Chapter 4

Contemporary Great Power Technological Competitive Factors in the Fourth Industrial Revolution

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The convergence of new technologies is creating a fourth industrial revolution that will transform almost every aspect of 21st-century life. Even as the new technologies generate much greater wealth, the revolution will reshape trade patterns as it returns both manufacturing and services to home markets. The United States is particularly well positioned to take advantage of these changes—but only if it revises its immigration policies to attract and retain the best minds from around the world. China is also well positioned, but it must overcome increasing distrust of its government. Russia is dealing with an ongoing demographic crisis even as foreign and domestic investors have lost trust in its potential for growth.

As with earlier iterations, the fourth industrial revolution is developing from the convergence of multiple technologies. Despite the shorthand sometimes used to identify the three previous revolutions—steam, electricity, digital—none was driven by a single technology.[1] Each needed a merging of numerous new technologies alongside relevant economic, social, and political change before it could evolve.

In *The Fourth Industrial Revolution*, Klaus Schwab states that the unifying of new technologies—"artificial intelligence [AI], robotics, internet of things, autonomous vehicles, 3D printing, nanotechnology, biotechnology, material science, energy storage, and quantum computing, to name a few"[2]—is going to revolutionize almost every aspect of life, mostly in a positive way. But when discussing the fourth industrial revolution's impact on international security, he was concerned that the technologies will provide much greater power to nonstate actors and create instability in many regions. Therefore, the fourth industrial revolution is a critical factor in the emerging era of Great Power competition (GPC) headlined in 2020 by the United States, China, and Russia.

In this chapter, we do not attempt to deal with all the technologies driving the fourth industrial revolution; instead, we focus only on those that will most directly impact GPC, economic potential, and international trade in the short term: robotics, AI, 3D printing, energy, and biotechnology. The chapter also considers two important factors essential to

U.S. efforts to exploit new technologies: current immigration policy and research and development (R&D) investments.

Although we discuss each of these technologies individually, it is the combination of them in new ways that will revolutionize the global economy. For instance, the first industrial revolution is often referred to as steam driven, but steam had to be combined with improved steel production, new manufacturing techniques, the telegraph, and other technologies both new and old to create the railroads that revolutionized trade and production. While space limitations forced us to select only a few of the technologies driving today's revolution, readers should keep in mind that the others are essential to enabling the chosen technologies (for instance, advances in material science are essential to advances in the chosen technologies).

Robotics

Robotics covers a vast field that will fundamentally alter how humans do things—from in the deep sea to outer space. We start by examining industrial robots and then move on to collaborative robots.

General Motors purchased its first industrial robots in 1961. Since then, robots have steadily evolved with improvements in degrees of freedom, range of motion, strength, speed, reliability, accuracy, and repeatability. Industrial robots' increasing flexibility and effectiveness are resulting in rapid and steady growth of sales. Sales averaged 115,000 per year from 2005 to 2008 but increased to 422,000 by 2018.[3]

Sales keep growing because robots dramatically improve productivity. The U.S. steel industry offers a prime example. From 1962 to 2005, it shed 75 percent of its workforce, but its shipment of steel products in 2005 equaled that of the early 1960s. Robots increased output per worker by a factor of five. Despite the massive shedding of jobs in the industry, steel manufacturing has been one of the fastest growing industries in the past three decades, behind only computer software and equipment.[4]

New sensors and improved mechanics mean industrial robots are becoming cost effective even in high-tech industries. China's Changying Precision Technology Company has automated its mobile phone production lines and cut factory personnel from 650 to just 60 while increasing productivity by 250 percent.[5] Although perhaps an extreme example, this type of streamlining is driving chief executive officers to explore how industrial robots can improve their companies' competitiveness. Robots tasked with routine computer electronics assembly cost about $7.25 per hour to operate, and the purchase cost of robots is expected to come down 22 percent by 2025, even as these machines become easier to integrate into current operations.[6] In 2020, Chinese labor costs $6.50 per hour.[7]

Products with potential for even greater growth—and hence greater impact on many aspects of life—are collaborative robots, or *cobots*. Unlike industrial robots, which must be separated from humans for safety, cobots are specifically designed to work in collaboration with people. And unlike industrial robots, which are expensive and have limited flexibility, cobots are cheap and flexible. Designed to be mobile, they are easy to be moved to different locations and assigned new tasks. They are already working in homes, laboratories, hospitals, nursing homes, warehouses, farms, and distributions centers to tend, test, carry, assemble, package, pick, place, count, secure, and inspect.[8] They are even being used as exoskeletons to provide strength and protection to people. And unlike most large industrial robots, cobots are relatively easy to upgrade.[9]

In 2019, basic cobots cost about $24,000.[10] Assuming a 40-hour workweek and 3-year lifespan, this works out to approximately $4 an hour—well below U.S. labor costs and competitive with wages in emerging economies. And if a plant is running with three shifts, the hourly cost is about $1.35—well below even most emerging economy wages. Of course, robots need no medical, retirement, or leave benefits. Just as important, cobots are easily programmable. In fact, a "non-technical person can teach [a cobot] what to do through arm movement and simple button presses, and [a cobot] can master a new task in half an hour or so. There is also little assembly or setup required."[11] Moreover, the low prices, minimal technical support required, and flexibility mean that many of the 6 million small and medium enterprises worldwide will buy cobots. Goldman Sachs notes that today's versions have a payback period as short as 6 months.[12] ABI Research predicts global revenue from cobots will "grow at an annual rate of 49.9 percent between 2016 and 2025 compared to 12.1 percent for industrial robots."[13]

Even as costs of cobots come down quickly, their capabilities are growing at an exceptional rate. In 2012, the Defense Advanced Research Projects Agency awarded a $1.3-million grant to develop a robot that could sew. Inevitably nicknamed "sewbots," these systems are mastering the complex task of sewing—and thus are threatening to disrupt the global clothing industry.

The field of robotics seems to have reached the knee of its exponential growth curve—the point at which the curve turns vertical. From heavy-duty industrial robots to small personal robots, the range of capabilities is expanding rapidly even as cost drops and ease of use improves. By eliminating any labor-cost advantage to production in low-cost regions, robots are, and will continue to be, central to the return of production to home markets. Even as industry masters the mechanical aspects of robotics, key advances are being made in the field of AI, which will further enhance the advantages robots provide in production.

Artificial Intelligence

AI will play the role electricity did in the second industrial revolution, when the world moved from steam to electrical power; it will be an integral part of every new technology. From task-specific AI that autonomously executes a job such as controlling a mining truck in an open pit to more powerful AI that assists with complex planning, analysis, and decisionmaking, this technology will be essential. Unfortunately, the term *artificial intelligence* causes considerable confusion. Much of the current discussion concerns artificial general intelligence (AGI), which itself boasts a range of different definitions. In fact, there is a great deal of disagreement in the AI research community as to when or even if AGI is achievable. However, this chapter focuses on how limited, or task-specific, AI is rapidly improving productivity. Task-specific AI is essentially a machine operating with a set of guidelines to accomplish chores. Although such a system will provide great practical capabilities in its specific field, it will not be capable of fully independent operation.

Task-specific AI-driven robots are executing manual tasks in virtually every field of human endeavor, but AI is not limited to physical work. In January 2017, Japanese insurance company Fukoku Mutual Life Insurance replaced 34 insurance claim workers with software from IBM Watson Explorer. The software scans hospital records and other documents to determine insurance payouts, factoring in the specific injuries, each patient's medical history, and the procedures administered. Fukoku Mutual reportedly spent $1.7 million (200 million yen) to install the AI system, and now pays $128,000 per year for maintenance. By using the software, the firm saves roughly $1.1 million per year on employee salaries—meaning it hopes to see a return on the investment in less than 2 years.[14]

This kind of breakthrough acts as a major incentive for other firms to follow suit—simply to remain competitive in their industries. The result has been a steady return of service industries to their home countries as AI takes over many of the back-office tasks, such as computer programming, bookkeeping, handling insurance adjustments, and manning call centers, that used to be contracted to firms in India or the Philippines.

Another form of AI can develop optimal designs for a wide variety of structures. Autodesk's "Dreamcatcher system allows designers to input specific design objectives, including functional requirements, material type, manufacturing method, performance criteria, and cost restrictions."[15] But the improved designs often cannot be produced using conventional manufacturing techniques,[16] thus the need for another emerging technology: 3D printing.

3D Printing

The first 3D-printing patent was granted in 1986. Slow speeds and uneven finishes meant that 3D printing was initially used mainly to produce prototypes and a limited number of unique low-volume products. But in the past decade, it has transformed from an industry focused on prototyping to one engaged in creating a wide range of products. In addition to increasing the speed of printing and refining the finishes, a great deal of effort has gone into expanding the number of materials that can be used. More exciting, 3D manufacturing is rapidly developing entirely new materials: "up to 140 different digital materials can be realized from combining the existing primary materials in different ways."[17] 3D printing is quite literally changing what can be made.

Meanwhile, researchers and 3D-printing companies continue to pursue both versatility and speed. Multimaterial printers were one of the big steps in this effort. Instead of printing a series of pieces that then must be assembled, the multimaterial machine forms the assembly in one go. As businesses learn to use these multimaterial printers, the range of products they will be able to print will expand exponentially. Furthermore, 3D printing's efficiency is unmatched: Its material wastage is near zero.

The range of products—from medical devices and aircraft parts to buildings and bridges—and the order of magnitude increase in the speed of printing are already challenging traditional manufacturing.[18] Better printing speeds mean that 3D printing has moved beyond prototyping and high-value parts. In April 2016, Carbon3D released a commercial printer that was 100 times faster than existing printers. Such improvements allowed 3D printing to capture 20 percent of the global plastics manufacturing market in 2016.[19] Not to be outdone, metal printers have combined high speed and low cost to make them a system of choice even for mass production of small parts. The fact that key patents are expiring soon will further accelerate enhancements in printer capabilities and capacities.[20]

3D printing opens up the possibility of a totally different supply chain, one that runs with lower costs and a smaller carbon footprint. The materials and energy required for manufacturers to create new parts will be harnessed into electronic design files that can be printed on demand anywhere in the world. In these new transformative supply chains, many spare parts may not even need to exist, which could translate into huge savings on warehousing costs.[21]

3D printing is revolutionizing manufacturing in many industries. The ability to change each product by changing the software means the era of mass customization and local production is on us. No longer will parts have to be shipped across oceans and then trucked to the user; they will be printed on site. 3D printing is clearly on the path to causing major disruptions in global supply chains.

Energy

Energy, in the form of petroleum, natural gas, and coal, has been a key component of global trade for the past half-century, but the influence of petroleum on both global trade and national security may be waning. Rapid advances in energy technology are changing the world's energy markets—and in many cases moving energy sources from overseas companies to locally produced oil, gas, and renewables. In its *World Energy Outlook 2017*, the International Energy Agency stated, "Four large-scale shifts in the global energy system set the scene for the World Energy Outlook 2017: the rapid deployment and falling costs of clean energy technologies, the growing electrification of energy, the shift to a more services-oriented economy and a cleaner energy mix in China, and the resilience of shale gas and tight oil in the United States."[22]

Gas and Oil

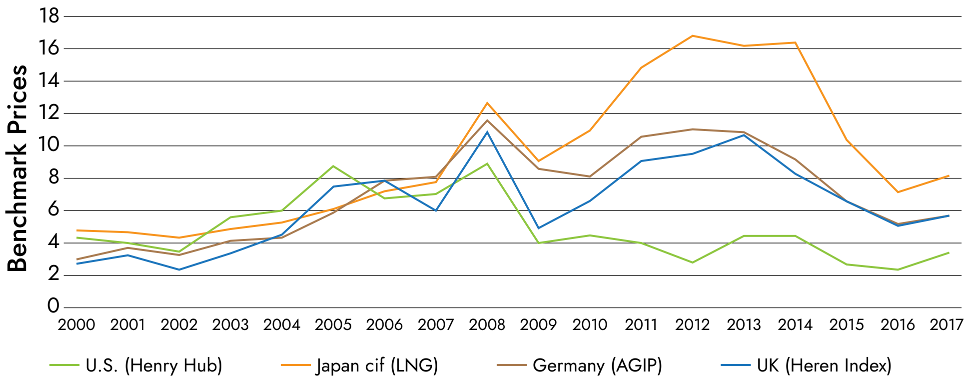
The U.S. fracking revolution is driving a global increase in demand for natural gas, even as oil use may have peaked. In November 2016, the *Wall Street Journal* ran a front-page article reporting that global oil producers such as Royal Dutch Shell and even state-owned Saudi Aramco anticipate that the world has reached peak oil usage and are preparing for a future decline in demand.[23]

U.S. shale oil production (fracking) has been the fastest growing source of oil globally. In 2012, the U.S. Energy Information Administration (EIA) estimated that shale oil production could reach 2.8 million barrels per day (bpd) by 2035; it did so by 2013.[24] In late November 2014, the EIA predicted the United States would become the world's largest oil producer by 2020.[25] This milestone was reached by June 2014.[26]

Perhaps the most powerful aspect of U.S. shale oil operations is the speed with which they can be closed or reopened in response to demand. From October 2016 to January 2017, U.S. crude production increased 500,000 bpd in response to the West Texas Intermediate (WTI) price increasing from $45 to $50 a barrel.[27]

The combination of the novel coronavirus pandemic and the short-term Saudi-Russian "oil wars" resulted in a collapse in the price of oil to less than $20 a barrel. Even the April 2020 tentative pact between Russia and Saudi Arabia did not result in major price increases. In mid-April 2020, *The Economist* predicted that oil prices will remain low as the oil industry restructures post-pandemic.[28] Although price spikes will still occur during times of crisis, U.S.

Figure. Global Natural Gas Benchmark Prices in USD per MMbtu



shale oil supplies may well ensure that the WTI price will not exceed $60 a barrel (in 2018 dollars). Even the September 14, 2019, attack on Saudi oil facilities resulted in only a few days' increase to the mid-$60s before WTI returned to the mid-$50s.

Natural Gas

Fracking has also created a natural gas boom in the United States. As recently as 2007, U.S. companies were racing to build liquid natural gas (LNG) import facilities. The demand for natural gas was growing quickly, and U.S. production was falling. In October 2005, the Henry Hub (U.S.) spot price rose to $13.42 per million British thermal units (MBTU). Then the fracking revolution occurred, which forced a massive drop in price to $1.93 per MBTU by December 2015—a reduction of 85 percent (see figure). Suddenly companies were applying for permits to turn their LNG import facilities into LNG export facilities.

As late as 2005, those U.S. industries that made heavy use of natural gas for their products (for instance, the petrochemical industry) or to generate energy for production were at a disadvantage in global competition. U.S. companies paid significantly more for this vital input. By 2008, fracking had completely reversed the situation, and the cost advantage to U.S. manufacturers has only increased since then.[29] The result has been heavy investment in new U.S. petrochemical plants that use natural gas as a feedstock, with 310 new projects under way that will satisfy most U.S. demand and increase U.S. exports from $17 billion in 2016 to $110 billion by 2027.[30] This unplanned advantage for America's chemical subsector will have spillover benefits as the expansion stimulates local development of directly related service and manufacturing businesses.

Renewables and New Transmission Lines

In its 2017 report, the International Energy Agency (IEA) noted new renewables installation increased to almost two-thirds of all newly installed electrical energy production.[31] By 2021, global generation from renewables should be "equivalent to the total electricity generation of the United States and the European Union put together today."[32] In its 2019 *Global Energy Perspective*, McKinsey & Company predicted that, even as energy consumption doubles by 2050, renewables will generate over 50 percent of the world's electricity by 2035.[33]

In 2006, the IEA predicted that by 2013 global installed photovoltaic capacity would be 20 gigawatts; it was actually 7 times larger—140 gigawatts—and increased to 227 gigawatts by 2015. These statistics reflect only utility-scale generating capacity and thus do not account for the growing private installation of renewable energy. Both developing and developed countries are seeing huge growth in local production and grids.[34] In fact, Bangladesh is the world's largest market for home-based solar power systems.

During the first three quarters of 2016, 15 percent of additional residential and nonresidential solar generating capacity was privately installed in the United States.[35] Business is also growing in providing renewable energy to major corporations.[36] However, two major problems with renewables persist. First, they are inherently intermittent. Wind intensity varies in unpredictable ways, and solar fails every night and during bad weather. Even hydropower is subject to reduction during periods of drought. Second, the best solar exposure or steadiest winds are often far from the places where people live. Thus, renewable energy and power transmission must be thought of as an integrated problem. Around the world, nations and private business are installing renewables along with long-line high-voltage transmission systems.

Like Europe and China, the United States needs to invest in transmission lines if it is to maximize the use of renewables. Fortunately, it has a successful model—Texas. Because its power grid is contained within the state, Texas overcame the various forms of political resistance and built transmission lines from its windy western plains to its energy-hungry eastern cities. At times, wind provides 40 percent of the state's power needs. Other regions have great potential for renewables—for example, the Great Plains and offshore for wind and the Southwest for solar. In March 2017, Xcel announced plans to install 800 megawatts of new wind generation capability in the Dakotas and Minnesota.[37] Delayed by regulators since 2005, a 3,000-megawatt line is finally being built to take Wyoming's wind energy to southern California.[38] Other investors are seeking to link wind and solar energy to the southeastern and eastern United States.

Impact of Batteries on Energy Sources

Whether users are major power companies looking for a way to store power to feed back into the grid or individual homeowners seeking to get off of it, batteries can offer them an alternative to fossil fuel backups. This is another field in which many researchers—commercial, government, and academic—are pursuing a variety of possibilities. Major battery technology breakthroughs in 2019 include a battery that can fully charge in 10 minutes, thermal-energy devices that can store 1.2 megawatt-hours and can be hooked in series to create almost unlimited storage, and new processes that could double the storage capacity of lithium-ion batteries.[39]

Commercial power companies need massive storage capability to take over the "peaker" function now performed by natural gas–burning plants. These plants come online only during periods of peak load to prevent brownouts or even blackouts. Driven partly by California's Public Utilities Commission, Southern California Edison plans to install a 100-megawatt storage battery by 2020. Moving much more quickly, Elon Musk combined Tesla Motors and SolarCity to create a new way of supplying power. In July 2017, he signed a contract to provide 100 megawatts of storage in Australia and had the system running and highly profitable by January 2018.[40] By October, it was on "track to make back a third of its construction costs in its first year of operation."[41] Tesla has contracted to increase the capacity of this system by 50 percent in 2020.[42]

The convergence of fracking, renewables, energy grids, and batteries means that more and more energy production will be local or regional. Renewables can be moved vast distances via transmission lines, so they can tie a region together. But there will not be a global market for renewables. Unlike oil, propane, coal, and LNG, it is impractical and unnecessary to move renewable energy across oceans. Thus, unlike the gas/oil market, which contributes to globalization, the renewables market will contribute to regionalization—and even to localization—as more and more businesses and homes take advantage of better battery capacity to move off-grid.

Emerging Biotechnology

Just as information technology and the Internet have transformed society, business, government, and warfare since the late 20th century, emerging biotechnology will shape the global landscape for the next several decades. The world is entering a new era of biotechnology, highlighted by the advancing ease with which genomes can be engineered for specific purposes. Synthetic biology and associated genome-editing tools will be essential for addressing the global challenge of resource scarcity and environmental sustainability, while providing unprecedented advances in public health and medicine. The expanding U.S. biotechnology industry, including a wide range of startup companies, along with larger scale corporations, is already exploring capabilities for manufacturing high-value products, creating what is now referred to as the bioeconomy. Products of the bioeconomy include the creation of biology-based commodities, fuels, textiles, and consumer goods—all of which are proposed to be produced on innovative biomanufacturing platforms. Because the locus of this economic innovation is in industry, and particularly startups, government funding does not primarily drive the bioeconomic trajectory, making government just one of many actors shaping the field. In order to establish and maintain global leadership in biotechnology, the United States requires a holistic national approach that supports innovation and growth in the bioeconomy, establishes strategic priorities, and ensures responsible use.

Emerging biotechnology will have important implications for the Department of Defense (DOD), and internal DOD leadership has acknowledged this by including biotechnology as one of its 11 modernization priorities.[43] Moreover, DOD intends to create a community of interest in biotechnology to coordinate biotechnology R&D across the Armed Forces. Just some of the many promising advances for defense could include innovative body armor designed from spider silk, jet fuels or runway material produced from algae, living plant-based sensors, and flame-resistant coatings. Many other advances, such as those related to skin or gut microbiotics, could benefit the health or performance of warfighters directly; however, DOD is not driving biotechnology innovation, and many challenges exist to the most beneficial incorporation of biotechnology into DOD requirements. Outside of traditional force health protections and the development of medical countermeasures, what advantages over adversaries could biotechnology provide? What unique DOD challenges and problems are best met with biotechnological solutions versus other emerging technologies? These questions have yet to be addressed as industry continues to innovate.

At the same time, new dual-use technologies for defense will present significant challenges to biodefense, in addition to the ethical and moral dilemmas they have already created; the capabilities that drive the U.S. bioeconomy are the same tools that could allow for the creation of bioweapons (see also chapter 8). Most recently, the National Academy of Sciences published a biodefense consensus report, providing a framework for assessing those capabilities that are the most concerning to the DOD warfighter—namely, the creation of viruses from scratch, the modification of harmful bacteriological pathogens, and the development of harmful chemicals through biomanufacture.[44] DOD will need to address these issues in ways that do not stifle the technology's advancement or America's competitiveness in the global bioeconomy.

Enabling Factors

As noted in the introduction, two factors should enable U.S. technological advances. The first, investment, is on a positive trend; the second, immigration policy, is having a powerful negative effect.

Obviously, in a period of swift technological change, robust investment in R&D is essential to leveraging those shifts. Fortunately, despite all the hype about the Made in China 2025 plan to dominate 10 key emerging technologies, the United States still invests significantly more in R&D than does China. Unfortunately, from 2003 to 2016, U.S. Government spending in nondefense R&D was essentially flat. Since then, government investment has increased sharply.[45] In 2018, the United States invested 2.84 percent of its gross domestic product (GDP) in R&D. China invested only 1.97 percent of a significantly smaller GDP.[46] The key question is whether the United States will sustain this investment in the face of rapidly increasing debt-servicing costs and continued deficit spending.

The bad news is that current U.S. immigration policy is having a major negative impact on America's progress toward a fourth industrial revolution economy. While immigration policy is a hot political issue, one element that is not usually associated with immigration is the intellectual nature of the fourth industrial revolution. Exploiting the revolution requires large numbers of smart, skilled, and educated people. Innovation at the top of the scale requires advanced education in science, technology, engineering, and math (STEM) skills. The 330 million people of the United States cannot hope to stay ahead of the 7 billion people in the rest of the world. In the past, the United States has had great success by encouraging the best STEM students from around the world to come to America for an education and then stay to work.

In 2017, foreign nationals in the United States accounted for 81 percent of the full-time graduate students in electrical engineering and petroleum engineering; 79 percent in computer science; 75 percent in industrial engineering; 69 percent in statistics; 63 percent in mechanical engineering, and economics; 59 percent in civil engineering; and 57 percent in chemical engineering.[47]

The United States is generally recognized as having the finest university system in the world, and it attracts large numbers of the best foreign students. This is a major advantage, but what really counted was the fact that the number of foreign STEM graduates who chose to remain in the United States to work increased by 400 percent from 2008 to 2016. Essentially, the United States was attracting and keeping some of the finest minds in the world.

The policy of encouraging immigrants to stay paid off. Despite representing only 13 percent of the U.S. population, immigrants start more than 25 percent of the new businesses in the United States. More than 20 percent of the chief executive officers of the 2014 Inc. top 500 business are immigrants.[48] And 55 percent of the new companies worth more than $1 billion have at least 1 immigrant as a founding member.[49]

Then, in 2017, two things happened that dramatically reversed the flow of foreign students into U.S. universities. First, the U.S. Government made it much harder for students to obtain visas or to be certain they could renew them year to year. At the same time, the Trump administration restricted the number of graduates who can remain in the country to work. The result has been a major downturn in the number of foreign students enrolled in U.S. universities. Other countries, having seen the success that the United States was having, have started their own aggressive recruiting programs to attract foreign students—and current U.S. policy is only assisting those foreign programs in attracting top students. It makes no sense for a foreign student to invest heavily in a U.S. education when the visa might not be renewed and thus the investment will not pay off in a degree; even if he or she succeeds in getting a degree, the U.S. job market, which needs STEM graduates, will be closed. It makes much more sense for these students to go to school in Canada, Australia, or the United Kingdom. Canada and Australia, in particular, are encouraging overseas students.

Not only do current U.S. policies deprive the United States of intelligent, productive students and potential citizens, they also hurt America universities. Overseas students pay much higher tuitions than do U.S. citizens and so, in effect, subsidize their education. Universities across the country are having to cut STEM programs due to the reduction in funds flowing in from overseas.[50] In short, U.S. immigration policies in 2020 are directly responsible for reducing the flow of the people America needs to thrive in the fourth industrial revolution. By failing to effectively distinguish between types of potential immigrants, the United States is excluding a great deal of talent. In sharp contrast, forward-thinking governments elsewhere are enticing the best and brightest from around the world to move to their nations. Current immigration policies are damaging American prospects for success in a rapidly changing global economy.

Conclusion

The convergence of the aforementioned technologies will change societies in ways that are hard to imagine. It is already clear these technologies will change what, how, and where we manufacture commodities. Most important, manufacturing will be located near the market, which means the trend of onshoring manufacturing to America will continue. New technologies are also returning service-industry jobs to the markets they aid, and renewable energy is inherently regional rather than global. Environmental movements will reinforce these trends by pushing to reduce the impact of manufacturing and agriculture on the environment.

The fourth industrial revolution is shifting trade networks from the global to regional and even local levels. The United States may well be the nation best positioned to benefit from this shift. The U.S. economy already derives 84 percent of its GDP from the United

States, Canada, and Mexico. Although the supply chains are deeply embedded in Asia, U.S. manufacturing and services have been in the process of moving production back to the United States for years. The United States benefits from effective rule of law, strong protection of intellectual property, the largest market in the world, an exceptional university system, heavy investment in R&D, and a pervasive entrepreneurial spirit. These attributes will allow the country to thrive in this era of rapid technological change.

Until 2017, foreign investors thought so too. Foreign direct investment (FDI), particularly in manufacturing, was running at record levels in 2015 and 2016. Unfortunately, the uncertainty introduced by tariffs has reduced FDI into the United States by over 50 percent. However, the long-term advantages are still present, and FDI flows should recover once the United States establishes and sticks to stable trade agreements. America must also ensure its immigration and R&D policies do not hold it back. Economically, the United States has distinct advantages over both China and Russia as the fourth industrial revolution begins to reshape our world. The one key weakness is the gridlock in America's current political systems. Failure to adjust our laws and regulations to the new reality risks squandering those advantages.

China could also benefit greatly from the fourth industrial revolution. The Chinese Communist Party specifically developed its Made in China 2025 plan to take advantage of the new technologies. The party selected 10 priority sectors to subsidize, which included robotics, green energy, artificial intelligence, biosciences, and materials. Essentially, China is investing heavily in each of the technologies discussed in this chapter; it is also working hard to shift its economy from export based to consumption based, to decrease its reliance on exports. It needs to do so because it is already suffering from businesses leaving to protect intellectual property rights and increasing labor costs. However, even as these efforts progress, China will have to deal with the dramatic reduction in labor required in its industries and its rapidly aging, and hence less productive, population. It must do so even as its economy slows significantly and pushback to its Belt and Road Initiative grows. While the Chinese government has once again turned to stimulus spending, a key question is whether the cumulative public and private debt is manageable.

On the positive side, China's working population has been declining for the past couple of years and will continue to do so. Thus, it will need fewer jobs. At the same time, China has an enormous talent pool due to the sheer size of its population. Furthermore, Chinese universities have steadily improved in global rankings. Most important for China's future is the fact that Asian trade is also regionalizing and China is central to the fastest growing region in the world. If the Chinese Communist Party's use of centralized management can mitigate these challenges, China too can be a big winner in the fourth industrial revolution.

In contrast, Russia is not well positioned to benefit. Transitioning to advanced manufacturing requires major investment, and Russia currently suffers from a lack of investor confidence. The Institute of International Finance ranked Russia "last among 23 emerging economies in terms of 'real' FDI."[51] Russian businesses have not been particularly innovative, nor has the country created an environment that encourages foreign innovators to establish businesses there. Compounding its problems, Russia's economy remains dependent on exporting energy, which generated 60 percent of its GDP.[52] Today, technological improvements in various fields as well as global warming concerns are driving a worldwide shift to alternative energy. Russia also faces major human capital issues due to its demography and low-quality university system. No Russian institution rated in the top 250 of *U.S. News & World Report*'s university rankings, and only 2 made it into the top 400.[53] Finally, as a kleptocracy, Russia does a poor job of allocating capital to the industries that benefit most from the convergence of these new technologies.

Notes

[1] Klaus Schwab, *The Fourth Industrial Revolution* (Cologny, Switzerland: World Economic Forum, 2016), 6–7.

[2] Ibid., 1.

[3] "Global Industrial Robot Sales Reach Record Level in 2018," Xinhua, September 19, 2019, available at <www.china.org.cn/business/2019-09/19/content_75222098.htm>.

[4] Allan Collard-Wexler and Jan De Loecker, "Reallocation and Technology: Evidence from the U.S. Steel Industry," *American Economic Review* 105, no. 1 (January 2015), 131–171.

[5] Mihai Andrei, "Chinese Factory Replaces 90% of Human Workers with Robots: Production Rises by 250%, Defects Drop by 80%," *ZME Science*, February 3, 2017, available at <www.zmescience.com/other/economics/china-factory-robots-03022017>.

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