has reached its peak—although overall rates of unemployment vary little.[24]

Some experts predict the next wave will lead to high levels of unemployment. This fear appears to be borne out of a misunderstanding of how the process of technologically-driven productivity growth actually works. Companies invest in process-innovation to both boost productivity and cut costs. And when new technology helps lower costs for all or most of the companies within a specific market, competition forces them to pass a significant share of those costs savings along to consumers in the form of lower prices (and some to workers in the form of higher wages and to shareholders in the form of profits). This added purchasing power from any of the three channels (prices, wages, or profits) is not buried, it is spent—and that spending demand creates new jobs.[25] This dynamic is the same whether productivity grows at 1 percent, or at 10 percent, per year. This is why the Organisation for Economic Co-operation and Development (OECD) finds that, "Historically, the income-generating effects of new technologies have proved more powerful than the labor-displacing effects: Technological progress has been accompanied not only by higher output and productivity, but also by higher overall employment."[26] There is simply no reason to believe this will not be true going forward.

This is not to imply no workers will be displaced and required to find new jobs. A number of studies have tried to estimate this impact, with perhaps the most widely cited among them, by Oxford's Osborne and Frey, estimating 47 percent of U.S. jobs *could* be eliminated by technology over the next 20 years.[27] But their study appears to significantly overstate the real number by including many jobs that have little chance of automation, such as fashion models, school bus drivers, and barbers. Even if the authors' estimated 47 percent job-loss rate is accurate, it would be equivalent to a net annual labor productivity rate increase of 3.1 percent, which is lower than the productivity growth rate the U.S. economy enjoyed in the 1960s, when unemployment was low and job creation and wage growth were high.[28]

A PricewaterhouseCoopers report predicts technology could potentially eliminate 38 percent of U.S. jobs by 2030.[29] But actual numbers are likely to be much less than either the PWC or Oxford estimates. The OECD estimates around 15 percent of U.S. jobs will be lost to automation over the next 15 years. ITIF estimates 20 percent of U.S. jobs are likely to be automated over the next 15 years.[30] And the McKinsey Global Institute estimates as few as 20 percent of jobs (in the UK) up to 26 percent (in Japan) in the G7 economies will be displaced by technology.[31]

One reason actual job-loss rates are unlikely to reach the higher-end estimates of nearly 50 percent or above is automation affects jobs as a whole to a lesser extent than certain specific tasks that comprise those jobs. As McKinsey concludes, "Very few occupations will be automated in their entirety in the near or medium term. Rather, certain activities are more likely to be automated, requiring entire business processes to be transformed, and jobs performed by people to be redefined."[32] In other words, technology will lead to more jobs being redefined and opportunities created in order to add more value, than to outright job destruction.

Nonetheless, automation rates are likely to increase, which while enabling higher per-capita incomes, will be disruptive, especially if they impact certain social groups at higher rates. Because automation technologies impact various industries, functions, regions, and occupations differently, their demographic impacts also vary. To assess these potential impacts, two different data sets on the risk of automation by U.S. occupational category (the Oxford University study and the ITIF study) were examined. While ITIF's projection for the share of jobs lost from automation was considerably lower than Oxford's, both methodologies yielded similar findings with regard to the demographic distribution of job loss.

Gender: Using the Oxford data, there is only a small positive correlation (0.11 correlation coefficient) between the risk of layoffs and share of jobs in an occupation predominantly held by women. The ITIF data, however, shows a small negative correlation (-0.07). This suggests that the NPR could very well have similar impacts on men and women workers.

Race: There is a modest positive correlation between the risk of layoff and share of jobs in occupation held by non-whites in the United States (0.21 for Oxford, 0.27 for ITIF). In other words, racial minorities are projected to face a modestly higher relative risk of job loss due to automation than whites. Likewise, the Joint Center for Political and Economic Studies found that "Over 31 percent of [U.S.] Latino workers and 27 percent of African American workers are concentrated in just 30 occupations at high risk to automation. By comparison, these 30 occupations account for 24 percent of all white workers and 20 percent of all Asian American workers".[33] The fact that occupations with a higher than average rate of minority employment face slightly higher projected rates of automation is arguably problematic, as, on average, African Americans, Native Americans, and Hispanics in the United States have less schooling and fewer digital skills, often have more limited employment networks, and are more likely to face employment discrimination—all of which make successful transition to new work opportunities more difficult.

Disabilities: There does not appear to be any data on how the NPR will impact workers with disabilities. However, it does appear likely the coming wave of technological progress will benefit individuals living with a disability that affects their daily activities. For example, smart-home technology that allows users to control their thermostat via an app using only their voice may be a mere convenience to the average consumer, but provides a sense of independence to someone with mobility impairments. Likewise, the connectivity of 5G combined with the sensing capabilities of augmented reality can make workplaces, schools, and public spaces more accessible to people with a variety of conditions. For example, individuals with limited vision can use augmented-reality glasses to help them navigate their surroundings and recognize objects and faces.[34]

Age: Both data sets suggest younger workers face a slightly higher risk of job loss from new technology than older workers, with a negative correlation between risk of layoff and average age in each occupation (-0.10 for Oxford, -0.11 for ITIF). Occupations with a higher average worker age being less at risk is arguably a positive, as, on average, older workers suffer more severe consequences as a result of being laid off (e.g., they are more likely to have family obligations), and often face more difficulty securing new employment.

Wages and Education Levels: The biggest differential impact of the NPR is likely to be related to wage and skill levels, with automation impacts significantly larger for lower-wage and lower-skill occupations. The correlation between the average wage of an occupation and its risk of automation is negative and quite large (-0.59 for Oxford, -0.52 for ITIF). The correlation of average years of schooling and risk of automation is also negative and large (-0.64 for Oxford, -0.51 for ITIF). And when using ITIF data, the highest risk occupations have the lowest median wage ($32,380), while the next-highest has the second-lowest median wage ($34,990), and so on. The White House Council of Economic Advisors also used the Oxford data and found 83 percent of jobs making less than $20 per hour would come under pressure from automation, as compared with 31 percent of jobs making between $20 and $40 per hour, and just 4 percent of jobs making above $40 per hour.[35] This is not a reflection of the actual wage of the jobs (in fact, the incentive to automate jobs is greater the higher the wage level.) Rather, it refers to the kinds of jobs/tasks that are most amenable to automation (routine, low-productivity jobs that pay poorly). The OECD also estimated 44 percent of American workers with less than a high school degree hold jobs made up of highly automatable tasks, while only 1 percent of people with a bachelor's degree or higher hold such a job.[36]

Many will argue occupations with lower average wages being more at risk is problematic, since it will mean that individuals with lower incomes are more at risk. While true, if this occupational impact pattern occurs, the occupational profile of G7 economies will by definition shift to one with a higher share of middle- and upper-wage jobs (as lower-wage jobs are automated at higher rates and therefore employ fewer people). This would result in relatively fewer lower-paying jobs and more better-wage jobs—a plus for many workers now employed in occupations whose wages remain low and stagnant. The reason behind employment shifting to more middle- and higher-wage jobs is not necessarily intuitive. As more lower-wage jobs become automated, the prices of the goods and services still produced by the lower-wage workers (were there no associated cost savings, firms would have no incentive to employ technology to boost productivity) also declines in relative terms. These savings result in consumers across the income spectrum spending more on other goods and services—with the employment generated by this added production in industries with low-, middle-, and high-wage jobs. Thus, added demand creates more middle- and higher-wage jobs.

Moreover, the fact that many workers in low-wage jobs have more skills than they need for their current job, suggests that at least some workers now holding low-wage jobs have enough skills to move relatively easily into higher paid, moderately-skilled jobs.[37] In all G7 nations there are workers who have college degrees but are employed in jobs that do not require one. Although some are in these occupations by choice, many others settle for these positions because there are simply not enough available jobs that require a college education. On average, these workers should have an easier time transitioning to newly created middle-wage jobs than workers with less education and skills. For the latter, policies to boost skills, especially of workers in low-wage jobs, will be a key to ensuring more workers are able to successfully make employment transitions.

Firm Size: There does not appear be any data related to the potential impact of the NPR on firm size—although the general assumption is the NPR will lead to an increase in average firm size. As Atkinson and Lind find in *Big is Beautiful: Debunking the Myth of Small Business*, average firm size in the United States has increased modestly over the last two decades, in part as ICT has enabled more firms to gain greater economies of scale and market scope (e.g., e-commerce has increased the size of potential markets).[38] NPR technologies, such as AI, are likely to continue this trend. Such a trend should be quite positive, as firm size in all G7 nations is strongly and positively correlated with a set of economic indicators policymakers value: productivity, wages and benefits, worker safety, employment diversity, and even job creation.[39] Regardless, policymakers should be agnostic to firm-size impacts from the NPR. After all, when firms succeed, they are rewarded with robust profits; when they lose out in competition, they shrink or go out of business.

Places: It appears likely the NPR will have slightly different impacts on various places, depending on the extent to which each would be classified as urban or rural. A study by the Center for Business and Economic Research at Ball State University relied on the Oxford data and U.S. Census data to assess the risk of job loss from the NPR based on the category of U.S. county.[40] It found that while the differences between the different types of counties were not large, counties in larger metropolitan areas and more rural areas were projected to lose slightly fewer jobs from automation than mid-sized counties. Likewise, a second study by Frank et al found small cities were the most at risk from technology-based job loss, due perhaps to a number of rural counties specializing in industries in which past waves of automation have already boosted productivity (e.g., mining and agriculture), and many large metro areas specializing in knowledge-based jobs that are harder to automate.[41] Semi-rural and semi-urban counties are at the highest risk perhaps because they specialize more in the production of routine goods and services. Overall, ensuring more effective regional economic development polices will be important in dealing with varying NPR impacts place to place.

PRINCIPLES TO GUIDE NPR POLICY EFFORTS

When it comes to establishing an effective policy regime for advancing NPR innovation while also limiting the negative impacts from increased occupational disruption, there are many things G7 nations can do. While all G7 nations have some effective programs already in place, their challenge will be to learn from both each other and other global leaders to identify and then implement effective reforms and policy innovations. Before discussing some of these ideas, it is worth laying out three key principles that should guide G7 nation efforts.

Principle 1: Embrace and support the next technology wave. Technology-driven innovation is central to the process of increasing living standards because better "tools" allow economies to produce more and better products and services. While some have called for governments to slow the pace of technological innovation, including outright technology bans, restrictive regulations, and taxes on "robots", such steps would limit economic growth while doing little or nothing to help affected workers. These policies would reduce economic exuberance and confidence, thus making it harder—not easier—for workers to find new jobs. Rather, G7 nations should establish policies that not only support the more rapid development of better NPR technologies, but also work to ensure all economic sectors, including government, are transformed by these new production systems.

Principle 2: Focus on helping dislocated workers make speedy and successful transitions. In a natural impulse to alleviate hardship, some want to provide laid-off workers with very generous and long-term benefits. Others want to limit organizations' abilities to lay workers off in response to technological change. Still others call for "universal basic income" for all adults, regardless of employment status. Embracing these proposals would not only slow economic growth by keeping workers out of the labor force longer than would otherwise be the case, they would harm the very workers they are intended to help, as there is strong evidence suggesting the longer a worker is out of the labor force the harder it is for them to re-enter. Rather, the goal should be to support both innovation and effective programs to help workers adjust.

Principle 3: Support a full-employment economy. Dislocated workers will have a much easier time making successful transitions if there are low unemployment rates—not just nationally, but also regionally. This means G7 nations need to ensure not only that monetary policy tilts toward full employment (balanced, of course, with the need to control inflation); but also that they have in place effective economic-development policies and programs for lagging regions so workers in these regions will have more employment opportunities should they lose their job to technology.

POLICIES TO SPUR THE DEVELOPMENT OF THE NEXT PRODUCTION REVOLUTION TECHNOLOGIES

One of the most important things G7 nations can do to advance the NPR is to increase funding of research targeted at these technologies. While the private sector is funding research in these areas, much of it is for later-stage, applied research rather than riskier, longer-term, basic, and earlier-stage applied research. One model could be the STARnet program, a partnership between the U.S. Defense Advanced Research Projects Agency (DARPA) and leading semiconductor companies to support cutting-edge early-stage research at leading U.S. research universities.[42] Other G7 nations may want to consider establishing and cooperating on similar programs that are focused on research areas such as AI, nanotechnology, autonomous systems, and robotics.

As nations support NPR innovation, it will be important that they focus on the entire ecosystem rather than predominantly on small firms and startups—or conversely, on large, established companies. As Atkinson and Lind found in *Big is Beautiful* small companies are not, in fact, more innovative than large companies, as both have a role to play in advancing the next production revolution.[43] For example, a 2013 study by Montresor and Vezzani of European high-tech firms concluded that, "Their capacity for increasing the level of technological knowledge over time is dependent on their size: The larger the R&D investor, the higher its rate of technical progress."[44]

POLICIES TO SPUR THE ADOPTION OF NEXT PRODUCTION REVOLUTION TECHNOLOGIES

The biggest impact from NPR for G7 nations will come from the adoption, rather than the development, of these next-wave technologies. While economy-wide policies and factors, such as taxation and skills, will influence NPR adoption, factors determining adoption will differ industry to industry. For that reason, G7 nations may want to cooperate on the development of sector- and systems-based strategies for NPR adoption. Sectors include firms in the same industry, while systems are broader and go beyond any particular industry. For example, the construction industry comprises firms that build things. But the construction system is broader, and includes providers of materials (e.g., sawmills), designers (e.g., architects), builders (e.g., carpenters, welders, etc.), and building owners. Economies are composed of a wide array of systems, including transportation, information, transaction, and health care. Government can play a key role in helping systems adopt NPR technologies through public procurement to drive competition and change, supporting precompetitive industry R&D, and streamlining and aligning regulation. They can also fund pilot demonstration programs and compare outcomes in areas such as smart cities, smart grid, and smart healthcare.

Much of the next production revolution, particularly artificial intelligence, will depend on data. To maximize the effectiveness of AI, nations will need to establish privacy regulations that not only ensure widespread public trust in the use of data, but also enable the use and reuse of data by organizations, much of which will not be related to persons and as such should not be subject to privacy rules. But some data will relate to persons (e.g., health data, education data, etc.). However, in many cases, organizations can use big data sets in ways that effectively de-identify data so that the risk of reidentification is extremely low. It will also be important for cross-border data flows to be enabled as firms in a wide array of industries, including mining, banking, retail, automobiles, and health care, currently rely on cross-border data flows to drive innovation.[45]

Moreover, national privacy rules do not need to be harmonized to enable safe cross-border data flows because those rules "travel" with the data—although firms cannot escape national regulatory privacy requirements by moving data to another nation with weaker standards.[46] In other words, if a U.S. firm doing business in Europe collects data on EU persons and moves those data to the United States for processing, the U.S. firm must comply with the EU privacy regulations because the data are on EU persons.

POLICIES TO RESPOND TO EMPLOYMENT AND OCCUPATIONAL DISRUPTION

If G7 nations are to avoid a populist backlash against the NPR, they will need to take greater and more effective steps to help regions and individuals at risk from technology disruption.

Regions: To help communities and regions maintain their economic base in a time of technological disruption, nations need to rethink—and in some cases, expand—their regional development efforts. While some workers who lose their jobs from new technologies can and will move to regions where employment growth is stronger, not all workers will be able, or willing, to do so. As such, smart policies and programs to spur growth in these lagging communities can help minimize social disruption from the next production revolution.

Workers: G7 nations can do more to ensure workers displaced by technology change have stronger capabilities and tools to make successful transitions. Overall, policymakers should embrace the concept of "flexicurity," as Scandinavian nations have, which rather than attempting to ensure no workers will ever get laid off, minimizes the number of workers who are at risk. And for those who do get laid off, it provides support so they can make successful and expeditious transitions. Policymakers should also consider adopting operational models identical to those of some of the world's best-in-class programs, such as Singapore's Skills Future program, the lessons from which are fourfold. First, policy needs to make a major commitment to skill development and workforce transition. Second, such efforts need to be closely linked to employers and markets, including though workforce training vouchers and credits. Germany has done an excellent job in this regard with its longstanding and widespread employer-supported apprenticeship system. Third, such efforts need to be much more flexible and less bureaucratic and take full advantage of advanced information technology tools. Finally, incremental changes in existing institutional arrangements will not be enough. If policymakers are to respond effectively to the challenges of a more turbulent labor market, they will need to drive significant institutional reform, particularly in the high school and higher education sectors, and focus on providing more support for institutions focused on technical training and providing skills employers value.

G7 nations may want to focus on several areas. For example, they could help facilitate more workers obtaining better skills and other competencies such that if they are dislocated by technology, they will be better positioned to make a successful transition. One key is to shift the education system, particularly at the high school and post-secondary levels, toward in increased focus on teaching both "21st-century skills" and more technical skills needed by employers.

As Manuel Trajtenberg wrote in a study of the NPR and workers, the skills employers desire and demand are poorly related to the competencies taught in school. Employers want workers with strong analytical, creative, and adaptive capabilities, which are competencies few secondary or collegiate schools impart.[47] Moreover, schools appear to be teaching technical subjects that are unrelated to the needs of the next economy. For example, more high school students in California take pottery than computer science.[48] And only 7.7 percent of U.S. high school students successfully complete a statistics class, compared with approximately 87 percent for geometry; yet statistics is clearly a much more valuable competency than geometry.[49] Thus, reforms such as high school career academies;[50] project-based learning; reducing the rigidity of state high school graduation course distribution and graduation requirements; and focusing on increased adoption of workforce-focused classes, such as business, statistics, computer science, and engineering, would all help future workers have a stronger base of skills with which to manage a more turbulent workforce. For example, the United Kingdom has established a mandatory national computing curriculum that sets out core computer science competencies for all students to master before leaving secondary school.[51]

In addition, more should be done to encourage and support corporate partnerships with new kinds of high schools. For example, IBM has worked to develop P-TECH (Pathways in Technology, Early College High School) in New York City, which runs from grade 9 to grade 14, and works to give students marketable skills in information technology.[52]

At the college level, G7 nations should focus on creating or transforming more colleges into new kinds of employer-relevant schools focused on ensuring students learn skills employers value, such as business-oriented writing, reasoning and critical thinking skills, statistics, public speaking, and computer science. An example of this is the University of Harrisburg, in Pennsylvania, a recently established private university focused on responding to the needs of employers in the region for workers educated and trained in applied sciences and technology-related fields. The university provides degrees in areas such as Analytics, Interactive Media, and Geospatial Technology. Another model is the Canadian system of polytechnics, in which publicly funded colleges and institutes of technology offer both four-year and advanced two-year degrees, certificates, and in-class training for apprenticeships.[53] The focus is on skills and technology, although hands-on learning opportunities are integral to the curriculum.

At the same time, G7 nations can do more to encourage employers to expand workforce training efforts. This can include wider use of portable skills credentialing; supporting sector-wide training and development plans, as Singapore has done; establishing an "Investors in People" program modeled on the United Kingdom's program of presenting an annual award to employers who do the best job of investing in their workforce; supporting industry-led skills alliances; encouraging the greater use of apprenticeship programs, as Germany has done; and increasing the use of portable training accounts, as France has established.[54]

G7 nations could also productively cooperate on how to better use technology to facilitate online skills assessment, career navigation, training, and workforce placement. Many government-run websites that attempt to do this are poorly designed, difficult to use, and limited in their offerings. Governments should therefore consider partnering with the private sector in this area. For example, the Markle Foundation's Skillful Initiative, funded in part through Microsoft Philanthropies, has partnered with LinkedIn to establish an online tool to help workers in the state of Colorado identify training for in-demand occupations.[55] Likewise, the U.S. Council for Adult and Experiential Learning has created websites that help workers understand the competencies needed for jobs in the petrochemical and financial services industries, find training for jobs in these industries, and ultimately find specific jobs.[56]

POLICIES RELATED TO COMMON APPROACHES TO AI

As AI matures and works its way into more aspects of society and the economy, some advocates have voiced concerns over potentially harmful consequences, such as it amplifying human bias, and they have argued that governments are not well-enough equipped to effectively govern its use. However, given the nascent and still evolving nature of AI, early regulation of AI could very well reduce its benefits without effectively mitigating risks.

It is neither necessary nor desirable to implement cross-border regulation of AI. AI will impact an array of economic functions, many of which are already regulated, and national governments vary widely in their regulatory approaches and priorities, making it unrealistic to expect countries to agree on common international regulations for AI. While international cooperation can and should play a key role in supporting the development of AI, such as by protecting cross-border data flows, any regulatory issues presented by AI are best addressed at the national level. Of course, the standards for these technologies will need to be developed internationally, through bodies like the International Standards Organization, Internet Engineering Task Force, and other voluntary, industry-led bodies.

Furthermore, regulatory approaches to AI, either national or international, should focus on the ends, not the means. AI is simply a tool that can be deployed in a wide variety of public and private sector applications, ranging from credit reporting to transportation to cancer screening—with many application areas already subject to specific regulation. Should the introduction of AI into a particular sector require a change in regulatory approach, any new rules should be narrowly tailored to that sector, not based on broad-scale regulation of AI itself. Any regulation should not be focused on the tool (AI), but on the use of the tool.

Moreover, efforts to ensure unbiased use of AI should be focused on accountability, rather than transparency. There is a growing push by a number of advocates for algorithmic transparency—the principle that public and private sector organizations should expose their algorithms and data to public scrutiny in order to open up AI "black boxes" and identify if and how they are producing unintended or harmful outcomes. As AI systems can be incredibly complex, the way they process data to make decisions is often opaque, leading many to believe "pulling back the curtain" on these systems to reveal their inner workings would curtail any harmful applications. This sentiment often manifests itself as demands for "algorithmic explainability," which would require an AI system to justify its decision-making to affected parties.

However, requiring algorithmic transparency or explainability would fail to accomplish this, at least with current technology, as explainability is not something that can just be turned on.[57] Because AI systems are so complex, process such large amounts of data, and can change as they encounter new data, regulators, members of the public, and even systems developers are not always able to glean meaningful information by shining a light into the inner workings of these systems. Additionally, there is no compelling reason to require an explanation for a decision when the consequences of error are minimal (e.g., your phone voice assistant giving you a picture of a dog when you ask for a cat). Nor is there a compelling reason to require an explanation *solely* because an AI system helped make a decision, which would hold AI to a standard that does not exist in a world where humans make decisions, many of which are unintentionally biased.[58] In situations where explanations are necessary, such as a creditor having to explain to a consumer why their application was denied, existing regulations already apply, regardless of whether a human or an algorithm made the decision. Furthermore, from a technical perspective, there are potential tradeoffs between explainability and accuracy. In some cases, increasing an AI system's accuracy involves increasing its complexity, which can also make the system harder to interpret, while making a system more explainable means reducing its complexity and potentially its accuracy as a result.[59] In applications that require high degrees of accuracy, such as autonomous vehicles or health care, a less-accurate but more-explainable system would be less desirable than a highly accurate but inexplicable system.

Instead, when governments consider AI governance, they should focus on promoting algorithmic accountability: the principle that an algorithmic system should employ a variety of controls to ensure that it acts in accordance with its developers' intentions; unintended outcomes can be identified and rectified; and the algorithmic system maximizes beneficial outcomes in accordance with relevant legal, economic, or social context.

Finally, regulation of (and NPR technologies in general) should not be based on the precautionary principle, which focuses on pre-emptively guarding against the hypothetical risks a technology might pose. Despite the recent rapid development of AI and related technologies, NPR technologies are still in their infancy, and their impact on society and the economy is only just starting to be realized. Imposing restrictive regulations on these technologies based on speculative fears would slow their development and limit their benefits. G7 countries should instead embrace the innovation principle, which states that policymakers should address risks as they arise, or allow market forces to address them, and not hold back progress because of speculative concerns.[60]

COMMON THEMES AND CONCLUSIONS:

The G7 partners can make an important contribution by agreeing to common principles and commitments in response to the NPR. They are:

1. The Next Production Revolution will be a progressive force in G7 economies, generally raising productivity, living standards, and innovation. As such, the G7 governments commit to supporting NPR innovation and associated organizational transformations.

2. To maximize both the potential of the NPR globally and within G7 economies, G7 governments should increase cooperative efforts to support innovation, including establishing cooperative R&D efforts and supporting a shared, voluntary, industry-led standards-setting process for Industry 4.0 and other related technologies.

3. It will be difficult for any G7 nation to fully reap the benefits of the NPR if the benefits are not reasonably shared and workers who are dislocated by technological change are not given effective help to ease labor market transitions. As such, G7 nations should commit to identifying what is working best within their own

nations, and cooperate with other nations to help put in place global best-in-class regional development, workforce education and training, and worker-readjustment policies.

4. The NPR is still at its very early stage, and as such it is extremely difficult to predict how the technologies will develop or be applied, notwithstanding the predictions of supposed futurists to the contrary. Nations would be well advised not to apply the precautionary principle to these technologies, as overly restrictive regulations will slow the development of both NPR innovation and the adoption of NPR technologies.

If G7 nations work together cooperatively, in a spirit of embracing the NPR, while also working to ensure the benefits are widely shared, they can look forward to a more prosperous economic future over the next several decades.

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