Asia's Role in the Four Industrial Revolutions

A steam locomotive along the Yokohama waterfront by Hiroshige III (1842–1894). Source: *MIT Visualizing Cultures* website at https://tinyurl.com/yc8ba7at.

By Mousumi Roy

The United States and Europe have been at the forefront of the Industrial Revolutions over the last two and a half centuries. Almost all Asian countries, except Japan, were latecomers to these revolutions. Nevertheless, many of them, including China, South Korea, Singapore, Hong Kong, Taiwan, India, Indonesia, and Malaysia, made significant progress by the end of the Third Industrial Revolution. What follows is a brief depiction of the involvement of Japan; the "Asian Giants," China and India; and the four "Asian Tigers," South Korea, Singapore, Hong Kong, and Taiwan, in the first three Industrial Revolutions and a more extended discussion of the role several Asian nations are taking in what at least one scholar has called the Fourth Industrial Revolution.

THE FIRST INDUSTRIAL REVOLUTION
(Mid-Eighteenth Century through Mid-Nineteenth Century)

The First Industrial Revolution began in Britain with the invention of weaving machines, most famously the spinning jenny, in 1764 for the textile industry and expanded through other transformative inventions such as the steam engine, railroads, and machine tools.[1] During this period, the Indian subcontinent in Asia became part of the British colonial empire, which benefited greatly from India's natural resources. The British also dominated trade with China through their control of ports in Singapore and Hong Kong. The gross domestic products (GDP) of India and China declined, while the GDPs of Western Europe and the United States increased (see Figure 1).

THE SECOND INDUSTRIAL REVOLUTION
(Late Nineteenth Century through Early Twentieth Century)

The Second Industrial Revolution took place in Europe and the United States between the late nineteenth and early twentieth centuries. New inventions, including the use of interchangeable parts, the Bessemer steel production process, and the assembly line for mass production, helped significantly increase manufacturing output and production systems.

Japan was a latecomer to the First Industrial Revolution and much more of a player in the second. During the Meiji period (1868–1912), the Japanese government eventually created state-led capitalism, assisting industrial and business growth in a variety of ways. By the early twentieth century, Japan, in addition to becoming an imperial power that controlled what is now Taiwan, as well as Korea, was creating a substantial industrial sector. World War I was a tremendous boon for Japan's economy, with exports more than quadrupling, and shipbuilding and steel production becoming important. New manufacturing techniques, such as assembly lines, and other scientific management procedures were introduced in factories, and the nation experienced financial growth and prosperity. Although the economy was devastated in World War II, due to a variety of factors, including an educated and well-disciplined workforce and American pro-growth Occupation policies, Japan experienced the first Asian economic "miracle."

THE THIRD INDUSTRIAL REVOLUTION
(Mid–Late Twentieth Century)

The development of digital computing, personal computing, and the internet catalyzed the Third Industrial Revolution.[2] The USA, (West) Germany, and Japan led industrial growth and development during this revolution, exemplified by visionaries such as Bill Gates and Steve Jobs. The US, enjoying both technological and financial dominance, had the world's largest GDP. Japan successfully rebuilt its economy so that its world GDP rank grew from fifth place in 1960 to second place in 2000.[3] Internet and computer technology, high-speed air travel, and satellite communications helped industries expand globalization. More multinational companies (MNCs) moved to Asian countries—basing manufacturing operations within Asia, where labor and material costs were significantly lower. It created opportunities for China, India, and other Asian nations to collaborate and share knowledge with companies and governments from developed countries and improve their own industries.

During the Third Industrial Revolution, Hong Kong, Taiwan, Singapore, and South Korea—the four Asian Tigers—emerged as highly successful economies challenging and exceeding Japan. Taiwan began the process of rebuilding its economy after World War II. American help and domestic policies caused a surge in exports from US $174 million in 1960

Figure 1: GDP of national economies as a share of the world's economy between 1 and 2003. Note that China and India each comprised a much higher share of the world's GDP until the early eighteenth and nineteenth centuries, before the First Industrial Revolution. Source: Data table in Angus Maddison, *Contours of the World Economy 1–2030 AD: Essays in Macro-Economic History* (Oxford: Oxford University Press, 2007) obtained from http://upload.wikimedia.org.

to US $1.56 billion in 1970. In the 1970s, Taiwan embraced advanced technologies such as microelectronics and personal computers. By the early 1990s, it was one of the world's largest exporters of personal computers.[4] South Korea, like Taiwan, but even poorer after the Korean War, began significant economic development during the 1960s. By the turn of the century, South Korea was one of the world's leading economies, with a gross national product (GNP) that grew from US $2.3 billion in 1962 to US $295 billion in 1992.[5] Hong Kong, always an entrepot, created a booming textile and light manufacturing industry sector, and its world GDP grew from forty-fourth in 1960 to twenty-fifth in 2000.[6] Singapore has also promoted programs of economic restructuring, modifying education policies to expand technology and computer education, and offering financial incentives to industrial enterprises.

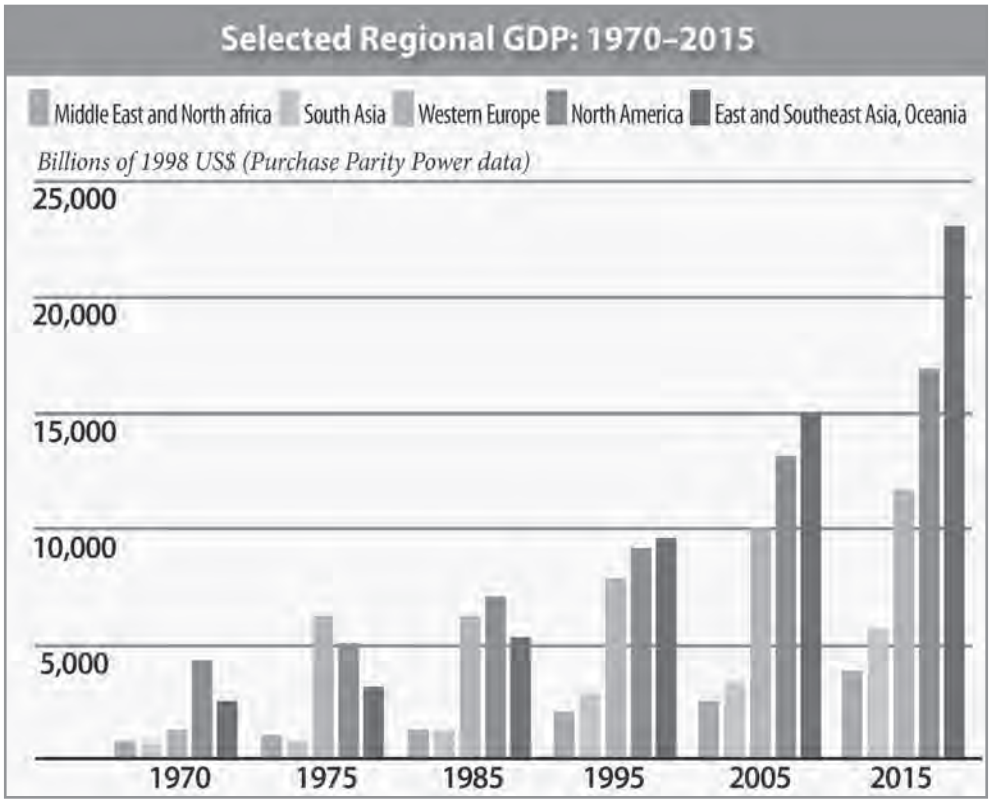


Figure 2: As Asian economies grow, they are likely to play a more significant role in the Fourth Industrial Revolution. Source: CIA's Long-Term Growth Model at https://fas.org/irp/cia/product/globaltrends2015/375953.gif.

By the end of the Third Industrial Revolution, China had become the manufacturing center of the world, exporting an impressive quantity of items such as toys, consumer products, and clothing, and enjoyed the world's seventh-largest GDP. After its 1947 independence, the Indian government adopted a socialist and protectionist path, but in 1991, after decades of poor economic performance, government policymakers initiated market competition and globalization. The policy shift incentivized private business and industry to substantially increase production of goods and services. India's exports of high technology products, particularly software, continually grew.[7] Indian workers with broad English-language and technological skills were competitive in the global service labor market; India became a hub for Western call centers and, thanks to improved annual growth rates, was the world's thirteenth-largest GDP by 2000.[8]

The emerging economies of Asia in part owed their successes to the consistent and careful planning of their governments, which in most cases were authoritarian but shared the goal of reducing poverty through industrial development, encouraging and supporting private enterprises until they were self-sufficient. International institutions such as the World Bank and International Monetary Fund (IMF), along with wealthier nations like Japan and the United States, provided much-needed financial investment and technological knowledge, too. Other emerging countries in Asia, such as Malaysia and Indonesia, also achieved upward mobility in the world's GDP rankings during the Third Industrial Revolution.

THE FOURTH INDUSTRIAL REVOLUTION (Twenty-First Century)

The Fourth Industrial Revolution began roughly at the turn of the twenty-first century (see Figure 3). According to Klaus Schwab, Founder and Executive Chairman of the World Economic Forum, the Fourth Industrial Revolution grew out of the third; however, it is not a continuation—the speed and the pervasiveness of the technological breakthroughs make this

Industrial Revolutions

First Industrial Revolution
(Mid-18th to Mid-19th Century)

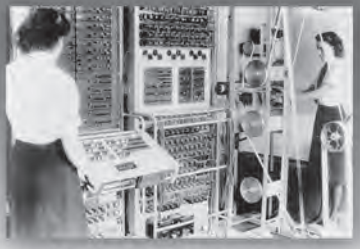
Examples of New Technologies
Mechanization, Steam Power, Water Power, etc.

Replica of the De Witt Clinton steam locomotive. The original locomotive was built in 1831. Source: *Wikimedia Commons* at https://tinyurl.com/ybk372ln.

Second Industrial Revolution
(Late 19th to Early 20th Century)

Examples of New Technologies
Assembly Lines, Electricity, Mass Production, etc.

The ten millionth Model T on the assembly line in the Ford Motor Assembly Plant in Highland Park, Michigan, 1924. Source: *Robohub* website at https://tinyurl.com/y9sf5g68.



Third Industrial Revolution
(Mid-20th to Late 20th Century)

Examples of New Technologies
Information Technology, Internet, etc.

The Colossus was the first electronic digital programmable computing device and was used to break German code during World War II. It remained a military secret well into the 1970s. Source: *Wikimedia Commons* at https://tinyurl.com/yakt6khh.

Fourth Industrial Revolution
(21st Century)

Examples of New Technologies
Additive Manufacturing, Big Data, Virtual Reality, etc.

Researchers at the European Space Agency in Darmstadt, Germany, exploring virtual reality for controlling planetary rovers and satellites in orbit. Source: *Wikimedia Commons* at https://tinyurl.com/y9g98oe7.

Figure 3.

revolution quite distinct. Automation and connectivity are the two main characteristics of this revolution that are being advanced by many disruptive technological innovations, such as artificial intelligence (AI), big data, internet of things (IoT), robotics, and many more. These are creating a tremendous impact worldwide on how we live and work.[9] Developing cyber-physical systems (CPS) is one of the goals of this Industrial Revolution—it will eventually enable seamless integration of computational algorithms and physical components in all sectors, including agriculture, energy, transportation, health care, manufacturing, and more. In 2017, the US National Science Foundation was working closely with multiple federal government agencies to identify basic CPS research directions common to these sectors that have various applications, along with rich opportunities for accelerated practical use.[10] The United States has been at the forefront of this revolution; however, Asia is not far behind.

By the end of the Third Industrial Revolution, Japan, China, India, and other Asian countries had successfully transformed their industries and economies. In 2016, China, Japan, and India held the third, fourth, and seventh rankings in the World Bank index of national GDP as a share of global GDP. However, regarding purchasing power parity (PPP) GDP ranking, China currently holds the top position, followed by the United States, India, and Japan.[11] Singapore was successful in bringing prosperity to its citizens—its per capita GDP rose to over US $87,000 in 2016, higher than that of the US and Switzerland.[12] A well-educated labor force was of utmost importance in this revolution—Singapore consistently tops global rankings in primary and secondary education, particularly in science and math. Similarly, according to a 2016 report from the World Economic Forum, China had 4.7 million and India had 2.6 million graduates in science, technology, engineering, and mathematics-related programs, while the United States had only 568,000.[13]

The culture of entrepreneurship has been one of the main reasons for the Western world to be in the forefront of the Industrial Revolutions. Silicon Valley is an excellent example of a startup hot spot in the USA. However, startup formation in the USA has fallen 36 percent since the beginning of the twenty-first century, whereas it has proliferated in Asia, particularly in China—more than 10,000 new businesses are starting every day; that is equivalent to almost seven Chinese startup companies born every minute! China today leads the US in key technology sectors such as mobile payment and is increasingly competitive in advanced microchip, artificial intelligence, and other next-generation technologies.[14]

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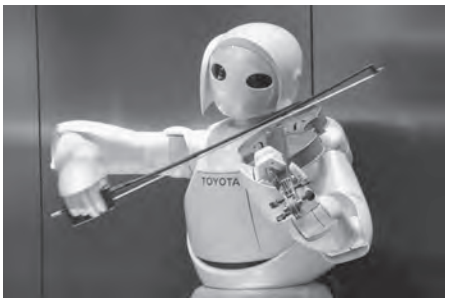
Key Industries of the Fourth Industrial Revolution

One of the essential technologies that has been contributing to the growth of the Fourth Industrial Revolution is the application and advancement of AI. AI had reached a milestone in 1997 when IBM's Deep Blue supercomputer beat world champion Garry Kasparov in chess. John McCarthy introduced the term "artificial intelligence" in 1955—he intended to "study how to make machines use language, form abstractions and concepts, solve the kind of problems now reserved for humans, and improve themselves." Since then, AI has grown significantly following Moore's Law. Much of the progress is due to the fast growth in computer processing power, availability of more extensive data sets, and advancement of the fundamental algorithms for machine learning.[15] The boundaries of AI application are almost endless—starting with games and continued improvement of programming languages, vision and image processing, neural networks, expert systems, data integration, robotics, search engines, and much more. For example, IBM, Facebook, Google, and other companies are at the forefront of experimenting with machine learning techniques such as deep learning and predictive learning. AI technologies are predicted to increase the world's GDP by 14 percent by 2030.

Among Asian countries, China is investing heavily to seize the world's leading position in AI technology. China intends to use AI for wide-ranging purposes, including improving capabilities of robotics, developing driverless cars, designing digitalized factories, making faster chips, predicting crimes, transforming city services, and boosting national security.[16] Although the United States and China are competing for the lead, AI is on the rise in other countries in Southeast Asia, such as Indonesia, Singapore, Thailand, and Việt Nam. For example, Bumrungrad International Hospital in Thailand is the first medical institution outside North America to deploy IBM Watson for oncology, advancing and optimizing cancer care. As predicted by the reputed McKinsey Consulting Firm from the US, AI adoption in Southeast Asian factories could increase profits by as much as US $311 billion per year.[17]

Innovation in artificial intelligence will continue to result in many new industries throughout the twenty-first century. However, a few industries have already been born and are experiencing enormous growth, such as advanced robotics, autonomous vehicles, additive manufacturing/3-D printing, telecommunications and mobile phones, and biotechnology. The United States and Western Europe have made significant progress in all these industries. A brief overview of how these industries are growing in Asia, particularly in China, India, Hong Kong, Japan, South Korea, Singapore, and Taiwan, will be discussed in the following sections.

Advanced robotics—As a nation faced with a population that is both shrinking and rapidly aging, Japan is relying on advanced robotics not only to replace future laborers, but also to create future caretakers for its older citizens. The world-famous automobile companies Toyota and Honda have invested heavily in building next-generation robots. Toyota has built female and male models of social robots, Robina and Humanoid, for elder care. Honda's ASIMO robot is sophisticated enough to interpret human emotions.



Toyota Humanoid robot playing the violin. Source: YouTube at https://tinyurl.com/y8hx6r5o.

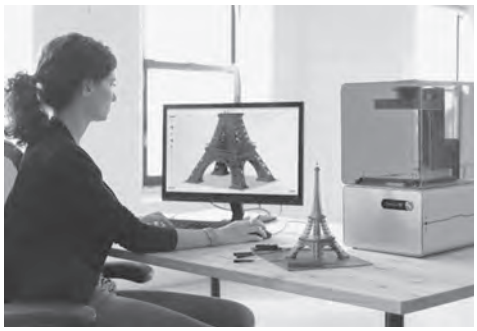
Japan, China, and South Korea currently dominate the market in sales for high-value industrial and medical robots.[18] Restaurants that use robot waiters to take orders, serve customers, and clean tables are cropping up in all three countries. China has also invested heavily in industrial automation in order to make its vast manufacturing sector more competitive in global markets.[19]

Autonomous vehicles—The concept of an autonomous car, once limited to fiction as in the famous 1980s US TV show *Knight Rider,* has become a reality—thanks to long-term investment from several companies, notably Google and Tesla. China and Japan are at the forefront of autonomous cars. Japan aspires to make Tokyo a self-driving city in time for the 2020 Olympics.[20] Its


Autonomous Waymo Chrysler Pacifica hybrid. Source: *Wikimedia Commons* at https://tinyurl.com/yagrwhmr, Dllu.

government is compiling guidelines for self-driving cars and crafting a legal framework as it tests driverless trucks, buses, and taxis on the roads in 2017. Chinese automobile company SAIC Motor received permission to road-test its self-driving cars in California, and China aims to lead the global autonomous car industry by 2030. Among the Asian Tigers, Taiwan, South Korea, and Singapore have made considerable progress in bringing autonomous cars to the market. Multinational company NVIDIA and Taiwan's Industrial Technology Research Institute (ITRI) have partnered in building autonomous vehicles to provide public transportation by 2018.[21] South Korean companies such as Samsung and Hyundai have started making autonomous vehicles as well. South Korea has opened the world's largest factory for testing autonomous cars inside a city environment: K-city, an eighty-eight-acre facility with a budget of US $17 million. Singapore launched the world's first self-driving taxi service in August 2016, with plans to expand to a fully self-driving taxi fleet by this year. Doing so has been an international effort: the French automaker Group PSA partnered with NuTonomy in 2017 to bring more autonomous vehicles to the streets of Singapore.[22] Indian company Novus Drive has been testing the country's first driverless shuttle, and Nissan Motors from Japan has filed numerous self-driving tech patents in India.[23]

Additive manufacturing, or 3-D printing technology—3-D printing was first patented by Charles Hull in the United States in 1986. However, the technology was being developed at the same time in Japan and other European countries. 3-D printing did not grow into its own industry until the start of the twenty-first century. With the development of different types of printers and printing processes, this technology flourished into an industry of its own. Consumer products such as toys and jewelry are already being made using 3-D printers, and 3-D printers themselves have become a consumer product. The tremendous growth of material science technology is another factor for expediting the advancement of the 3-D printing industry. New materials that are lighter, stronger, more adaptive, and more sustainable are being used in 3-D printing parts for robots, automobiles, medical, military, textile, and other industries.[24] The worth of this industry surpassed US $5.1 billion in 2016 and is expected to exceed $21 billion by 2020.[25] China, the world's center of mass manufacturing, has embraced 3-D printing and is about to surpass the US regarding the amount spent on 3-D printers in 2017. Japan and India are also taking advantage of this low-cost production system to enhance their other industries. Taiwan is determined to be one of the leaders in 3-D printing with the help of ITRI. Innovations like 3-D-printed smartphones, musical instruments, and metal 3-D printers are helping Taiwan make significant strides during this technological revolution.[26] Singapore opened its first metal additive manufacturing facility in 2017 to serve Singapore's key industrial sectors, including oil and gas, marine, precision engineering, and construction industries.[27] South Korea invested US $37 million in 2017 to accelerate the development of 3-D printing across the country.[28] Most other countries in Asia are also investing in this technology.



Desktop 3-D printing. Source: *MIT News* website at https://tinyurl.com/y855szsr.

Telecommunications and mobile phones—The telecommunications industry is going through a revolutionary phase with the explosion of mobile phones and social media users. The variety and number of mobile phones and their users have grown particularly rapidly in Asia, which leapfrogged from limited landline users to a vast number of mobile users. In a 2014 study by the CIA, China and India took the top two spots in numbers of mobile/cellular phone subscribers. China crossed a billion mobile subscribers in 2012, and India passed this landmark recently in 2016.[29] Billions of subscribers in Asia are in the process of moving on to smartphones, thus providing huge opportunities for phone makers. Samsung, from South Korea, has become the top smartphone manufacturer, with a 21 percent share of the market. Four of the top five smartphone manufacturers are from Asia and three of them from China (Huawei, Oppo, Vivo). Huawei, the top-ranking smartphone manufacturer from China, surpassed Apple between July and September 2017 to achieve second place in the worldwide smartphone market share.[30] Huawei has created a "one network, one platform, N application" system utilizing IoT, cloud computing, big data, and other next-generation information and communication technology (ICT). China Mobile is working with Huawei, ZTE, and other smartphone companies to develop a next-generation 5G transmission system.[31] Xiaomi, another smartphone maker in China, is predicted to rise to second place behind Samsung by the end of 2018.[32] Between 2000 and 2015, global internet penetration grew sevenfold from 6.5 percent to 43 percent, and by 2015, global mobile broadband penetration had reached 43 percent, a twelve-time increase since 2007.[33] South Korea ranked No. 1 in the share of its population that owned a smartphone (88 percent), whereas the US ranked fourth. Some of the most reliable 4G networks today are in Japan, Singapore, and South Korea. Chinese smartphone brands have also made substantial impacts, particularly in Southeast Asia.

Smart city and communication network concept. Source: © Shutterstock.

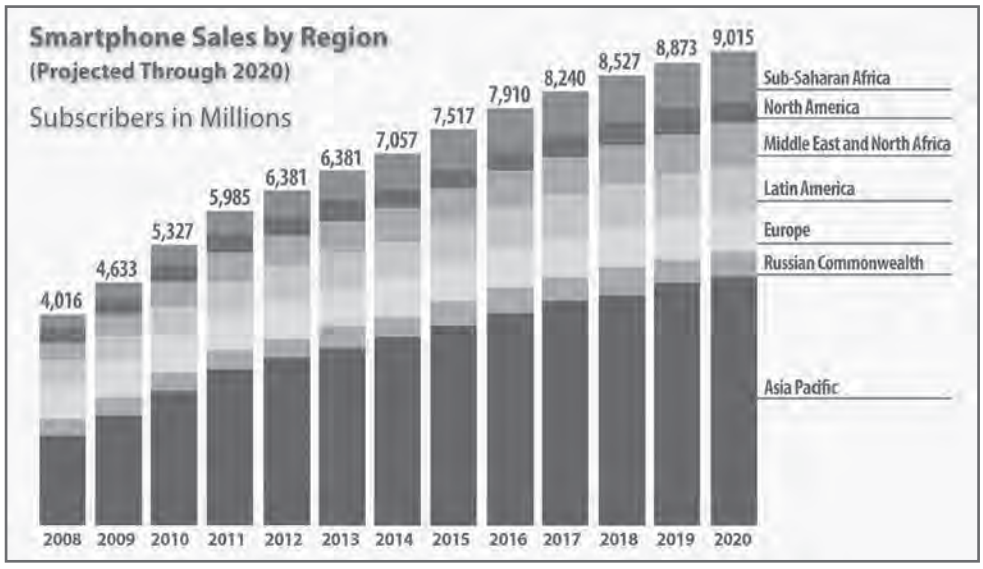


Figure 5: Asia will have the largest growth in smartphone sales through 2020 (chart notes subscribers in millions). Source: *Business Insider* website at: https://tinyurl.com/yau5h979.

In India, mobile phones are compared with Swiss Army knives, combining functions such as torchlights, audio recorders, and radio, thus fulfilling diverse societal needs. Such devices have become windows to a world of information, education, livelihood, employment, and lately shopping and e-commerce. In Southeast Asia, mobile apps are being created to diagnose, monitor, and even provide expert assistance for a range of medical illnesses, including malaria and dengue. Mobile phones have also been wirelessly connected to devices like blood pressure monitors, electrocardiographs, and other biometric sensors.[34]

Social media usage in China is on par with that of the US and Europe. WeChat, a China-based mobile, text, and voice messaging service, gained around 150 million users in just twelve months in 2015. WeChat and QQ are the top mobile apps in China, while WhatsApp and Facebook are most popular in India. While many Asian countries have yet to adopt smartphones and 4G technologies, the next generation of mobile technology—the "5G" system—is in the developing phase. Japan and South Korea are leading in 5G development, followed by the US and China. South Korea is planning to introduce a 5G system partially during the 2018 Winter Olympics, and Japan intends to use it during the 2020 Olympics.[35]

Biotechnology—Biotechnology as an industry holds tremendous opportunities for growth, particularly in genetic engineering. The US has led research in this field by achieving human genome sequencing in 2003, a feat that took fifteen years and US $2.7 billion. However, today, a decade later, genome sequencing can be done in one or two days at a cost of about US $1,000! China has emerged as a global leader in DNA sequencing, thanks to the Beijing Genomic Institute (BGI).[36] Japan has also progressed in genomic research and approved the modification of genes from fertilized human egg cells for basic research in April 2016. Their government has decided to use gene editing to develop treatment for congenital diseases.[37] India and other Asian countries are also investing in genomics and in the process of commercializing gene sequencing technology.

DNA testing in a scientific laboratory. Source: © Shutterstock.

The direction of the global economy depends largely on Asia, which holds both its biggest share and the greatest share of highly educated young workers.

Analysis of big data, genetic engineering and other biological breakthroughs, the invention of new materials, and the development of cyber-physical systems are all at the forefront of the Fourth Industrial Revolution, and Asian countries are poised to be significant participants. Supercomputers, drones, smart factories, and nanomaterials are all examples of the achievements of this revolution. Mobile technologies, artificial intelligence, and IoT may make geographical borders irrelevant. However, many governments are trying to enforce boundaries to retain control of technologies. For example, many Google and Facebook apps are blocked in China. New rules and regulations will be needed to navigate the ownerships and uses of these new technologies.

Many emerging economies in Asia became autonomous nations only during the Third Industrial Revolution and were initially far behind the developed world in technology and finance. Nevertheless, these countries have pursued industrialization as a means to reduce poverty and have achieved substantial GDP growth. The direction of the global economy depends largely on Asia, which holds both its biggest share and the greatest share of highly educated young workers. Key ingredients for its success include government policies oriented toward economic and social openness, prioritizing investment in education and innovation, superior technological skills, and—above all—enthusiastic partnerships with citizens in welcoming the technologies of the future. By all indicators, Asia is and will continue to be a dominant force in ushering in the Fourth Industrial Revolution. ■

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