Evolution of Science, Technology and Innovation Policies for Sustainable Development:

The Experiences of China, Japan, the Republic of Korea and Singapore

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Economic and Social Commission for Asia and the Pacific

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For Further information on this publication, please contact:

East and North-East Asia Office
Economic and Social Commission for Asia and the Pacific
7th Floor, G-Tower
175 Art center-daero, songdo-dong,
Yeongsu-gu, Incheon 22004, Republic of Korea
Escap-sroenea-registry@un.org

Foreword

Science, technology and innovation (STI) have been heralded as key means of implementation for the 2030 Agenda for Sustainable Development. However, as the fourth industrial revolution begins, the wave of optimism surrounding the transformative potential of frontier technologies has been tempered by increasing concerns about the potential negative impacts on jobs and the future of work, ethical issues, regulatory considerations, and widening technological inequality.

It is important to note that the disruptive nature of technology is nothing new. It will be critical to learn from the past as we shape the future. For technology to be effectively implemented for inclusive and sustainable development, it is critical to first chart the practical steps needed for balanced and integrated development.

With these points in mind, this report charts the STI development in the four leading countries in the Asia-Pacific region as measured by the Global Innovation Index. The experiences of China, Japan, the Republic of Korea and Singapore serve as examples of an evolving landscape for STI policies, particularly as frontier technologies and public sector innovations feature more prominently in the future of STI policies.

Experiences from the four countries show the important - yet different - roles of international technology transfers in "catch-up" growth, as well as the role of government policies in building up the domestic ecosystem of STI for moving beyond the "middle-income trap"; including infrastructure, human resources, the financing of research and development, and public institutions. Continued investments in frontier technologies by each of these four countries are a conscious effort to further improve productivity and therefore competitiveness.

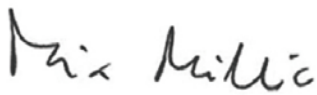
Although economic development was traditionally the main objective of STI policies, given the links between technological advancements and productivity, this objective is evolving in the light of the increased attention being paid to social and environmental challenges. In the era of the 2030 Agenda, we are seeing a divergence from historical approaches where environmental degradation and inequalities were seen as unavoidable trade-offs in pursuit of economic growth. In the four countries covered in this report, economic development remains an important dimension of STI policies. However, also seen are the integration of social and environmental dimensions into their STI policies.

Engaging with stakeholders from different sectors also emerges as a common element across the four countries. All four countries have developed deep partnerships with private sector firms as a source of innovation for the fourth industrial revolution, and to integrate some of these technologies into public services.

By explicitly including STI in both the Sustainable Development Goals and the Addis Ababa Action Agenda, the United Nations has made a commitment to support countries in their efforts to harness STI for inclusive and sustainable development.

ESCAP has a mandate to strengthen the regional STI agenda through our role as a convener, think tank, and policy adviser. ESCAP regularly facilitates intergovernmental STI dialogues - for example through the Committee on Information and Communications Technology and Science, Technology and Innovation - providing a platform for regional dialogue and collective action. ESCAP also conducts research and analysis - publishing reports on emerging STI agendas – as well as advising member States on STI policy, strategies and initiatives. Through the work of the Asia-Pacific Research and Training Network on STI Policy (ARTNET on STI Policy), ESCAP supports research and training for decision makers in critical policy areas.

I hope that ESCAP member States will benefit from knowledge-sharing and that the experiences of China, Japan, the Republic of Korea and Singapore contained in this report will assist them in the formulation of STI policies that support the implementation of the 2030 Agenda for Sustainable Development.



Mia Mikic

Director, Trade, Investment and Innovation Division
Economic and Social Commission
for Asia and the Pacific

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The leading contributor to chapter I was Xielin Liu, Professor, University of Chinese Academy of Sciences, China. The leading contributor to chapter II was Sabrina Luk, Assistant Professor, Nanyang Technological University, Singapore. The leading contributor to chapter III was Joshua Chambers, Founder and Managing Director of GovInsider.

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Explanatory notes

The following symbols have been used in the tables throughout the report:

– **A dash** indicates that the amount is nil or negligible.

- **A hyphen** indicates that the item is not applicable.

· **A full stop** is used to indicate decimals.

/ **A slash** between years indicates a financial year or portion of two-year period, for example, 2017/18.

- **A hyphen** between years, for example, 2017-2018, signifies the full period involved, including the beginning and end years.

Reference to "dollars" ($) indicates United States dollars, unless otherwise stated.

Reference to "billions" indicates one thousand million.

Annual rates of growth or change, unless otherwise stated, refer to annual compound rates.

The following abbreviations have been used:

A*STAR	Agency for Science, Technology and Research (of Singapore)
AI	artificial intelligence
APPI	Act on the Protection of Personal Information (of Japan)
ASEAN	Association of Southeast Asian Nations
CII	critical information infrastructure (of Singapore)
CMA	Computer Misuse Act (of Singapore)
CMCA	Computer Misuse and Cybersecurity Act (of Singapore)
DHS	Department of Homeland Security (of the United States)
fintech	financial technology
ESCAP	United Nations Economic and Social Commission for Asia and the Pacific
FDI	foreign direct investment
FY	fiscal year
GDP	gross domestic product
GERD	gross expenditure on research and development
GNI	gross national income
GNP	gross national product
GovTech	Government Technology Agency of Singapore
ICM	info-communications media
ICM ITM	info-communications media industry transformation map
ICT	information and communications technologies

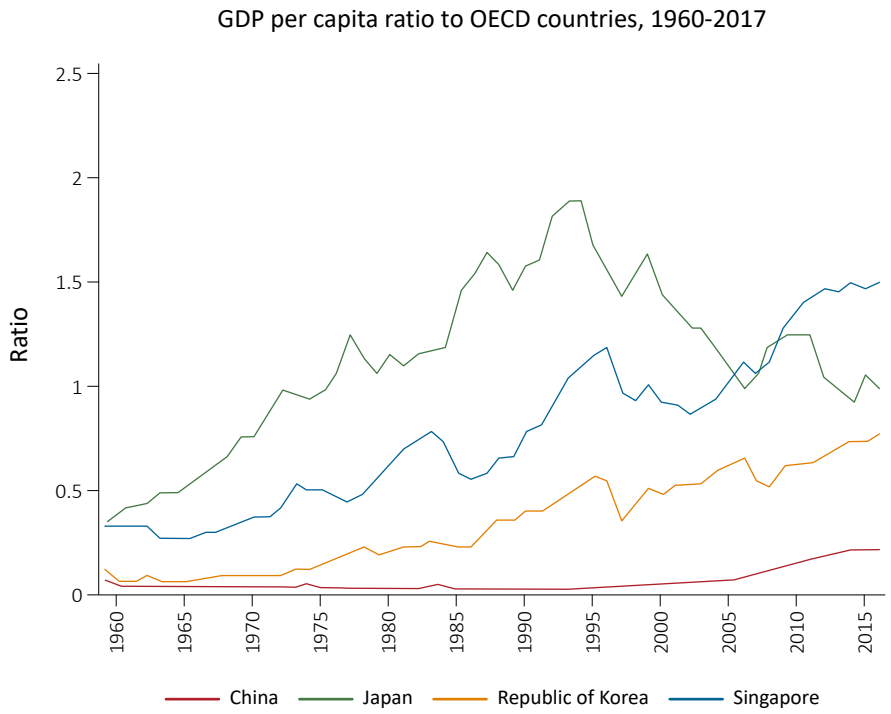
IDM	interactive digital media
IMDA	Info-communications Media Development Authority (of Singapore)
IoT	Internet of Things
IT	information technology
MAS	Monetary Authority of Singapore
METI	Ministry of Economy, Trade and Industry (of Japan)
MEXT	Ministry of Education, Culture, Sports, Science and Technology (of Japan)
MOTIE	Ministry of Trade, Industry and Energy (of the Republic of Korea)
MSIT	Ministry of Science and ICT (of the Republic of Korea)
NDRC	National Development and Reform Commission (of China)
OECD	Organisation for Economic Co-operation and Development
OEM	original equipment manufacturer
PDPA	Personal Data Protection Act (of Singapore)
PIPA	Personal Information Protection Act (of the Republic of Korea)
PSD	Public Service Division (of Singapore)
PV	photovoltaics
R&D	research and development
SDGs	Sustainable Development Goals
SME	small and medium-sized enterprise
STBP	Science and Technology Basic Plan (of Japan)
STI	Science, technology & innovation
UNESCO	United Nations Educational, Scientific and Cultural Organization
USSR	Union of Soviet Socialist Republics

Introduction

Science, technology and innovation (STI) are a critical means of implementation for the 2030 Agenda for Sustainable Development.[1] They have great potential to catalyse and accelerate the achievement of the Sustainable Development Goals, and public STI policies play a critical role in realizing that potential.

Historically, STI policies have played a significant role in the socioeconomic transformation of countries. In the Asia-Pacific region, this is particularly true for Japan, the Republic of Korea and Singapore, and most recently China. These four countries have undergone rapid economic transformations in the decades following the end of the Second World War, with millions of people coming out of poverty. Figure 1 shows the growth in GDP per capita of each of the countries relative to GDP per capita of the OECD average over the last five and a half decades. All four countries have closed the gap with the OECD average, although to varying extents and over different time frames.

Figure 1. GDP per capita ratio of four Asian countries to that of the OECD average, 1960-2017

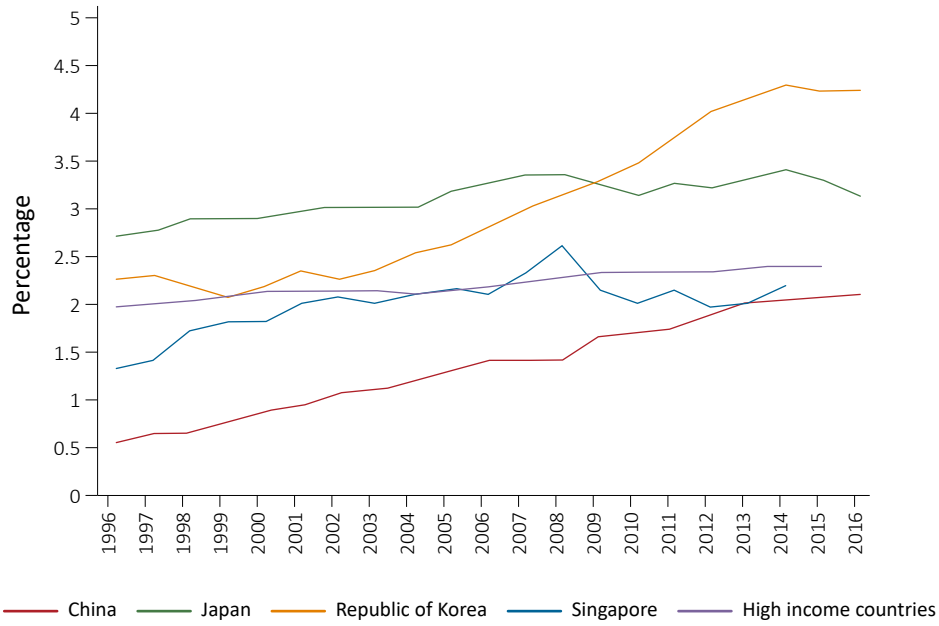


Source: World Bank, World Development Indicators from https://databank.worldbank.org
Note: Ratio is GDP per capita (current United States dollars) for each country/GDP per capita (current United States dollars) of the OECD average.

The four countries have made significant investments and strides in science, technology and innovation to support their long-term economic growth.

All four countries have gross expenditure on research and development (GERD) to GDP ratios close to, or greater than, the average for high-income countries (figure 2). The Republic of Korea has the second highest GERD to GDP ratio globally[2] (see figures 2 and 3).

Figure 2. Gross expenditure on research and development as a percentage of GDP, 1996-2016

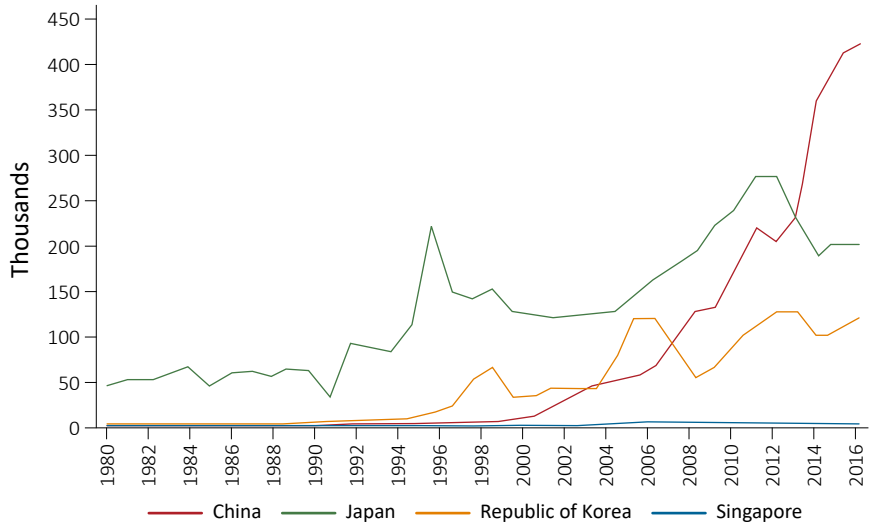


Source: based on UNESCO data available from http://data.uis.unesco.org/.
Note: Data for Singapore are not available for 2015 and 2016; those for high-income countries are based on World Bank income classification.

Significant advances in science, technology and innovation as a result of STI policies have placed China, Japan, the Republic of Korea and Singapore at the forefront of innovation.

The number of patents – the currency of science, technology and innovation – filed and granted in the four countries has steadily increased. The number of patents granted grew in Japan in the early to mid-1990s; in the Republic of Korea, from the late 1990s to the mid-2000s; and in China, from the beginning of the current decade (figure 3).

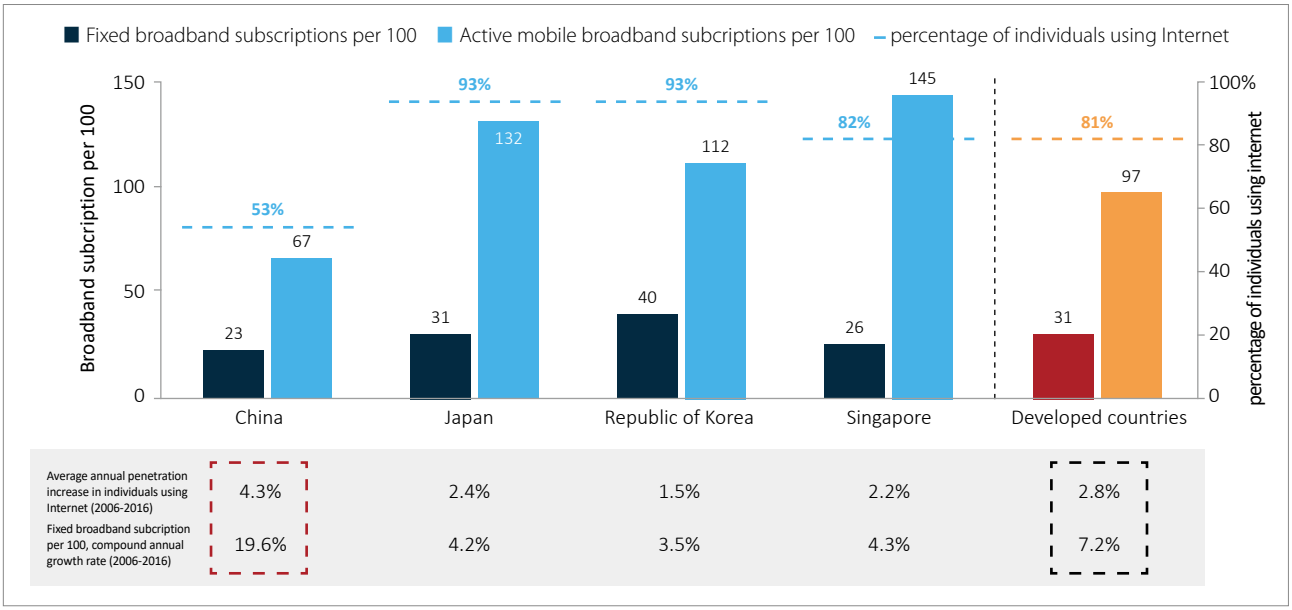
Figure 3. Total patent grants, by country of filing, 1980-2016



Source: based on WIPO data available from www3.wipo.int/ipstats/en.
Note: Data for Singapore are not available for the period 1980-1994; data for China are not available for the period 1980-1984 and 1990.

These countries are also among the most advanced in the world in terms of digital infrastructure – a necessary condition for many scientific, technological and innovative activities – with high broadband subscription and Internet penetration rates. Broadband subscription rates and Internet penetration in Japan, the Republic of Korea and Singapore are higher than the average for developed countries (see figure 4). China's Internet penetration and subscription rates, although lower than the developed country average, have been increasing much faster than the developed country average (19.6 per cent compound annual growth rate in China compared with 7.2 per cent compound annual growth rate in developed countries between 2006 and 2016).

Figure 4. Broadband subscriptions, by type and Internet access, 2016



Source: based on International Telecommunication Union (ITU) data available from https://www.itu.int/en/ITU-D/Statistics/Pages/stat/default.aspx

Future breakthroughs in frontier technologies are expected to offer solutions for achieving the Sustainable Development Goals. Such breakthroughs have the potential to revive productivity, make resources available to end poverty and mitigate environmental degradation. However, they also raise concerns about rising inequality and unemployment as a result of automation, cybersecurity issues and privacy. Hence, STI policy direction is critical to leverage frontier technologies for sustainable and inclusive growth.

These four countries are already looking forward to the future, and they have introduced comprehensive national plans to direct development of frontier technologies, such as the Next Generation Artificial Intelligence Development Plan (China); Future Vision towards 2030s (Japan); People-centred "Plan for the Fourth Industrial Revolution" to Promote Innovative Growth (Republic of Korea); and the Smart Nation Initiative (Singapore).

Traditionally, the focus of STI policies has been on promoting economic growth. Since the 1990s, however, STI policy in these countries has been moving beyond a focus on purely economic growth towards also achieving sustainable and inclusive growth; policy is increasingly being directed towards social and environmental objectives.

Governments can use several instruments to build technological and innovation capabilities. One instrument often used by countries with more advanced STI capabilities is to promote innovation in the public sector itself. Fostering innovation in the public sector can enhance public service delivery and the business environment, such as through e-government services. More importantly, given the sheer size of the public administration, it can also support the development of technological and innovation capabilities and markets. Japan, the Republic of Korea and Singapore are consistently ranked in the top countries in the world on the e-Government Development Index,[3] which measures the extent and quality of governmental digital service provision.

Rapid advances in science, technology and innovation in China, Japan, the Republic of Korea and Singapore, and their leadership role in some domains of technology and innovation present learning opportunities for other countries in the Asia-Pacific region. Countries in the region can benefit from understanding the historical evolution of STI policies and the policy tools used to foster economic growth and sustainable and inclusive development in these four countries. Their individual experiences can help other countries specifically to identify relevant STI policy tools and measures to leverage frontier technologies and direct public sector innovation in pursuit of the Sustainable Development Goals.

The objectives of this report are:

(a) To trace and draw key knowledge from the evolution of STI policies in China, Japan, the Republic of Korea and Singapore;

(b) To identify developments in STI policy on frontier technologies and public sector innovation in these four countries;

(c) To briefly assess how the above policies have contributed to the achievement of sustainable and inclusive development;

(d) To identify key policy lessons and cooperative opportunities for ESCAP member States in the Asia-Pacific region with regard to STI policies for realizing the Sustainable Development Goals.

This report contains three chapters. Chapter I provides a comparative overview and a discussion of the historical evolution of STI policies and how they have contributed to the socioeconomic development of these four countries. It contains a discussion of the strategic STI policy objectives and measures deployed at different phases of development. Chapter II is focused on policies for frontier technologies, providing a comparative analysis of how each country has sought to build capabilities in cutting-edge technologies and products. Chapter III affords a view of developments in public sector innovation in the four countries with a focus on its implications for the Sustainable Development Goals. Each of these chapters also provides a brief reflection on how STI policies have been designed to support sustainable and inclusive development. In the conclusions of the report, the key findings from the preceding chapters are summarized, and the linkages between STI policies and the 2030 Agenda are discussed. The concluding chapter also contains a reflection on what are some of the opportunities that other Asia-Pacific countries have for collaboration and learning.

Chapter I. Development of science, technology and innovation policies

A. Background and overview

Science, technology and innovation policy has played a significant role in the economic transformation of Japan, the Republic of Korea and Singapore, and most recently, China. It has enabled structural transformations and the long-term productivity growth needed to sustain economic development.

This chapter provides a comparative overview of STI policies implemented in these four countries to sustain their process of economic transformation. It furnishes a historical introduction describing how these economies reached their current levels of economic and technological development. To do so, the chapter contains a discussion of the main objectives and elements of the countries' national STI policies, tracing their evolution over different stages of development.

STI policies have not only supported economic growth but have also expanded access to knowledge, technologies and innovations that support the well-being of citizens. This chapter also contains a brief reflection on how STI policies have been aimed at accomplishing the social and sustainability goals now contained in the 2030 Agenda for Sustainable Development.

Three distinctive periods of STI policies can be observed in each of the four Asian countries related to their level of industrialization: pre-industrialization, catch-up (when the level of industrialization converges with that of advanced economies) and the post catch-up stages. As the four countries have industrialized over different time frames, the years corresponding to the three periods of STI policies differ (table I.1). For example, in Japan the pre-industrialization period ranged from the Meiji Restoration (1868) to the end of the Second World War (1945). The catch-up phase occurred in the three decades following the Second World War. From the 1980s, Japan started to chart its own development course and STI pathway (table I.1). For the Republic of Korea, its pre-industrialization period was from 1945 to 1959. The catch-up period started in the 1960s when industrialization began in earnest and continued into the 1990s until the occurrence of the Asian financial crisis in 1997. Finally, the country's post catch-up period has been the time since 2000.

Table I. 1. Period classification, by country

Country	Pre-industrialization	Catch-up	Post catch-up
China	1949-1977	1978-2012	2012-present
Japan	1868-1945	1946-1970s	1980s-present
Republic of Korea	1945-1959	1960-1999	2000s-present
Singapore	1965-1980	1981-2010	2010-present

B. Country experiences: policy evolution in China, Japan, the Republic of Korea and Singapore

1. China

Science, technology and innovation policy has played a critical role in the substantive economic transformations that China has undergone.

China's STI policies have evolved in line with its stages of development. In its pre-industrialization phase, STI policy was focused on developing industrial capacity for economic recovery and building capabilities in defence technologies to support national security. To achieve these strategic objectives, public action was focused on transferring technology and skills from the then Union of Soviet Socialist Republics (USSR) and on building a base of science and technology institutions.[4]

China's catch-up phase started in the 1980s as the country began transitioning towards becoming a market-oriented economy. STI policies were focused on facilitating this transition and putting into place instruments to strengthen industry-research linkages, incentivize innovation in firms and access specific technologies not yet developed domestically.

Currently, China's STI policy is aimed at supporting innovation-led growth by strengthening the innovation system and building capabilities in frontier technologies through the establishment of institutions and targeted programmes. Table I.2 provides a summary of the strategic STI policy objectives and the related policy measures taken in each stage of China's economic development.

Table I. 2. Evolution of science, technology and innovation policy objectives and measures, China

	Pre-industrialization (1949-1977)	Catch-up phase (1978-2012)	Post catch-up (2012-present)
Strategic STI policy objectives	Building industrial capacity for economic recovery and development National security	Aid transition from socialist planned economy to socialist market economy Building indigenous innovation capacity for future growth	Become a global innovation centre Innovation-driven development
Key policy measures	Technology and skill transfer from the former USSR Focusing on priority sectors to build core capabilities in defence and industry Establishing science and technology institutions for research and education	Establishing high-technology zones and incentivizing development of high-technology Strengthening linkages between research and industry through research institution restructuring and intermediaries Technology transfer in target sectors through foreign direct investment Fostering industry-led innovation by incentivizing firm investments in R&D	Institutionalizing innovation through institutions and incentives Strengthening intellectual property management Building and strengthening capabilities in frontier technologies and ICTs through targeted programmes Using science, technology and innovation for green growth and rural development

(a) Pre-industrialization phase: 1949-1977

After the end of the Second World War and Chinese civil war, as with many post-war economies, the Chinese economy was left with limited productive capacity and scarce financial capital to mount a recovery. The research and university systems were struggling with both a lack of financial resources and a lack of human capital. The economy at the time was dominated by agriculture with a small share of industrial activity.[5]

Influenced by the planned economy model of the USSR, the government of China set up public research institutions, including the Chinese Academy of Sciences, and a clear division of research, education and production was established - the university focused on education, public research institutes on science and technology research, and the enterprise on production. Long-term science and technology development plans, such as the 1956 "Science and Technology Development Vision Plan" were established. The government used these public research institutions to focus on the development of capacities within China of key priority areas identified in these plans.

During this period, China focused on learning from the USSR, including through funding researchers to study in the USSR, and through the 156 USSR technical assistance projects in China.[6] Initial progress between 1949 and 1965 in science, technology and innovation experienced a setback during the Cultural Revolution (1966-1976), including through the closure of research institutes and a loss of scientific human capital. The contribution of scientific and technological progress to economic growth in China fell from 27.8 per cent in the period 1952-1957 to 4.1 per cent in the period 1965-1976.[7]

(b) Catch-up and industrialization phase: 1978-2012

In this period, China underwent several changes in its science, technology and innovation architecture. It rebuilt its institutions, created several new ones, progressively advanced its research sophistication, increased the role of the market and started focusing on the building of domestic technological capabilities.

China pursued a top-down innovation policy characterized by targeted investments in science and technology. However, greater freedom was given for the market to respond to technological demand. This adjustment occurred against a backdrop of economic liberalization. Science and technology were assigned an important role in economic development. In March 1978, at the National Science Conference, political leader Deng Xiaoping declared that "science and technology are productive forces", thus raising the importance of science and technology policy.

Two distinct phases with different objectives and policy instrument can be observed in the catch-up stage.

(i) Laying foundations for transition (1978-1997)

A series of new policies was implemented which laid the foundation of China's science and technology policy system. The Government increased its emphasis on basic scientific research, established a national natural science fund system, strengthened the Chinese Academy of Sciences and established key national laboratories. Further, it successively established 53 national high-technology industrial development zones and formulated specific plans promoting innovation clusters.

a. Moving towards a demand-oriented science, technology and innovation policy

The 1985 "Decision on the Reform of the Science and Technology Management System" shifted the traditional planned economy system towards a more market-oriented one. It directed development-oriented research institutions to pay attention to market demand and strengthen their integration with industry. This decision marked the entry of the Chinese science and technology system into the "competition and market" stage of development.

Prior to 1985, China's technological progress relied on technology imports, as its indigenous technological development was relatively limited. Economic growth was driven largely by an increase in factor inputs (60 per cent) as opposed to technological progress (30 per cent), which was below the 60 per cent contribution of technological progress to economic growth recorded in developed countries.[8]

Consequently, technology policies in the 1980s were directed towards building the technological capabilities required to bolster major industrial developments, such as energy, transportation, machinery, consumer goods and construction. For example, the energy policy called for building nuclear power plants in economically developed but energy-scarce areas of the country.

b. Improving basic research capacity

The Government also sought to improve basic research in science. It established the National Natural Science Foundation of China in 1986 to support basic research in natural sciences. Other institutions - State laboratories mandated to improve basic research and some applied research, and the Chinese Academy of Engineering - were also established. In 1997, the Government launched Programme 973, also known as the National Basic Research Programme, for basic research in the Ministry of Science and Technology; in 1998, it established the National Knowledge Innovation Programme in the Chinese Academy of Sciences to improve basic research capability in high-technology areas, such as human genome sequencing and quantum computing.

c. Fostering innovation and building high-technology zones

To leverage the benefits of proximity and networks, China built science parks around high-intensity research regions. This resulted, for example, in the rapid rise of the Zhongguancun science park, a technology hub near Beijing in close proximity to Tsinghua University, Peking University, Chinese Academy of Sciences and other important universities.

Clusters were established to build capabilities in advanced technologies, foster innovation and facilitate technology transfer. Efforts were focused on seven high-technology fields identified by the Government: biotechnology, aerospace technology, information technology, advanced defence technology, automation technology, energy technology and new material technology.

d. Emergence of high-technology firms

High-technology enterprises were developed under the Torch Programme launched in 1988, which channelled funding, preferential tax treatment and other incentives towards firms in high-technology zones and science parks.[9] This step led to a proliferation of high-technology companies, including the Lenovo Group Ltd. and Shenzhen Huawei Technologies Co., Ltd. By 1998, more than 16,000 companies were located in the national high-technology zones. Simultaneously, Chinese research institutes established high-technology companies to commercialize technologies that they had developed. For example, the Chinese Academy of Sciences, with its 123 research institutes, created more than 900 high-technology companies. In 1978, there were no private technology companies in China, but by 1998 China's private technology companies' research and development funds were valued at $5.4 billion, and annual technical revenues amounted to $6.6 billion.[10]

(ii) Market-led innovation (1998-2012)

a. Pushing the "innovation imperative" to firms

Towards the turn of the century, innovation started becoming an explicit mandate, and the policy focus was shifted to the firm as the central actor in technological innovation. State-owned companies were mandated to set up technology centres to improve their innovation management capabilities. Similarly, private large and medium-sized companies were asked to establish technology centres. Further, high-technology companies were directed to spend more than 5 per cent of their annual sales on R&D in order to promote indigenous capabilities in advanced technology.

Innovation activities in technological small and medium-sized enterprises (SMEs) were also supported with the launch of the Technology Innovation Fund for Small and Medium-sized Enterprises in 1999. This fund has grown exponentially in value, from $30.3 million in 1999[11] to $760.4 million in 2012.[12]

b. Technology transfer through foreign direct investment

The Government of China used foreign direct investment (FDI) as a tool for technology transfer. FDI facilitated contact between foreign and domestic companies and provided domestic firms with opportunities to learn directly from foreign ones.

The Government played a pivotal role in encouraging FDI flows to selected industries and restricting it in others based on China's competitive advantage. The Government initiated a "technology-for-market" strategy, which granted foreign companies access to the Chinese market in return for transferring technology to domestic firms or setting up R&D centres.[13,14]

c. Strengthening indigenous innovation capabilities

The adoption in 2006 of the National Medium- to Long-term Plan for Science and Technology Development 2006-2020 was aimed at making China a global leader in innovation. The concept of a national innovation system underpinned this strategy. Government-procurement policy tools were instituted to further encourage innovation. While State-owned enterprises remained the main unit for indigenous innovation, the relative importance of private enterprises increased.[15] China's R&D expenditure as a percentage of GDP increased from approximately 1.4 per cent in 2007 to 1.9 per cent in 2012.[16]

d. Deepening research-industry ties

In addition to supporting the innovation capabilities of different actors, policies were also formulated to deepen linkages between academia and industry through the establishment of intermediary organizations between academia and industry. Government-led research consortia were established based on collaboration between leading companies, universities and government-led research institutes. New R&D institutions, such as the Shanghai Industrial Technology Institute and the Jiangsu Industrial Technology Research Institute, were established to deepen research-industry ties. These linkages serve as vehicles for accumulating innovation

resources and accelerating the transformation of scientific and technological achievements into industrial capabilities. They also play an important role in regional development and in partnering with enterprises on indigenous innovation.

(c) Post catch-up phase: 2012-present

In the post catch-up stage, China has increased its focus on innovation and frontier technologies. The Government has introduced a wide range of policies to support the development and adoption of frontier technologies in multiple spheres, such as smart manufacturing and artificial intelligence. China has maintained its pivot to firms as the main body of innovation.

(i) Institutionalization of innovation-driven development

The shift towards an innovation-driven development strategy has been institutionalized. In 2015, the Central Committee of the Communist Party of China and the State Council of the People's Republic of China jointly issued a call aimed at "deepening the reform of the system and mechanism and accelerating the implementation of the innovation-driven development strategy".[17] Under this call, the importance of creating better institutional conditions and indigenous innovation was emphasized.

The new strategy has important implications for China. For example, in the past China's investments to drive economic growth were focused on building manufacturing and infrastructure capacity. However, this led to rapid depletion of natural resources and an increase in heavy pollution.[18] To maintain economic growth and address the challenges of sustainable development, China is now focusing on innovation. The Government plans to increase spending on basic science, core technology, green development and frontier technologies, such as big data and artificial intelligence.

(ii) Targeted policies to develop and diffuse frontier technologies

China has launched several policies and plans to support the development and diffusion of frontier technologies. For example, following the increasing global importance of the digital economy, information technology (IT) and the Internet have become a focus policy area for the Chinese Government. The "Internet plus" paradigm is promoting Internet banking, e-commerce and usage of information and communications technologies (ICTs) to increase productivity. Developments in IT and the Internet have generated tremendous opportunities for Chinese industry and enabled the emergence of such companies as Alibaba Group Holding Ltd. (an online e-commerce platform), Tencent Holdings Ltd. (a major provider of Internet-related services), Didi Chuxing Technology Co. (an online ride-sharing platform) and Xiaomi Corporation (an electronics company).

There are several other targeted policies for frontier technologies. For example, the New Generation Artificial Intelligence Development Plan is aimed at developing China's AI capabilities and making it a global leader in AI by 2030. The Made in China 2025 programme is designed to support innovation in manufacturing with the use of such frontier technologies as robotics.

(iii) Strengthening knowledge-sharing

To facilitate knowledge transfer and sharing, and strengthen intellectual property management, the Government is building an open knowledge-sharing system for major national scientific research institutes and platforms. The revision in 2015 of the Law for Promoting Commercialization of Science and Technology Results enabled this development by giving universities and scientists more autonomy to manage technology transfer.[19]

(d) Science, technology and innovation for sustainable development and inclusive growth

China's rapid economic growth has had adverse environmental and social consequences. It has led to heavy pollution and resource scarcity. It has also led to an increase in inequality in wealth.[20] China has gradually made efforts to address this situation and is leveraging science, technology and innovation for sustainable and inclusive growth.

China has increasingly focused on developing its renewable energy industry to move towards sustainable growth. One of its policies is to promote the solar industry in order to reduce air pollution while simultaneously responding to growing energy needs and supporting economic growth. The development of China's manufacturing capacity of solar photovoltaics (PV) has contributed to a steep reduction in their global costs; between 2008 and 2015, the average cost of solar PV dropped by almost 80 per cent.[21] China is hence supporting a shift in power generation towards renewable sources – including wind and hydropower – across the world, which will reduce the global impact of air pollution. Consequently, China has experienced rapid growth in solar energy. In 2016, it had the largest installed PV capacity in the world (approximately 25 per cent of global cumulative capacity) and contributed nearly half of global additional annual capacity.[22]

China has also implemented several programmes for inclusive growth aimed at enabling economic development in rural areas. The Spark Plan, implemented between 1986 and 2016, promoted economic development in rural areas through the transfer and diffusion of technology and knowledge. With an average annual budget of $70 million, the programme stimulated the development of local agricultural and other industries in rural areas. The Spark industrial belt encompasses 114,000 companies and a total labour force of 12.3 million.[23] The development of rural road infrastructure (by the end of 2013, 99.97 per cent of townships and 99.70 per cent of villages had road access)[24] and increased rural Internet penetration (by the end of 2017, there were 209 million rural Internet users and the penetration rate of the Internet in rural areas was 35.4 per cent)[25] has enabled the benefits of digital economy, such as efficient and intelligent farm management systems, agricultural product supply chain management systems and online agriculture, to be extended also to rural areas. This progress is reflected, for example, in the emergence of "Taobao villages" where clusters of rural entrepreneurs can access global markets through e-commerce.[26]

(e) Key messages

1. Starting in the 1950s, the objective of China's STI policy was to build national defence capability, improve industrial capabilities and achieve food security. Policy measures were focused on transferring technology from and cooperating with the former USSR and on setting up science and technology research and policy institutions. Execution was centralized.

2. In the 1980s, STI policy was directed towards supporting economic development. The policies were focused on linking research to market demand, strengthening basic science research infrastructure and facilitating technology transfer. Research institutions started responding to market demand and collaborated with industries or set up their own companies. In addition, industrial clusters and high-technology zones were established to build advanced technology capabilities and facilitate technology transfer from academia to industry.

3. Towards the end of the millennium, the focus was shifted from research institutions to firms as the unit of innovation. Policies incentivized or mandated State-owned enterprises as well as small and large private enterprises to invest in R&D. This focus continued and was re-emphasized throughout the 2000s. It was accompanied by a restructuring of research institutes and the establishment of intermediary organizations to deepen their research collaboration and its applications with relevant industries.

4. In the 2000s, FDI policy became a major instrument to facilitate technology transfer. Based on China's competitive advantage, the Government encouraged FDI flows towards selected industries while discouraging others, and granted market access in return for technology transfer.

5. Currently, the Government of China continues to focus on promoting innovation-based growth and is fostering policies that promote the development and diffusion of frontier technologies.

6. China has leveraged STI policy for inclusive and sustainable growth. It has promoted a renewable energy industry. It has also promoted rural development through efforts to increase agricultural productivity and efforts to improve rural connectivity and Internet penetration.

2. Japan

Japan is a global leader in science, technology and innovation. This section contains an examination of the evolution of its STI policies from its pre-industrialization phase starting in the late 1800s and extending to the current era.

Early STI policy was focused on absorbing international knowledge and developing Japan's human capital. Later, applied and basic research were promoted through government institutions, and firm innovation capabilities were encouraged through subsidies granted to private companies and the promotion of strong linkages between industry and academia. There has also been a strong sectoral approach in Japan's STI policy. The initial emphasis was on heavy industries, while later on it was shifted to electronics and life sciences. Table I.3 outlines strategic STI policy objectives and instruments used in each phase of Japan's development.

While STI policy objectives have largely been focused on supporting industrialization and economic growth, in its post-catch up phase greater emphasis is being given to support sustainable and inclusive growth. This shift has been a response to the rising social and environmental consequences of economic growth.

Table I. 3. Evolution of science, technology and innovation policy objectives and measures, Japan

	Pre-industrialization (1868-1945)	Catch-up phase (1945-1970s)	Post catch-up (1980-present)
Strategic STI policy objectives	Transitioning to an industrialized society by building manufacturing capacity	Facilitating rapid economic growth to narrow the technology and economic gap with the United States. Placing secondary focus on social needs	Addressing economic, social and environmental challenges
Key policy measures	Supporting technology imports Selecting industries through legislation and financial support Establishing STI-related governmental institutions (e.g. government research institutes) Establishing educational organizations and training human resources	Supporting industry through facilitating foreign technology introduction Selecting priority sector Supporting innovation activities through R&D funding and public-private partnership Expanding access to all levels of education	Maintaining competitiveness by strengthening R&D activities, especially basic research Identifying and investing in future technologies Reorganizing STI-institutions to strengthen university-industry linkages

(a) Pre-industrialization phase:1868-1945

Japan is among the first countries outside of Europe and North America to attempt to absorb scientific knowledge and technologies from these countries. Starting in the late 1800s, Japan built its science and technology capacity through government support for imports from abroad, particularly from the industrial powers at the time. The focus was first on acquiring technologies for light industries, such as textiles, and later, with increasing demand for iron and steel related to the first Sino-Japanese War (1884-1885) and the Russo-Japanese War (1904-1905), efforts were focused on importing technology for the growing heavy industries.[27] The growth of war-oriented industries further expanded domestic technological capacity in the 1920s and 1930s, which then spread to more general industrial technologies.[28]

The Government played a central role in building domestic capacity and facilitating diffusion of technology. Initially, it facilitated imports of foreign equipment with the aim of diffusing technology to the private sector. The Government also played a strong role in guiding technological development in specific sectors aligned with the national interest. For example, during the First World War, the promotion of the automobile industry began in the army, while the navy aimed at mastering shipbuilding technology. Additionally, several science and technology institutions were set up to manage and direct science and technology activities in Japan.

Japan also built science and technology human capital through skill transfer programmes and the introduction of science and technology-focused education. It sent civil servants and students to Europe and the United States and invited foreign engineers and researchers to transfer skills to Japanese trainees.

Public policies strongly supported education, rapidly improving educational attainment across all levels. After the Ministry of Education was established in 1871, the enrolment rate for elementary school children increased from 28 per cent in 1873 to 93 per cent in 1903.[29] In 1877, the University of Tokyo was established.

Specialized science and technology education that built strong linkages between education and research was also promoted. For example, the engineering faculty system in Japan was designed not only to educate engineers but also to establish systematic scientific knowledge. The tight network among the alumni who then became university professors, government officials, technical officials, company engineers and national institution researchers played a key role in knowledge diffusion. Industry and basic sciences were able to connect owing to this network, with subsequent knowledge dissemination to the Government for the development of industrial policy and to the private sector for enhancement of economic growth.

During this period, Japan was transformed from an agricultural to an industrial society. The manufacturing growth rate averaged 6.34 per cent between 1887 and 1938 compared with 2.60 per cent for services and 1.36 per cent for agriculture.[30]

(b) Catch-up and industrialization phase: 1945-1970s

Japan's economy and industry suffered large losses during the Second World War, with more than a third of the industrial machinery having been destroyed. The main objective of the STI policy in the post-war period was to facilitate industrial recovery and economic growth. Starting in the 1960s, STI policy also supported social outcomes. The choice of specific technology areas pursued in the 1960s and 1970s was sometimes determined by social needs, such as finding solutions to pollution, traffic congestion and water scarcity problems. The strategic objective of Japan in this period was closing the technological and economic gap with the United States.

(i) Importing industrial technology

After the Second World War, modern technology for industrial development was imported from advanced economies. About 80 per cent of the imported technology was related to the mechanical and chemical industries. As a result, industrial production grew at an annual rate of more than 20 per cent in the late 1950s,[31] and Japan's electronics and automobile industries gained global success. Japanese businesses also innovated and improved the imported technology, leading to the development of several novel products. For example, Sony emerged as a global leader in consumer electronics, launching several new devices to the world, such as the portable cassette player (Walkman) and the videotape recorder.

(ii) Private sector-led research and development investment

The above-mentioned indigenous technological improvements were made possible by private companies investing in R&D. Private companies established in-house research laboratories called "central research laboratories". While some technological advances were made through efforts to develop Japan's own technologies, industrial laboratories mainly focused on improving existing or imported technologies. Their efforts were aided by the policies of the Ministry of International Trade and Industry. Initially, they protected nascent industries from foreign competition and supported exports until the manufacturers developed capabilities to face global competition.

(iii) Strengthening organizational framework and investing in science, technology and innovation

In the 1950s, a comprehensive administrative organization for science and technology was established in response to requests from the Japan Business Federation. In 1956, the Japan Science and Technology Agency was established in the Prime Minister's Office to promote research, reduce dependence on foreign technology and strengthen research-industry links. In 1959, the Council for Science and Technology was established to guide comprehensive national science and technology policy.

In the mid-1960s, the focus was shifted towards the development of indigenous technological capabilities. To do so, the Government had to invest in developing research capabilities. Research for building indigenous technology was not attractive for the private sector as it entailed long-term, high-cost and high-risk investments. In 1966, with the aim of inducing technological breakthroughs and spillover effects, the Government implemented "large-scale industrial research and development system", commonly known as "big projects", financing the costs and absorbing the risks of large-scale industrial research activities. The Government chose priority areas, paid subsidies for technology development by private companies and guided the efforts of private enterprises, universities and national laboratories towards promising industries.

(iv) Developing human capital

Human capital was an important factor to support the post-war economy. Compulsory education was expanded to junior high schools offering vocational education. The Government also expanded and improved higher education. Between 1945 and 1975, the number of scientists and engineers per 1,000 population increased more than fourfold from 2.8 to 11.3.[32]

(c) Post catch-up phase: 1980s-present

The economic and technological gap between Japan and the United States narrowed in the 1980s as a result of rapid industrial productivity growth in the preceding decades.[33] In the late 1980s, Japanese companies performed well both domestically and internationally. Their investment in new equipment and machinery surged. Japanese companies, such as JVC (Victor Company of Japan Ltd.), Sony Corporation, Panasonic Corporation, Toyota Motor Corporation, Honda Motor Company Ltd. and Canon Inc., dominated the global market with their leading technology, taking market share away from United States and European competitors. Japan's trade surplus soared in the 1980s; as a result, trade relations became more strained with some trading partners.[34] When Japan reached technological parity with the United States, it had to chart its own technological path with no proven model to follow, so it focused on increasingly complex and sophisticated technologies that required greater basic research.

(i) Private sector investment in research and development

To maintain competitiveness and increase independence, private sector industrial players started investing more in R&D over time. This increasing private sector investment also stemmed from the inability of universities and public research institutes to produce enough relevant knowledge to maintain national economic competitiveness. In the mid-1980s, private companies accelerated investment in and internationalization of basic research and R&D; they established laboratories abroad and employed foreign researchers at companies, universities and national institutions. The private sector industry actors built 289 R&D bases overseas from 1985 to 1997.[35]

(ii) Public sector investment in basic science to support new industries

The shift from the technology import strategy to the development of indigenous capabilities required basic research in emerging areas, such as biotechnology, information processing and new materials. Further, as a measure to fight the recession following the asset price bubble collapse in the early 1990s, the Government increased its investment in research and development.

(iii) Increased industry-academia collaboration

To tackle economic stagnation, the Science and Technology Basic Law and the five-year Science and Technology Basic Plan were adopted in 1995 and 1996 respectively to promote more science and technology research. They supported basic research activities of universities and public research institutes that could support the emergence of new industries and economic restructuring. This strengthened cooperation between industry, academia and the Government. Industry-university research collaboration in emerging technology sectors was born, and technology transfer subsequently became easier. Innovation in SMEs was encouraged through collaboration with technology parks and research institutes, and the expansion of so-called incubators.

(iv) Science, technology and innovation policy to create future industries and transform society

STI policy is increasingly being mainstreamed into broader public policies; the Fifth Science and Technology Basic Plan (2016-2020) is focused on the future and is aimed at creating new industries and transforming society (see section (d) below and chapter II). It is aimed at promoting future industries and a smart society where technological solutions are sought to address social challenges. To do so, it is developing 11 systems, including a new manufacturing system and an intelligent transport system. High-level and system-specific coordinating bodies have been set up to address the uncertainties and complexities posed by these new innovation systems that are based on frontier technologies. The expansion in the number of coordinating bodies is, on the other hand, overwhelming coordination efforts and draining human resources.[36]

(d) Science, technology and innovation for sustainable development and inclusive growth

Japan's rapid economic development in the 1950s and 1960s led to an increase in pollution, with consequent adverse environmental and social effects, such as deteriorating public health. Leveraging science and technology and using STI policy to solve environmental and public health problems became one of the focus areas in the late 1960s.[37]

The first oil crisis in the early 1970s was a trigger which led the Government of Japan to diversify energy supply and develop new and clean energy sources. Various projects, including the New Energy Technology Research and Development System, or "Sunshine Project", were implemented.[38] New institutions, such as the Environment Agency (now the Ministry of the Environment) and the National Institute for Pollution Research, were established in the early 1970s. Science and technology systems were strengthened to facilitate the development of technological innovations that could address the growing environmental pollution and public health challenges. This advance led, for example, to the development of technologies for emissions control.[39]

The focus on leveraging STI policy for sustainable and inclusive growth has consistently been amplified. The Fifth Science and Technology Basic Plan (FY 2016-FY 2020) defines four policy goals to ensure sustainable and inclusive development for Japan and the world in line with the Sustainable Development Goals. One of the pillars of this plan is deepening the relationship between STI and society's diverse stakeholders to ensure inclusive and sustainable growth. The plan delineates 13 important policy tasks in three categories (see table I.4) to address economic, environmental and social challenges. These include improving energy efficiency, combating climate change and improving public health and food security.

Table I. 4. Important policy tasks of the Fifth Science and Technology Basic Plan

Category	Policy tasks
Sustainable growth and self-sustaining regional development	1. Ensuring stable energy and improving energy efficiency 2. Ensuring stable resources and cyclical use 3. Securing a stable food supply 4. Establishment of a society in which people enjoy long and healthy lives with world-leading medical technology 5. Building infrastructure for sustainable cities and regions 6. Extending service life for efficient, effective infrastructure 7. Improving competitiveness in manufacturing and value creation
Ensure safety and security for the country and its citizens and a high-quality, prosperous way of life	1. Addressing natural disasters 2. Ensuring food safety, living environments and occupational health 3. Ensuring cybersecurity 4. Addressing national security issues
Addressing global challenges and contributing to global development	1. Addressing global climate change 2. Responding to biodiversity loss

(e) Key messages

1. Initially, STI policy was directed towards developing modern manufacturing capabilities for transitioning to an industrialized society. The Government supported and subsidized technology imports from more advanced industrialized countries for the purpose of diffusing the technology and building industrial capabilities.

2. Gradually, the STI policy focus was shifted towards developing indigenous capabilities so the country could become globally competitive. The Government encouraged academia-industry collaboration, subsidized R&D in the private sector and supported the development of new sectors by investing in research in emerging areas, such as biotechnology, information processing and new materials.

3. The private sector played a central role in Japan. It set up its own research units. In the 1950s, such units focused research efforts largely on improving imported technology. However, as Japan reached technological parity with advanced industrialized countries, they repositioned themselves and increasingly focused on conducting more novel research and developing new technologies. The Government played a strong facilitation role by responding to the demands of industry and aligning them with national objectives.

4. Rapid increase in access to higher and vocation education was an important enabler for the success of its STI policy. Early and continued investment by the Government in science and technology education, in particular engineering, led to the development of a strong human resource base and networks to establish their own R&D systems.

5. STI policy started incorporating sustainability concerns and social needs from the late 1960s, in line with rising pollution and public health concerns. In recent years, inclusive growth and sustainable development is increasingly becoming a central tenet of STI policy.

6. The Government has a comprehensive set of policies and coordination mechanisms to ensure that Japan can build competitive advantage with the advent of the fourth industrial revolution. STI policy is coordinated at the highest level and is increasingly a core aspect of all policymaking.

3. Republic of Korea

STIs have been key drivers of the Republic of Korea's economic growth history; this section contains a discussion on how STI policy supported such growth. The policy objectives have been broadened over time from an initial focus on supporting industrial development to more holistic economic development objectives, and to sustainable and inclusive development aims in the current phase.

The policy instruments to achieve these objectives have also changed over the years. To build industrial capability, the Republic of Korea received external technical support, which was focused on technology imports, building human capacity and setting up science and technology institutions. The Government supported conglomerates in order to accelerate technological advances. As the Government's focus shifted from light to heavy industries, technological complexity increased. This situation led to investment in R&D, initially by the Government and later by the private sector. The increasingly rapid pace of technological change and growing social and environmental concerns at the end of the century forced the reorientation of STI policy. STI policy priorities are now focused on sustaining the country's industrial competitiveness advantage through the strengthening of basic research, investing in future technologies and new industries, supporting SMEs and building on public-private partnerships.

Table I. 5. Evolution of science, technology and innovation policy objectives and measures, Republic of Korea

	Pre-industrialization (1945-1959)	Catch-up phase (1960-1999)	Post catch-up (2000-present)
Strategic STI policy objectives	Developing basic capabilities for industrial and economic growth	Sustaining strong economic growth by narrowing technology gap with the United States	Addressing economic, social and environmental challenges, and enhancing innovation-led growth
Key policy measures	Providing external support for technology imports and building domestic industrial capacity Establishing science and technology institutions	Supporting conglomerates to accelerate technology transfer and diffusion Making industry selections and rationalization Building domestic R&D capacity through government-funded research institutes and national R&D projects Expanding science and technology education	Sustaining industrial competitiveness advantage through strengthening basic research, investing in future technologies and new industries Supporting SMEs Developing a national innovation system through public-private partnerships

(a) Pre-industrialization phase: 1945-1959

In the 1950s after the cessation of hostilities of the Korean War, the Republic of Korea was a low-income economy with limited resources. In 1953, its GNI per capita was only $67.[40] That situation required the country to accept international assistance from the international community; this effort was led by the United States and the United Nations. The aid provided included investment projects and technical assistance in the form of sending international experts to the Republic of Korea and of providing overseas training for Koreans. This assistance led to the transfer of equipment, technology and knowledge that enabled the emergence of industrial capacities.

In recognizing the importance of science and technology for industrial development, basic key education and research institutions were established. For example, the Science Education Bureau was established in the Ministry of Education for expanding access to science and technology education. In the Ministry of Commerce and Industry, an administrative organization was established to develop industrial technologies in such areas as mining, fisheries and electricity.

The Government's emphasis on education led to an expansion in access to and demand for general education. Primary school enrolment increased from 1.6 million children in 1945 to 3.6 million in 1959. Vocational, general high schools and higher education institutions of science and engineering were established for science and technology education. Part of the funding for the expansion of science and technology education and for training professors in science and technology in the United States came from United States foreign aid. In the 1960s, when the trainees returned, the Government channelled their skills in order to promote science and technology. Although funds were limited, the increased access to education laid the foundation for future high levels of economic growth. The United Nations Educational, Scientific and Cultural Organization (UNESCO) also supported education through the establishment of a number of educational and research organizations.[41]

(b) Catch-up and industrialization phase: 1960-1999

In the 1960s, the Republic of Korea's policy was shifted towards an export-based, industrialization-led, high-growth strategy. In 1962, the first five-year economic development plan began. With this policy change, exports expanded, leading to economic growth. Export-based policy put pressure on domestic companies to improve their productivity and remain competitive in the international market, and this pressure prompted them to accelerate technology learning. Economic development further accelerated in the 1970s. The development of heavy and chemical industries led to a diversification of technological needs and an increase in technology requirements. At the end of the 1970s, after two decades of strong economic growth, the Republic of Korea faced several economic challenges: technological protectionism in advanced economies; deterioration in the international economic situation; and oil shocks, the last of which occurred in 1979. The Republic of Korea overcame these challenges, however, through the development of domestic R&D capabilities that sustained high levels of economic growth in the 1980s.

(i) Imports of capital goods, technology licensing and original equipment manufacturer contracts to build industrial capacity

The Republic of Korea relied on importing foreign technology and knowledge to build the country's domestic capacity. The process was private sector-led with strong support from the Government. FDI was not preferred; instead the Government opted for foreign debt as a key tool because it wanted to retain independence from multinational corporations.[42] In its place, domestic companies established extensive networks with foreign companies and built technology capability through reverse engineering, international licensing, capital goods import and original equipment manufacturer (OEM) contracts. These networks were a major source of technology learning for Korean companies.[43] For instance, Korean companies relied heavily on supplying to foreign OEMs. These foreign buyers provided the technical assistance needed to help Korean producers meet their technical specifications and enabled Korean companies to raise their technological capabilities. The foreign technology transfer policy also had a sectoral focus. The early focus was on light industries, but in the 1970s, it shifted towards heavy industries.

The Government provided strategic and tactical guidance through its five-year economic development plans. From 1962 to 1992, the Government implemented seven development plans to support domestic technological capacities, under which clear goals were set to coordinate actions across several dimensions, such as industry, technology and education. The first five-year technology promotion plan in the 1960s was focused on introducing foreign technology for industrial development, establishing and improving science and technology governance (e.g. regulatory framework, administrative institutions and information dissemination) and developing technical human resources domestically (increasing the number of industrial high school graduates, improving educational facilities and contents, and workplace training).[44]

(ii) Supporting conglomerates to accelerate technology diffusion

The Government of the Republic of Korea created conglomerates (chaebols) as a means of achieving economies of scale in mature technologies, developing strategic industries and promoting exports.[45] The Government supported their diversification and facilitated their access to capital. It provided chaebols with scarce foreign exchange and preferential financing. It also granted them large-scale import substitution projects and facilitated the import of production technology through government-guaranteed foreign debt.

These conglomerates enabled innovation learning by[46]:

- Attracting high-quality human resources that led to skills' accumulation because of implicit knowledge formation
- Facilitating the introduction of foreign technologies
- Promoting rapid learning through training and R&D activities
- Diffusing knowledge among subsidiaries.

(iii) Investing in domestic research and development, and building institutions

In the late 1970s, the policy focus was shifted towards building domestic technological capabilities in order to maintain industrial competitiveness. Technology protectionism in the advanced economies and forays into increasingly sophisticated technology were the key drivers of this shift. Both the Government and corporations started investing in technology development. Private companies began R&D activities with the support of the Government and participated in many national R&D projects promoted by the Government.

One of the objectives of the Ministry of Science and Technology, which had been established in 1969, was to provide governmental R&D support for science and technology. Five strategic heavy industries were identified: machinery, steel, shipbuilding, electronics and chemicals. Government-funded research institutes were established to develop the technological capabilities required for heavy and chemical industries. They subsidized the high-cost, high-risk R&D undertaken by the chaebols in these industries. Initially, most of the R&D expenditure was born by the Government. In the 1970s, government research institutes accounted for 83.9 per cent of R&D expenditure and 43.7 per cent of researchers.[47]

In the 1980s, the national R&D system was reorganized towards greater investment in national resources and increasing the role of the private sector. The Ministry of Science and Technology supported the establishment of company-affiliated research institutes. Industrial technology research associations were founded in each industrial sector to jointly use technology, manpower, funds and research facilities in order to overcome common barriers in developing cutting-edge, highly competitive technologies. This advance led to the development of various technologies, including semiconductor technology. The Government also began to build an extensive network of public, non-profit and private technical support organizations for the diffusion of technology, especially for SMEs.[48]

In the 1990s, science and technology policy promoted a stronger private-sector led technological innovation system. By the early 1990s, in contrast with previous decades, 70-80 per cent of the total R&D was financed by the private sector.[49] The number of company-affiliated research institutes, which started with 46 in 1981, increased to 1,000 in 1991 and to 4,810 in 1999.

As the R&D capacity of the private sector grew, the Government promoted large-scale national R&D projects, financed basic research and developed university research capabilities to break away from imitation strategies and forge domestic technological capabilities. Government-funded research institutes reflected these shifts. With the increasing development of specialized technology, by the mid-1990s, most ministries participated in science and technology administration, and a system was set up to plan and promote independent national R&D projects in each ministry. In 1997, the Ministry of Science and Technology was upgraded, and the National Science and Technology Council was established under the chairmanship of the President in order to strengthen its coordination functions.

(iv) Strengthening human resources in science and technology

Achieving high-speed industrialization required an educated workforce. Public and private expenditure in investments in education led to a rapid increase in education across all levels. The college/university graduation level increased from fewer than 20 per 1,000 persons in 1960 to more than 300 per 1,000 in 1994. Table I.6 shows the increase in education levels across the board. Two thirds of the total education expenditure was made by the private sector and parents.[50]

Table I. 6. Republic of Korea Human Resources Development Index

	1953	1960	1970	1980	1990	1994
Illiteracy rate	78.0	27.9	11.6	-	-	-
Percentage of enrolment by age						
Elementary (6-11 years)	59.6	86.2	102.8	101.0	100.7	100.5
Middle (12-14 years)	21.1	33.3	53.3	94.6	98.7	99.0
High (15-17 years)	12.4	19.9	29.3	68.5	86.9	88.7
University	3.1	5.0	8.7	16.0	37.7	48.8
Vocational school graduates (per 1,000)			31.6	104.5	67.7	184.4
University and college graduates (per 1,000)		18.8	36.0	103.7	258.0	311.8

Source: L. Kim and S. Sung, "Science and technology: government policy and corporate strategy", in Korean Economy Half-century Historical Assessment and 21st Century Vision, D. Cha and G. Kim, eds. (Sejong City , Republic of Korea, Korea Development Institute, 1995) (in Korean).

A long-term science and technology human resources policy was adopted to support the development of heavy and chemical industries. Under that policy, specialized personnel were supplied according to industry sector and manpower level. As a result, the number of students in science and engineering universities increased from 46,671 in 1970 to 139,300 in 1980; the number of students in colleges increased from 6,945 to 40,880 in the same period. In 1971, the Korea Advanced Institute of Science was established to nurture advanced science and technology personnel with practical skills particularly relevant to the industrial and defence sectors. In 1981, this educational institution merged with Korea Research Institute of Science and Technology to become the Korea Advanced Institute of Science and Technology to enhance the linkage between education and research. In addition, the Government promoted the establishment of science high schools, strengthened support for university-based basic science research activities, expanded military service exemptions for science and engineering graduate students and increased research scholarships. The establishment of the National Research Foundation and government research institutes was also critical in developing a strong R&D workforce.

The Government simultaneously pursued a policy of attracting overseas Korean scientists and engineers. From 1968 to 1990, more than 1,000 permanent and 1,000 temporary scientists and engineer returnees were supported.[51]

The R&D activities of universities accelerated in the 1990s as various projects and systems had been implemented to support them. A large number of small and medium-sized provincial and undergraduate schools were established. Graduate schools also expanded greatly, increasing from 303 in 1990 to 905 in 2000.[52]

In the catch-up and industrialization phase (1960-1999), the economy grew at an annual average rate of 9 per cent, raising GNP per capita (current prices) from $87 in 1962 to $10,550 in 1997. The country's exports increased in value from $40 million in 1963 to $143 billion in 1999, with the share of manufacturing in exports increasing from 17.6 to 91.5 per cent in the same period.[53]

(c) Post catch-up phase: 2000-present

At the turn of the century, the Republic of Korea had narrowed the technological gap with leading advanced economies and achieved strong economic growth. STI policy was reoriented to address a broader and more complex set of challenges, First, its objective was shifted to comprehensive development that incorporated social and environmental concerns (see section (d)). Second, the previous export-led industrialization strategy had to be rethought in the light of increasing competition from accelerated development of such newcomers as China, and rapid population ageing. Third, the accelerated pace of technological development necessitated building innovation competencies to compete with technologically leading countries. The previous model of technology diffusion would no longer be effective. Fourth, the existing university education system needed strengthening in order to encourage creativity and diversify competencies for innovation-led growth.

The Government responded positively to these challenges; since the 2000s, there has been a shift in STI policy to develop creative and innovative science and technology capabilities. The Government and industry-university research institutes have joined forces to advance the national innovation system and strategically promote frontier technologies that hold future potential. They have fostered and utilized creative science and technology personnel, promoted basic research, strengthened competencies and enhanced the innovation capabilities of SMEs and venture companies.

The Framework Act on Science and Technology (2001) outlined the basic framework for science and technology development, emphasizing the need for systematic and comprehensive innovation actors and organizations, and stipulated the establishment of a national innovation system. Based on the Act, the first science and technology basic plan enabled alignment and organization of public science and technology policies to support innovation-driven economic growth. For example, the Government made efforts to establish a system to constantly ascertain and support private technology development needs and to encourage private sector companies to participate in the national R&D programmes in order to strengthen support for industrial technology development and encourage voluntary investment.

The latest basic plan for science and technology (2018-2022) further elaborates on strategies to better address the challenges outlined at the beginning of this section:

- To expand the capacity of science and technology innovation, the Government will actively explore and support creative research talent
- To create an innovation-centred science and technology ecosystem, the Government will link research results to new industries and strengthen the capacity of companies to play a leading role in directing innovation
- To prepare for and leverage the fourth industrial revolution, the Government will foster new industries

The Republic of Korea's R&D to GDP ratio has increased to the highest in the world in recent years in an effort to grow its innovation base (see figure 1 in the introduction to this report).

(d) Science, technology and innovation for sustainable development and inclusive growth

In the 1990s, the concept of balanced welfare that considered factors beyond income began to gain attention. In the 2000s, there was growing demand for science and technology to play an active role in solving social and environmental problems, such as those related to public health, the environment and disaster management. STI policy in the Republic of Korea started to promote the development of science and technology, for example in environment and health care, with the objective of improving the quality of life.

The Government invested in new technology areas, such as information technology, biotechnology and environmental technology, with the dual purpose of supporting inclusive and sustainable development, and promoting growth industries. Green growth is a good example of expanding the sustainable development role of science and technology. The Government has invested in facilitating the development of 30 green technologies, including new and renewable energy technologies. Investment in green technology R&D increased from $1.8 billion in 2009 to $2.8 billion in 2012.[54] In 2013, other ministries jointly selected 10 high-priority action tasks in such areas as chronic diseases, cybercrime and food safety, to solve them, they prepared the detailed Comprehensive Implementation Plan for Science and Technology-based Solutions to Social Problems.[55]

The Republic of Korea has also focused on addressing the gender gap in science and technology over the last two decades. For example, it has introduced several initiatives to bridge the digital gender divide through programmes for improving e-literacy and building IT skills for women. Additionally, it has developed services for women, such as a mobile application for alerts on sex offenders.

The growing sustainability and inclusivity orientation of STI policy is reflected in the Fourth Science and Technology Basic Plan (2018-2022), which outlines four objectives for the future of the Republic of Korea:[56]

- A prosperous world where innovative new industries and jobs are abundant
- A convenient world in which the convenience of life has been dramatically improved
- A happy world in which a healthy life, safety and security are guaranteed
- A world with a virtuous circle of economic development and environmental preservation

For example, one of the components to achieve these future objectives is to leverage the spread of ICTs to solve social problems, such as those related to disaster reduction and improving health care. Table I.7 lists the policy tasks for the fourth strategy of that basic plan, calling for the use of science and technology for the realization of a happy life.

Table I. 7. Policy tasks of the fourth strategy of the Fourth Basic Science and Technology Plan (2018-2022)

Strategy	Policy tasks
Realization of happy life for everyone through science and technology	1. Realizing a healthy and energetic life through responses to demographic changes; realizing precision medical care; and establishing a national health-care system to protect the health of the people; 2. Building a safe society where people can live with peace of mind through the prevention and management of life-threatening factors; the expansion of disaster/safety education; the securing of a smart disaster safety management system; and the strengthening of defence capabilities based on science and technology; 3. Creating a pleasant and comfortable living environment through the ensuring of sustainability by responding to climate change; the realization of a pleasant and clean-living environment; and the building of a convenient and liveable smart city; 4. Realizing a warm and inclusive society through improving the welfare of the underprivileged; eliminating the digital information gap; resolving the science and technology culture gap; and strengthening the R&D role on issues close to people's lives.

(e) Key messages

1. The initial objective of STI policy in the Republic of Korea was to build industrial capability for rapid economic growth. This goal was reached through technology imports, capacity-building support from the United States and establishing science and technology educational institutions. The early establishment of science and technology educational institutions and their later expansion provided a strong foundation for future growth.

2. Initial technology imports were less sophisticated being geared towards development of light industries. As the focus shifted towards heavy industries, the technological requirements became more sophisticated. With increasing technological protectionism and with the Republic of Korea transitioning to complex technologies in the 1980s, the focus was shifted from technology imports to developing domestic R&D capabilities. Government-funded research institutes were the key vehicle that drove this research, supplied human resources and coordinated with industry.

3. The private sector played a dominant role in science and technology development with Government support. To promote technology diffusion at scale, the Government supported conglomerates (chaebols). From the 1980s, the private sector also played a central role in investments in R&D to build indigenous science and technology capabilities. The private sector made the research more demand driven.

4. In the 2000s, STI policies were reoriented. First, the mandate was broadened to incorporate inclusivity and sustainability. Second, sustaining competency with an accelerated pace of technological change required reorienting STI policy towards strengthening indigenous R&D and innovation capabilities, a shift from the previous approach of technology diffusion.

5. In order to achieve these new objectives, the Government directed investments in new technologies and new industries. Increased R&D investments and public-private partnerships were aimed at leveraging the fourth industrial revolution in order to create jobs and foster inclusive and sustainable growth.

4. Singapore

Singapore has undergone rapid transformation in the last 50 years, from being a low-income, non-industrialized economy to becoming one of the most innovative and wealthy ones in the world. Science, technology and innovation policy has increasingly become a core component of national policies driving this growth. In this section, the evolution of STI policy in Singapore is discussed starting from 1965 when the country gained independence to the current era. STI policy objectives have been broadened over that time period. The initial focus was on building the technological capacity of industry by incentivizing FDI for technology transfer and diffusion and building basic science and technology skills and education. As STI policies were shifted to encourage high-value-added manufacturing, the Government increasingly provided incentives for investing in R&D, encouraged innovation in SMEs and invested in and attracted human capital. Over the last decade, as the innovation policy was aimed at building an innovation-centric economy, the focus has been shifted towards building an enabling environment for innovation, providing incentives for firms to innovate, and supporting innovation in the public sector.

Table I. 8. Evolution of science, technology and innovation policy objectives and measures, Singapore

	Pre-industrialization (1965-1980)	Catch-up phase (1981-2010)	Post catch-up (2010-present)
Strategic STI policy objectives	Stimulating rapid economic growth and building industrial technological capacity	Sustaining economic growth and maintaining competitiveness	Functioning as key driver for future development and innovation-led growth
Key policy measures	Incentivizing FDI as a tool for technology transfer and diffusion Building domestic science and technology skills through technical training institutes	Incentivizing domestic R&D to build high-value-added industries Supporting SMEs to spur innovation by providing access to funding, building links with R&D and creating an enabling environment Investing in human capital and attracting foreign talent	- Fostering and adopting public sector innovation - Incentivizing and supporting innovation in business, particularly SMEs

(a) Pre-industrialization phase: 1965-1980

Singapore had an underdeveloped domestic industrial base when it gained independence in 1965. Around that time, developed countries were seeking to transfer manufacturing industries overseas. The Government of Singapore seized this opportunity as a path to rapid industrialization.

The country's initial development strategy was to attract foreign companies in labour-intensive industries. During this period, Singapore was highly dependent on foreign multinational corporations for technology transfer.

FDI continued playing an important role in the 1970s as Singapore transitioned to a more technology-intensive development phase. The Government and companies encouraged technology diffusion from multinationals to the local economy. Tax incentives were given for manufacturing companies that undertook R&D in Singapore. This situation led to rapid growth of a local process of technological development within multinationals in the mid-1970s. This created a virtuous cycle. A base of local supporting industries emerged, which in turn invested in acquiring and exploiting imported technologies. FDI also enabled the building of the technological skills of workers through on-the-job learning, such as for operators and technicians employed by multinationals. In recognizing the importance of a skilled workforce for economic growth, the Government expanded access to primary and secondary education.

It set up technical training institutions, such as government training centres and scientific, technological institutions, to build the workforce required for the transition to technology-intensive high-value-added industries. These training institutes were industry-oriented, and they built industry-relevant skills. They were established and run as collaborative ventures between the Government's Economic Developmental Board and industry partners, such as Koninklijke Philips N.V., Seiko Holdings Corporation and the French Federation of Electrical, Electronic and Communications Industries.[57]

From 1965 to 1978, Singapore's average GDP growth rate reached 10 per cent due to the development of technology-intensive industries, such as precision engineering and electronics.

(b) Catch-up and industrialization phase: 1981-2010

Singapore transitioned to a technology and capital-intensive economy in the period 1981-2010. The goal of STI policy was to create modern high-value-added industries and foster innovation to remain competitive and ensure economic growth. Singapore built its R&D capacity, promoted SMEs, particularly for technology-based innovation, and invested heavily in human capital.

(i) Incentivizing domestic research and development for high-value-added technologies

From the 1980s, the emphasis shifted to developing indigenous technologies. Singapore built its own R&D capacity by providing incentives for private sector manufacturing companies to engage in R&D. The objective of Singapore's R&D and its broader STI policy was commercializing research to produce high-value-added technology products.[58]

In 1980, allocations from the national budget enabled the provision of tax incentives for manufacturing companies which undertook R&D in Singapore and for R&D institutes working with them. In 1984, Initiatives in New Technology was established as a scheme to provide loans for research projects; the objective was to support companies to train their staff in high-technologies, such as robotics, microelectronics, IT, biotechnology, optical and laser technology, engineering science and materials science.[59]

In response to the incentives, multinationals increased their R&D activities not only for technological upgrading but also increasingly to establish R&D centres in Singapore. Local firms also rapidly expanded R&D centres and began investing further in innovation. The strong growth of the Singapore Technology Group and other large government-linked companies added impetus to private investment in R&D.

The Government also established public R&D institutions and expanded R&D in tertiary institutions to supplement industry efforts. Industrial clusters and science parks were also used to attract R&D and strengthen linkages among firms and between universities and companies. The first science park, Singapore Science Park, was set up in 1980 near the National University of Singapore. Later, two scientific and technological corridors were established in northern and southern parts of the country to leverage the potential of clustering for science and technology. They consisted of business parks, science parks, universities and research institutions.

(ii) Creating institutions to support a science, technology and innovation-centric national development strategy

From the 1990s, the Government explicitly recognized the importance of STI policy R&D for economic growth. The first significant recognition came in 1989 when the long-term strategy and direction of Singapore's development highlighted the need to focus on R&D and specialization in high-technology niches.[60] The importance of innovation gained more recognition in the Strategic Economic Plan formulated in 1991.[61] This emphasis on science and technology led to the formulation of the first five-year national technology plan and the establishment of a new statutory board, the National Science and Technology Board, in 1991. The objective of these instruments was to promote industrially relevant R&D, build up science and technology manpower and develop a science and technology support infrastructure. These steps were followed by the formulation of a second five-year plan in 1996, called the Second National Science and Technology Plan, under which the budget allocation was doubled to $4 billion Singapore dollars, and in which the importance of investing in science in addition to technology was recognized. Towards the end of the century, the focus was shifted towards knowledge- and technology-based innovation, which were seen as the next economic growth drivers. The high-level Committee on Singapore's Competitiveness recognized that growth was increasingly driven by knowledge-based innovations and technology-based entrepreneurship.

(iii) Supporting small and medium-sized enterprises for technology-based innovation and entrepreneurship

Singapore has supported SMEs, particularly in developing innovative technologies, with the aim of fostering innovation-led growth. It has facilitated the availability of finance, linking such enterprises to R&D and provided an enabling environment.

In the mid-1980s, the Government began promoting the venture capital industry to facilitate technology-based innovation and entrepreneurship. In the early 1990s, it played a more direct role in venture capital development by creating new funds, such as Vertex Management Ltd. and EDB Ventures Pte., Ltd. This advance received further impetus in 1999 with the establishment by the Government of Singapore of the $1 billion Singapore dollars Technopreneurship Fund. This "fund of funds" was aimed at attracting leading venture capitalists to use Singapore as their regional operational hub and train a core of experienced venture capital professionals.[62]

Whereas previously most local startups were in manufacturing, largely as suppliers and contract manufacturers for multinationals, the new startups were focused on IT, software, Internet applications, biotechnology and life sciences. In 2001, the Government of Singapore invested $8.5 billion Singapore dollars in a research and development centre with the goal of growing the high-tech ecosystem in Singapore.

In addition to facilitating finance and access to R&D, the Government also invested in building supporting infrastructure for SMEs. In 2006, Singapore launched the enterprise scientific research innovation plan, which invested more than $100 million Singapore dollars in SMEs to engage in scientific and technological R&D and to strengthen innovation awareness among SMEs. The Government of Singapore incentivizes multinationals to cooperate with SMEs in the development of innovative products or services and supports SMEs to respond to local needs of transnational enterprises.

(iv) Investing in human capital

Singapore has also invested heavily in building the human capital required for undertaking R&D and innovation activities. First, it has strengthened the quality of its primary and secondary education system. Second, it has sought to cultivate specialized talent. For example, Singapore has set up a national science award through A*STAR talent training programmes through the Economic Development Board. Third, there has also been an increasing focus on cultivating a culture of innovation. In 2001, the national innovation action plan was launched to enhance innovation awareness and build innovation capabilities. Fourth, Singapore has emphasized the cultivation of practical talents and upskilling through on-the-job training. For example, students from Singapore Polytechnic University need to complete a year-long internship in order to establish a relationship with industry. Finally, Singapore seeks to attract foreign talent. For example, in 2003 Singapore planned to become a "global schoolhouse" with the goal of attracting 10 top foreign institutions within 10 years.[63]It also has programmes to attract leading scientists to take up positions in research institutions or as university professors in order to enhance domestic capacity for scientific and technological innovation.[64]

(c) Post catch-up phase: 2010-present

In recognizing STI and innovation specifically as central to future growth, Singapore is constantly seeking to increase its capabilities in innovation. It has sought to build an innovation-centred economy, has become one of the most R&D-intensive countries in the world and has been a leader in adopting innovation and technology for public sector management.

(i) Building an innovation-centric economy through business

The Government has set up several programmes to encourage and deepen innovation in firms. The scope of innovation and the support for it has broadened as the Government adopts a more holistic approach. For example, it set up the Innovation and Capability Voucher in 2009 to support SMEs with a specific amount of financial resources. In 2012, the plan was broadened to include applications from the technical field for "soft" innovation, which includes productivity, human resources and financial management. The scope of support has also been extended to system solutions to help SMEs overcome common business challenges and enhance their ability to develop businesses.

In 2016, Singapore launched SGInnovate, a private limited company wholly owned by the Singapore Government, to facilitate the efforts of aspiring entrepreneurs to build, commercialize and scale technology-based innovations. This company tries to develop capabilities in frontier technologies, particularly in growth sectors, such as digital health and financial technology. It is also a "curator", selecting and bringing together in the same space deep technology-focused players, such as those involved in digital health and robotics, with the aim of bringing about productive interaction and strengthening linkage among talented individuals within the ecosystem.

There has been progressively increasing investment towards building an innovation-centric economy. In 2016, a national plan called Research Innovation Enterprise 2020 was published, which outlines Singapore's plan to invest approximately $15 billion to support innovation and entrepreneurship, and build a knowledge-based, innovative and entrepreneurial economy.

(ii) Fostering and adopting public sector innovation

The Government of Singapore is not only an innovation facilitator but also an adopter. It has leveraged advances in ICT and frontier technologies to improve public service delivery. Many Singapore agencies have become leading users or consumers of the technology and innovations that they intend to foster.

Singapore's Smart Nation Initiative, launched in November 2014, is aimed at using information technologies, the Internet of Things, networks and big data to create technology-enabled solutions for the public sector and public services. Some of the initiatives include improving public transport networks, bundling the provision of government services and ensuring a secure open data marketplace for participatory governance. This initiative also marks a shift towards addressing social problems through STI policy. Some examples of projects under this initiative include:

Encouraging innovation and collaboration between citizens and companies by providing open data through government portals, such as Data.gov.sg and DataMall

Improving the provision of public services by deploying sensors to track and analyse housing, amenities and public infrastructure data under the Smart Nation Sensor Platform.

The Singapore Government also established in 2016 a new agency, Government Technology Agency, or GovTech, which is aimed at transforming how the Government delivers public services to its citizens. It is rolling out various platforms, such as a service to make the payment of tuition easier for citizens, and a trade information and management system for businesses. GovTech will be the central agency responsible for overseeing government digital services. It is an ambitious programme to leverage big data analytics, artificial intelligence and machine learning to transform public service delivery. (Further details are provided in chapter III.)

(d) Science, technology and innovation for sustainable development and inclusive development

Singapore is a densely populated city with limited natural resources. Singapore's Sustainable Development Blueprint,[65] similar to the Sustainable Development Goals, outlines social, economic and environmental indicators to be achieved by 2030 and calls for an important role to be played by technology and innovation.[66] For instance, Singapore supports energy efficiency by promoting green and energy-labelling schemes, as well as public procurement policies that promote the development and adoption of greener technologies and products.[67] Singapore is continuing to shift towards becoming a low-carbon society through the promotion of technologies and systems that enable a more efficient use of resources, such as smart grids, smart buildings and intelligent transportation.[68] A number of its innovation policy measures are focused on developing cutting-edge capabilities in the green economy, including the promotion of living labs to test ideas that are good for the environment and the development of a green buildings innovation cluster.[69]

Singapore has also promoted inclusive growth by implementing solid education and innovation policies that support entrepreneurship and the innovation capabilities of smaller firms. For instance, the Government has made strong investments in providing continuing education to prepare for the future of work (further discussed in chapter II). Its entrepreneurship and innovation policies, including measures to facilitate access to capital and to link SMEs with research institutions and large enterprises, provide opportunities for smaller firms and entrepreneurs to innovate. Finally, Singapore has also promoted inclusive innovation by supporting citizen-centric innovation. For example, by encouraging citizens to participate in the design of land transport and urban development plans[70] and by designing government services around citizens' needs.

(e) Key messages

1. Post-independence, Singapore pursued a rapid economic growth strategy by incentivizing FDI. This facilitated technology transfer from multinationals and diffusion among local firms through the import of technologies, as well as implicit learning from employees. The Government also set up technical training institutes to develop the workforce necessary to transition to high-value-added technology that it sought to promote.

2. As Singapore transitioned to capital- and technology-intensive industries, the focus was shifted from technology imports to domestic R&D. Incentivizing FDI remained a key tool to facilitate the setting up of R&D activities by multinationals. This was complemented by the promotion of industrial parks, which facilitated linkages between local and foreign firms and between universities and industry. This led to a sharp increase in the R&D activities of local firms.

3. The Singapore Government has strongly fostered innovation. In line with its previous policies, it opted for firm-driven innovation. It supported innovation in SMEs through fiscal and non-fiscal policy instruments. It has increased access to finance through direct funding and facilitating venture capital funding along with creating an enabling environment, for example by building linkages between SMEs and academia and other companies. It has also heavily invested in human capital and attracted high-quality foreign talent to build technological and innovation capabilities.

4. The Government has provided sustained support for developing skills and attracting talent. Initial focus was on expanding access to primary and secondary education, and training a workforce for participation in high-value-added industries. In addition to upskilling and strengthening basic education, recent focus has been on developing innovation skills and attracting and developing talent.

5. Since the mid-2000s, innovation has increasingly been a central component of the Government's broader economic policy. The scope of STI policy has been broadened and deepened towards building an innovation-centred economy. The Government is investing in new areas of innovation, for example the Internet of Things and big data under the Smart Nation Initiative to improve public service delivery. Through investments in public sector innovation, it has also become a consumer of the innovation it seeks to foster. Simultaneously, it has adopted a holistic approach to innovation, increasing its application to non-technological areas, such as supporting innovations in productivity, human resources and financial management in SMEs.

6. Singapore has designated an important role to STI policy in achieving the Sustainable Development Goals. It has launched several initiatives leveraging technology and innovation for sustainable and inclusive growth, such as supporting innovation in small firms, investing in green technology and encouraging participatory governance.

C. Key observations on the evolution of science, technology and innovation policies

The evolution of science, technology and innovation policies in China, Japan, the Republic of Korea and Singapore has followed divergent paths, employed different instruments and occurred over different time frames. Japan was the earliest of the four countries to start its industrialization process and the first to reach the post catch-up phase in the 1980s, whereas China has reached that phase more recently in the 2010s. While Singapore encouraged the participation of foreign firms for building domestic technological capacity, the Republic of Korea pursed a different approach, it supported the building of technological capacity through subsidizing technology acquisition by domestic firms. Despite these differences, there are commonalities across the four countries.

The following are key observations on the evolution of national STI policy as the countries have progressed through their different phases of economic and industrial development.

1. Facilitating technology transfer and diffusion

All four countries initially focused on technology transfer and diffusion. While the modalities and policy instruments they used differed, the emphasis of STI policy on technology transfer and diffusion was consistent across the four countries. For example, while the Republic of Korea subsidized technology imports for private sector firms, Singapore incentivized FDI to attract multinationals in order to introduce technology into Singapore.

2. Building human resources in science and technology

Another common facet of STI policy across the four countries was building human resources in science and technology in alignment with its broader STI policy objectives. Human resources development in science and technology encompasses a broad array of activities, from training low-skilled workers in factories to producing high-quality engineers and scientists, and to attracting foreign talent. Consequently, the objectives and the policy direction varied not only by country but also by stage of development. For example, the Government of Japan rapidly expanded its science and technology higher education to produce engineers and scientists as it transitioned from being a technology adopter to becoming a technology developer, while Singapore established technical training institutes to create a skilled factory workforce as it transitioned from low- to high-value-added industries.

3. Developing domestic research capabilities

After – or, in China's case, contemporaneously – facilitating technology transfer, all four countries focused on the development of domestic research capabilities, although the objectives, policy instruments used and implementation differed. All four countries invested in building domestic R&D capabilities during their catch-up phase before delving into higher-risk basic research. In China, developing defence capabilities led to investment in domestic basic research capabilities at the outset. A mix of tools was employed to build R&D capabilities: from incentivizing foreign firms (e.g. Singapore) to heavy government spending in research institutes (e.g. the Republic of Korea) to government-subsidized private sector-led development (e.g. Japan). At a later stage during their catch-up phase and in the post catch-up phase, there was an increasing focus on linking different actors – industry, universities and research institutes - in order to strengthen research capabilities.

4. Mainstreaming innovation and science and technology policy

At the outset, the focus of all countries was on science and technology policy. The emphasis on innovation started in the 1990s as innovation started gaining popularity globally, or with the country's entry into its post catch-up phase where innovation was necessary in order to maintain a competitive advantage. Explicit focus on innovation occurred in parallel with the mainstreaming of STI policy from a siloed policy area to a central component of all policy. This development is reflected in the governance architecture of STI policy, which currently often is at the highest level (e.g. the Council of Science, Technology and Innovation of Japan), the proliferation of governmental STI institutions and plans, and increasing interlinkages with other policy areas.

5. Broadening the mandate of science, technology and innovation policy

The initial objective of STI policy across the four countries was economic growth and building industrial capacity. As they developed and in line with the shifting global focus on sustainable and inclusive development, they broadened their objectives to include social concerns (e.g. addressing rural poverty through STI policy) and environmental concerns (e.g. tackling pollution through STI policy). Currently, all four countries have plans in place, although in varying degrees, on leveraging STI policy for inclusive and sustainable development.

6. Evolution in the role of government in promoting science, technology and innovation

Initially, Governments played a stronger and direct role in the development of science, technology and innovation, although the extent varied by country. For example, in the Republic of Korea, the initial government share of spending on R&D was greater than 80 per cent.[71] As the science and technology competence of the country developed, the role of the Government in STI promotion transitioned to that of a promoter and a facilitator.

Chapter II. Policies for frontier technologies

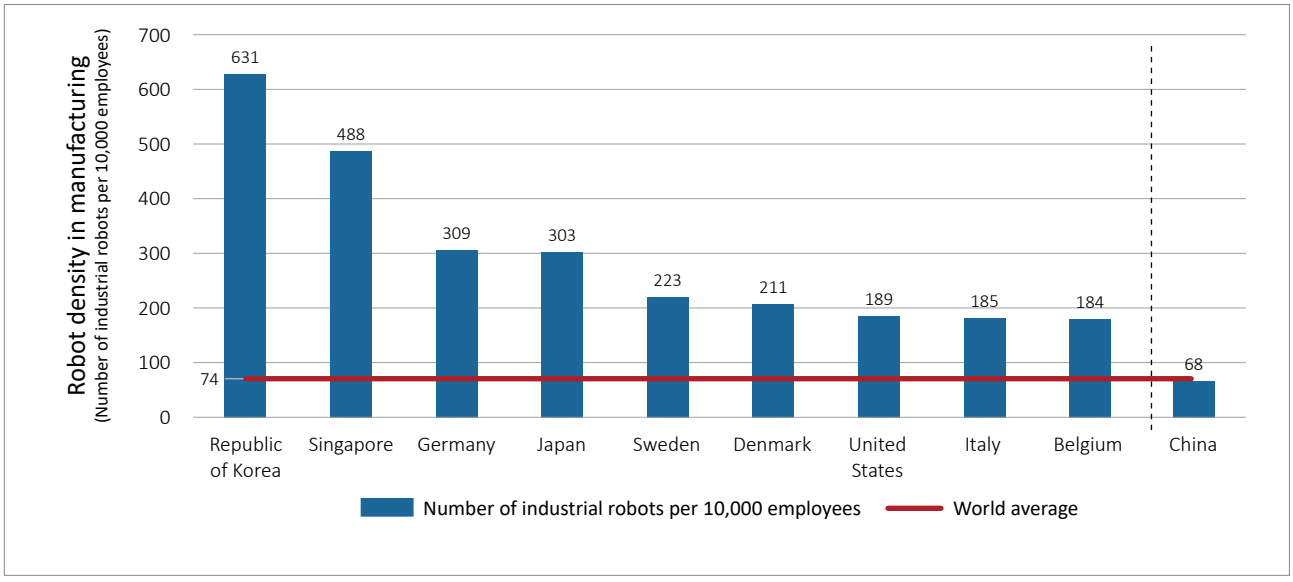
A. Introduction

Breakthroughs in frontier technologies are expected to bring about transformative changes in the economy and society. Frontier technologies offer new solutions and hold the promise of helping countries to achieve the Sustainable Development Goals. Such technologies can revive productivity, provide resources to end poverty and mitigate environmental degradation. However, for this promise to be realized and to avoid such risks as exacerbating inequality, they need to be directed towards achieving the Goals through a proactive and purposeful effort by Governments in collaboration with businesses, academia and civil society.

China, Japan, the Republic of Korea and Singapore are early adopters and developers of frontier technologies. For example, the Republic of Korea, Singapore and Japan rank first, second and fourth respectively on robot density in manufacturing (figure II.1). Furthermore, all four countries have established policies relating to artificial intelligence and the fourth industrial revolution.

This chapter contains a discussion of the policies implemented by the four countries related to frontier technologies. Without exploring each specific technology in detail, key policy considerations will be examined as they enable utilization of frontier technologies to achieve the Goals while mitigating risks.

Figure II. 1. Robot density in manufacturing 2016



Source: ESCAP, based on International Federation of Robotics Data. Available at https://ifr.org/ifr-press-releases/news/robot-density-rises-globally.

This chapter is focused on a few technologies commonly identified as frontier technologies, including artificial intelligence, robotics, the Internet of Things and 3D printing.

AI refers to computer algorithms that can perform tasks that usually require human intelligence.[72] AI can refer to narrow AI where it is applied to perform specific tasks (e.g. recognizing an image, driving a car or translating languages), or general or strong AI where cognitive ability can be applied flexibly and creatively as in the case of humans. Narrow AI is already being used or tested in a number of fields, such as facial recognition, social networks and transportation, while at this stage there is no documented case of using general AI.

The applications of AI can be broad and cover different cognitive tasks that humans perform. Speed, scale, reliability and efficiency factors may provide AI with an edge over human labour. Without physical form, however, AI is limited to the cognitive sphere. Robotics enables AI to be embodied in mechanical devices to perform tasks that directly affect the physical and biological spheres. Robots are programmable mechanisms that can perform specific tasks with a degree of autonomy. They come in many forms. Most robots in use today are not of humanoid form and are used for manufacturing production.

The increase in access to and speed of the Internet is enabling the proliferation of AI, robotics and the Internet of Things, which refers to devices, robots and sensors being connected with each other and to the Internet. This connectivity between devices enables data collection and analysis, as well as real-time response in the physical world. Increasing Internet use is also enabling the collection of big data, which in turn is interpreted by AI. The ability of devices to make decisions makes them "smart". AI and the Internet of Things underpin smart manufacturing, smart cities and smart energy.

The manufacturing of products can be done using 3D printing, which involves adding layers of material on top of one another, aided by specialized computer programs for process control and object design.[73] It is another technology that has the potential to transform production processes. Such printing enables the rapid production of a tailored item, rapid prototyping and the production of smaller parts in localized settings or more personalized products in small quantities. This form of printing represents a shift away from mass production to gain economies of scale, and it enables more distributed production, where individuals can produce items without relying on capital-intensive mechanistic processes.

An ESCAP report on frontier technologies for sustainable development in Asia and the Pacific provides further information about specific frontier technologies.[74]

B. Key policy issues in frontier technologies

The potential impacts of frontier technologies can be broad ranging, including both opportunities for and risks to the achievement of the Sustainable Development Goals. They have the potential to generate economic growth by increasing productivity and creating new markets. They can also improve health-care and education services by personalizing those services or delivering them to more remote locations via the Internet. On the other hand, frontier technologies also have potential negative externalities. For example, potential job displacement from automation poses risks and challenges for inclusive and sustainable development.

Policymakers are tasked with the challenge of maximizing the benefits while minimizing the risks of these technologies. The three key policy concerns pertaining to frontier technologies are described below.

1. Building capabilities to leverage new opportunities

Domestic capabilities in frontier technologies, in terms of research and development, firm capacity to use these technologies and an enabling ecosystem, are necessary to leverage the socioeconomic opportunities offered by frontier technologies. Developing domestic capacities also requires human capital and well-functioning institutional arrangements within Governments to develop and implement policies, particularly to understand and respond to frontier technologies.

Building capabilities of firms in frontier technologies is important because these technologies offer opportunities to realize operational efficiencies, productivity increases and cost effectiveness. However, affordability issues and shortages in skills and knowledge usually impede firms, especially small and medium-sized ones, from upgrading their technological capabilities and adopting frontier technologies.

An enabling ecosystem for frontier technologies is required to encourage their development and deployment. Infrastructure – in particular digital infrastructure – standards and adaptive regulation are required. Developing standards in such areas as system interface and data management are essential to guide the development of frontier technologies, provide consistent references and promote good practices. Adaptive regulations provide regulatory flexibility to enable experimentation in innovative products and services while still maintaining the necessary safeguards.[75]

2. Addressing the future of work

Frontier technologies, particularly robotics and AI, are expected to radically change the number and nature of jobs in the not too distant future. The impact on jobs will vary across sectors and countries. While a McKinsey report estimated that 51.5 per cent of employment in the Asia-Pacific region could be automated by 2030, the impact may not necessarily be as large as predicted[76] because, while automation may be technically feasible, it may not always make economic sense.[77]

The displacement of labour through automation may further increase income inequality within countries as well as between countries.[78] Policies are required to mitigate the risks of prolonged unemployment or entrenched income inequality and to develop skills to equip citizens for the future economy.

3. Personal data protection and privacy

Data privacy and personal data protection are other key policy concerns pertaining to frontier technologies. The large volume of personal data being collected, used and transferred to third party organizations for various purposes needs strong regulatory mechanisms to ensure privacy and prevent misuse. Unauthorized access to and use of personal data or accidental loss of personal data may lead to reputational damage, financial losses or threats to personal safety in addition to privacy concerns.

Advances in frontier technology and increasing digitization also raise concerns related to cybersecurity and ethical issues that arise with AI. For example, biases can be embedded within AI, potentially resulting in discrimination or unfair treatment.

C. Country experiences: frontier technology policy in China, Japan, the Republic of Korea and Singapore

1. China

(a) Introduction and key policies

China has introduced a wide range of policies and strategies to support the development and adoption of frontier technologies. It has both sector-specific policies and technology-specific policies.

Sector-specific policies are directed towards smart manufacturing, smart cities and intelligent vehicles (table II.1). For example, smart manufacturing, under the umbrella of the 10-year Made in China 2025 policy, is aimed at transforming China into a leading, high-end manufacturing power through the integration of smart technologies in manufacturing, the enforcement of green manufacturing, strengthening quality management and the globalization of Chinese manufacturing brands.[79] The plan is focused on 10 priority sectors, including aviation, biopharmaceuticals, agricultural technology and robotics. To implement Made in China 2025, the Government has adopted three concrete action plans or strategies (see table II.1 and table A.1 in the annex).

China also has specific plans to advance its position in AI, big data and blockchain technology. It plans to achieve major breakthroughs in AI theory by 2025 and a global leadership position by 2030. To support the development and adoption of AI technology, the Government has introduced two three-year plans, one development plan and, more recently, a white paper (see table II.1 and table A.1 in the annex).

Table II. 1. Frontier technology-related policies in China

Frontier technology	Policy, strategy, plan
Smart manufacturing - Made in China 2025	Action Plan on Implementing the Guiding Opinions of the State Council on Promoting "Internet Plus" (2015-2018)
	Intelligent Manufacturing Development Strategy (2016-2020)
	Development Plan for the Robotics Industry (2016-2020)
Smart cities	Notice on Carrying Out National Pilot Smart Cities
	Interim Measures for the Administration of National Smart Cities
	Pilot Index System for National Smart Cities
Intelligent vehicles	Intelligent Vehicle Innovation and Development Strategy (January 2018) (draft stage)
Big data	Planning Outline for the Construction of a Social Credit System (2014-2020)

Frontier technology	Policy, strategy, plan
Artificial intelligence	"Internet Plus" Artificial Intelligence Three-year Action Implementation Plan (May 2016)
	New Generation of Artificial Intelligence Development Plan (July 2017)
	Three-year Action Plan to Promote the Development of New-generation Artificial Intelligence Industry (2018-2020)
	AI Standardization White Paper (January 2018)
Blockchain technology	Blockchain Technology and Application Development White Paper (2016)
	Key Points on Informatization and Software Standardization 2018

(b) Frontier technology policy architecture

(i) Supporting research and development

China has several programmes to support R&D on frontier technologies – it has established national laboratories, provides research grants and is investing in frontier technology parks. It is also actively supporting private sector R&D through subsidies and encouraging local government participation.

The central Government has encouraged establishment of national engineering laboratories in different cities[80] for research, development and application of core technologies, such as big data and AI. In December 2016, 11 national engineering laboratories for big data application and 8 national engineering laboratories for Internet Plus were officially identified.[81] These laboratories were established by corporations, hospitals and leading Chinese universities. Some of them are jointly funded by the public and private sectors. For example, the National Engineering Laboratory for Big Data Distribution and Exchange Technologies was jointly funded by the National Development and Reform Commission of China, and the Shanghai Data Exchange Corp.[82]

The central Government also subsidizes research on AI, robotics, big data and Internet Plus. For example, the Ministry of Science and Technology in 2017 established a $315 million special fund for R&D of intelligent robots.[83] In 2018, the Government subsidized 56 megaprojects on cloud services, AI chips, service robots, facial recognition systems, medical and financial big data.[84] Most of the research projects are undertaken by private companies, such as Huawei Technologies Co., Ltd., TCL Corporation and Alibaba Cloud Computing Co. Ltd, while some are carried out by provincial authorities.

The National Natural Science Foundation of China, the largest research funding agency directly affiliated with the State Council, funds AI-related projects and jointly funds big data research centres and research projects on robots with local governments.

In recent years, the central Government has heavily invested in intelligent manufacturing and an AI technology park. In 2016, it allocated $780 million (about 1.5 times more than that in the previous year) to promote 133 key projects on intelligent manufacturing in 25 provinces.[85] In January 2018, the central Government announced that it would spend $2.1 billion to construct an AI technology park in Zhongguancun, Beijing, by 2023.[86] The new park will be focused on developing high-speed big data, cloud computing, biometrics and deep learning.[87] The plan is to house 400 enterprises and have an annual expected output value of $7.8 billion.[88]

(ii) Education and training

Education and training in AI is a key element of the 2017 New Generation of Artificial Intelligence Development Plan. The plan is aimed at building competencies for the future economy by promoting AI education and training across all levels of education. AI-related courses and programming will be offered to primary and secondary school students.[89] In universities, AI majors will be established and upgraded to a first-level subject.[90] Universities and colleges are also encouraged to adopt a new model of "AI + X" education, in which students are provided with AI education along with other disciplines.[91] Additionally, AI skills training will be provided in vocational schools, training institutions, business corporations and other organizations.

Several Chinese universities are launching new training programmes on AI. For example, in April 2018, the International AI Training Program for Chinese Universities, jointly implemented by the Ministry of Education, Beijing University and Sinovation Ventures AI Institute, was established to train 500 teachers and 5,000 students on the fundamental theories of AI and new research in AI over the next five years.[92] In 2018, Beijing University will launch a master's degree in AI innovation to provide three-dimensional training on AI, the AI industry and innovation.[93]

China is also establishing networks with overseas universities to strengthen research collaboration and enhance students' and teachers' knowledge of AI. In January 2018, a France-China AI consortium, consisting of eight Chinese and French universities, including Tsinghua University and Sorbonne University, was established to strengthen interdisciplinary research collaboration and serve as a platform to nurture talent.[94] The Ministry of Education plans to offer scholarships for teachers and students in universities to study AI in the United States and to partner with American universities to strengthen Sino-United States educational exchanges in AI.[95]

(iii) Regulations

As is the case in other jurisdictions, regulations have not caught up with the state of new technologies. In the area of privacy, China does not have a comprehensive national regulation on personal data protection, although there are high-level rules which were outlined in the 2012 "Digital Data Protection Rule" and strengthened recently.[96] However, there are guidelines as well as multiple sector-specific or region-specific laws and regulations pertaining to personal data protection.

That 2012 rule, which contains 12 articles and is broadly worded,[97]requires Internet service providers and government agencies to keep confidential any personal digital information collected, and they must not divulge, falsify, damage, sell or illegally provide such information to others.[98]

The Cybersecurity Law, which came into effect on 1 June 2017, is more robust than the aforementioned rule. It regulates how network operators and critical information infrastructure operators should protect personal digital information by standardizing the collection, usage and storage of personal digital information and how they should carry out certain data security practices to safeguard networks from interference, destruction or unauthorized access. In addition, the law contains guidance on whether and under what circumstances personal digital information can be transmitted outside of China's borders. Financial, operational and criminal penalties for violating the law are clearly stated. The law has increased government control over content, and it furnishes technology regulations for foreign businesses.

The Information Technology-Personal Information Security Specification, which came into effect on 1 May 2018, was "formulated based on the Cybersecurity Law in combination with legislation and legal practices in many jurisdictions".[99] It is a recommended national standard that puts forward seven basic principles of personal information security, such as transparency, risk assessment and proportionality (use and retention of only the minimum information necessary to achieve the stated purpose).[100] It sets out detailed compliance requirements for enterprises regarding the collection, storage, use, sharing, transfer and public disclosure of personal information collected in the course of business operations.[101] It sets out more stringent requirements for storing and transmitting sensitive personal information. It also requires enterprises to develop a privacy policy. Although the above-mentioned specification is non-binding, it is deemed to be a universal standard for enterprises' practice and will serve as a reference for regulators to determine whether enterprises comply with data protection rules.[102]

(iv) Institutional setting and key actors

The central Government of China has steered the formulation and implementation of AI-related and other frontier technology policies, providing direction for ministries and local governments. The highest level of the Communist Party's leadership has actively supported the development and use of frontier technologies in the country.[103] For example, the State Council, the highest executive body, formulates AI-related policies and strategies, and exercises unified leadership over the work of ministries. The National Development and Reform Commission formulates and implements the development plan for the robotics industry and the Internet Plus action plan, and it oversees the establishment of national engineering laboratories.

The domestic private sector, particularly larger firms, have been playing a major part in the formulation of policies related to frontier technologies and in spurring the development and adoption of such technologies. Four domestic technology companies (Baidu Inc., Alibaba Group, Tencent, and iFlytek Co., Ltd.) were selected in November 2017 by the Ministry of Science and Technology as the first members of the AI National Team to build open innovation platforms. Baidu will focus on autonomous driving, Alibaba Group on smart cities (the "City Brain" project), Tencent on medical imaging and iFlytek on voice intelligence.[104]

Technology companies have also made significant investments in AI-related R&D. In 2016, Sogou Inc. donated $28 million to Tsinghua University in order to set up the Tiangong Institute for Intelligent Computing to conduct research in AI.[105] In 2017, Alibaba announced that it would invest $15 billion in the Alibaba DAMO Academy (Academy for Discovery, Adventure, Momentum and Outlook) over the next several years to conduct research on the Internet of Things, data intelligence, fintech, quantum computing and human-machine interaction.[106]

(v) International collaboration

China has identified science and technology as a key area for international cooperation, including within the Belt and Road Initiative announced in 2015. Joint research and development, technology transfer and personnel exchanges have all been identified as part of the Belt and Road Initiative Action Plan.[107] For example, the Innovation Cooperation Center has been set up in Bangkok by the Chinese Academy of Sciences to promote cooperation on high-technology fields between China and Thailand and, more broadly, members of the Association of Southeast Asian Nations (ASEAN).[108] In addition, Chinese universities and research institutions have increased their links and preparation of joint papers with international universities in such fields as computer science. These grew by 207 per cent between the period 2006-2010 and 2011-2015; other relevant sectors, such as material science and engineering, grew by 145 per cent and 158 per cent respectively.[109]

(c) Key messages

1. Frontier technologies are a high-level policy priority for the Government of China. The Government adopted targeted policies and programmes for building capabilities in a range of frontier technologies and for specific sectors, such as smart cities, AI, smart manufacturing and intelligent vehicles.

2. The central Government has heavily invested in building frontier technology capabilities for the future economy. It is funding research, promoting smart manufacturing capacity and investing in technology parks for AI technology development and diffusion.

3. The Government is closely collaborating with large private sector companies in both research and development and in the implementation of frontier technologies.

4. China is emphasizing AI education and training at multiple levels to prepare its workforce for the future. It is introducing AI courses in schools, scaling up AI education in universities and developing AI training programmes for vocational education institutions and other organizations.

5. China has strengthened data protection and data security through the promulgation of the Cybersecurity Law and implementation of the aforementioned specification. The law enforces a number of rights and obligations that enterprises and other operators have regarding the collection, use, storage and transfer of personal information. The specification provides detailed guidance on the collection, use and retention of general and sensitive personal information and the development of a privacy policy by enterprises.

3. Japan

(a) Introduction and key policies

Japan's frontier technology policies are holistic, cutting across multiple sectors and technologies, and are aimed at leveraging frontier technologies for economic growth and for addressing social challenges (table II.2).

Under Japan's Fifth Science and Technology Basic Plan (2016-2020), science, technology and innovation are directed towards addressing social and environmental challenges in addition to economic development and industrial growth, improving the regulatory environment for innovation, promoting inclusive innovation and building public trust through dialogue and collaboration with industry, academia and citizens.[110] The plan is designed to promote the concept of a "super smart society" (or "Society 5.0"). Unlike previous basic plans that were sector-specific, the fifth plan is used to promote human-centred development with a focus on addressing specific social, environmental or economic challenges regardless of sector or technological field.[111] Its provisions encourage the development of advanced technologies to provide customized solutions to the problems of an ageing population, the increasing demand for medical care, the shrinking workforce, the shortage of skilled labour, reduced labour productivity, obsolete public infrastructure, limited energy resources, food limitations and natural disasters (table A.2 in the annex).

The Government of Japan also has specific policies to invest in the fourth industrial revolution for economic growth (see table II.2). For example, the "Future Vision towards 2030s" was introduced in May 2017 to spur growth through solving problems in mobility, supply chains, health care and lifestyle by leveraging frontier technologies (table A.2 in the annex).

Table II. 2. Frontier technology-related policies in Japan

Frontier technology	Policy, strategy, plan
Multiple	Fifth Science and Technology Basic Plan (2016-2020)
Multiple	Comprehensive Strategy on Science, Technology and Innovation 2016
Multiple	Facilitating the Fourth Industrial Revolution (2016)
Multiple	Connected Industries Policy (March 2017)
Multiple	Future Vision towards 2030s (May 2017)

(b) Frontier technology policy architecture

The Government uses different types of policy instruments to foster the development and adoption of frontier technologies. These include investing in R&D, supporting education and attracting highly skilled professionals, regulation and development of AI R&D guidelines and international collaboration.

(i) Supporting research and development

The Government has identified priority research areas, increased R&D investment and established new R&D infrastructure for frontier technologies. The Ministry of Economy, Trade and Industry and the Ministry of Education, Culture, Sports, Science and Technology in 2016 jointly formulated the Guideline for Enhancing Industry-Academia-Government Collaboration Activities in order to foster large-scale research collaboration with industry.[112]

The Government has allocated sizable financial resources to R&D and facilitates cooperation. For example, it has allocated $178 million to establish AI-related research centres[113] and $479 million to improve corporate productivity by supporting IT technology introduction and AI system co-development.[114]

Two new government-affiliated AI research institutes have been established in Japan. The Artificial Intelligence Research Centre, established under the National Institute for Advanced Industrial Science and Technology in May 2015, is an open innovation hub that connects local and international researchers and manufacturers so that they can carry out joint research; it also promotes the implementation of AI in the manufacturing, health-care, security and service sectors.[115] The RIKEN Center for Advanced Intelligence Project was established in April 2016 to develop deep learning technologies, nurture AI researchers and data scientists and conduct research on social, legal and ethical issues caused by the spread of AI technology.[116] The centre has also set up collaboration centres with three Japanese companies: Fujitsu Ltd., Toshiba Corporation and NEC Corporation.[117]

(ii) Education and attracting highly skilled professionals

The Government of Japan has introduced several measures to build domestic skills required for a frontier technology-powered economy. A new curriculum to be implemented in 2020 will make teaching programming skills compulsory in both primary and secondary schools.[118] Additionally, there will be greater focus on mathematical and IT education in higher education.[119]

The Japanese Government also intends to attract highly skilled foreign professionals in frontier technologies. In 2017, a new "green card" system was introduced to allow fast-track permanent residency for such highly skilled foreign professionals.[120]

(iii) Regulation and artificial intelligence research and development guidelines

Japan is introducing and reviewing regulations and guidelines to balance the opportunities provided by frontier technologies while mitigating the privacy and ethical concerns that they pose.

The Act on the Protection of Personal Information (APPI) was amended in September 2015 and enforced in May 2017 to strike a balance between the protection of an individual's rights and interests and the usage of personal information.[121] The amended APPI requires businesses to anonymize personal data before transferring such data to third parties while removing the need for the subject's consent. However, the consent of a data subject is required for cross-border data transfer. In 2017, Japan and the European Commission agreed to accelerate work on this matter with a view towards achieving a mutual adequacy decision on the transfer of personal data between two places.[122] If the European Union declares Japan's data protection framework "adequate", it will allow cross-border data flow without additional authorization.[123] The APPI amendment also established that sensitive personal data (e.g. on race, beliefs and medical records) are subject to enhanced protection.[124]

Japan has been actively proposing global AI R&D guidelines in international discussions at Group of Seven, Group of 20 and OECD summits. The proposed guidelines are a non-regulatory and non-binding "soft law" to promote the view that human beings remain the focus of policies, that an appropriate balance must be struck between the benefits and risks of AI and that interoperability among different AI systems should be the norm. The guidelines comprise nine AI R&D principles[125] developed in consultation with the private sector and other stakeholders.

The Basic Cybersecurity Act, which was enacted in November 2014, stipulates basic principles of national cybersecurity policy and specifically prescribes the responsibilities of the national Government, local governments, critical infrastructure business operators, cyber-related business operators and other relevant parties in order to facilitate active responses to cybersecurity threats.[126]

(iv) Institutional setting and key actors

The Government of Japan has established several new institutions at the highest levels of Government to support the fourth industrial revolution. While the Public-Private Council for the Fourth Industrial Revolution is the central body under the cabinet for coordinating frontier technology policy, there are also new institutions for technology-specific policies, such as the Robot Revolution Realization Council and Strategic Council for AI Technology (table A.5 in the annex).

The private sector has historically played a central role in Japan's technological development. Similarly, for frontier technologies, some Japanese companies, such as Toyota, Honda, Hitachi, and Mitsubishi, are key drivers of AI research and investment. For example, in 2017 Mitsubishi spent $1.94 billion on R&D in AI, smart mobility, automated vehicle navigation systems, networked smart appliances at home and the world's first 5G base stations. In recent years, SMEs such as Dwango Co., Ltd. and Recruit Holdings Co., Ltd. have also established AI research laboratories to strengthen their competitiveness (table A.6 in the annex).

(v) International collaboration

Japan collaborates with other leading frontier technology countries, such as Germany and the United States, to strengthen its competitiveness in big data and the Internet of Things. The Japan Science and Technology Agency and the United States National Science Foundation conducted research collaboration to leverage big data approaches to support disaster management.[127] In April 2016, the Ministry of Economy, Trade and Industry and the Federal Ministry for Economic Affairs and Energy of Germany signed a joint statement regarding Japan-Germany cooperation on the Internet of Things/Industries 4.0 to exchange best practices and collaborate in the fields of industrial cybersecurity, international standardization, international regulatory reform, support for SMEs, human resources development and R&D.[128]

(c) Key messages

1. Frontier technologies are a policy priority at the highest level of Government, and several institutions have been established to support their development. Japan takes a human-centred and holistic cross-sectoral approach to frontier technology, aiming to leverage it in order to address social problems and promote economic growth.

2. Japan has instituted several measures to strengthen its frontier technology capabilities. It has heavily invested in building R&D infrastructure in priority areas, it has promoted technology diffusion and deployment to industry, and it has fostered collaboration between Government, academia and industry. It is also attracting highly skilled foreign talent to bolster its frontier technology capabilities.

3. Japan is revising its education curricula to develop skills that prepare its workforce for the future economy. It is introducing compulsory programming education in schools and increasing the focus on IT and mathematics in higher education.

4. Japan has been a global norm shaper, promoting AI R&D guidelines and principles that ensure a human-centric focus. It has also sought to balance the benefits of improved service delivery through personal data use with data protection and privacy concerns by mandating businesses to anonymize personal data transfers.

3. Republic of Korea

(a) Introduction and key policies

The Republic of Korea has a human-centric approach towards frontier technologies, placing them at the centre of technological breakthroughs and emphasizing "coexistence and collaboration between humans and machines as a core value in the future".[129] The Government intends to leverage frontier technology for improving the quality of life, increasing productivity and developing new growth engines. The overall policy is a framework labelled "I-Korea 4.0"; there are also several sector- and technology-specific plans to guide this vision outlined by the Presidential Committee on the Fourth Industrial Revolution.

Specific strategies have been introduced for robotics, the Internet of Things and AI (table II.3). Since 2009, the Republic of Korea has introduced three five-year intelligent robot master plans and related strategies. The latest plans are aimed at aggressively expanding the production of industrial robotics and the use of robots in multiple fields, such as disaster response.

The Republic of Korea also has sector specific strategies in smart manufacturing, fintech and smart government. Transforming the traditional manufacturing system into a smart system is a national priority. In June 2014, the Manufacturing Industry Innovation 3.0 Strategy was introduced to tackle economic and social challenges surrounding the Republic of Korea's major manufacturing sectors of automotive, chemicals, electronics, shipbuilding and steel.[130] The strategy promotes smart factories that embrace automatization, data exchange and enhanced manufacturing technologies, such as the Internet of Things, big data and 3D printing, throughout the manufacturing process.

Table II. 3. Frontier technology-related policies in the Republic of Korea

Frontier technology	Policy, strategy, plan
Fourth industrial revolution	People-centred Plan for the Fourth Industrial Revolution to Promote Innovative Growth (I-Korea 4.0)
Intelligent robots	First master plan (2009-2013)
	Second master plan (2014-2018)
	Third master plan (2019-2024)
	Intelligent Robot Industry Development Strategy (2018)
Smart manufacturing	Manufacturing Industry Innovation 3.0 Strategy (2014)
Advanced IT and AI	Mid- to Long-term Master Plan in Preparation for the Intelligent Information Society (2016)
	Intelligence Information Society Fourth Industrial Revolution Medium- to Long-term Comprehensive Response Plan (2016)
Internet of Things	Master Plan for Building the Internet of Things (2014)
	Internet of Things Information Security Road Map (2014)
	K-ICT Strategy (2015)

Frontier technology	Policy, strategy, plan
Fintech	IT-Finance Convergence Support Plan (2015)
Cloud computing	Information Protection Measures for Vitalization of Cloud Services (2015)
	K-ICT Cloud Computing Development Plan (2016-2018)
	2017 K-ICT Cloud Computing Support Plans
Multiple (smart and open Government)	Smart Government Implementation Plan (2011-2015)
	Government 3.0 policy (June 2013)
	Open Data Master Policy Plan (2013-2017)

(b) Frontier technology policy architecture

(i) Supporting research and development and private sector investment

The Republic of Korea is heavily investing in R&D in frontier technologies and incentivizing private sector investments through subsidies. In recent years, the Government has fostered the development of various frontier technologies, such as robotics, AI, 5G mobile communications and smart cars, through investment and tax incentives.

For example, in 2016 the Government announced that it would spend $840 million by 2020 on R&D to boost the AI industry.[131]In the 2018 budget, the Government allocated $1.4 billion for research and development in core frontier technologies.[132] The Government plans to ramp up its total share of R&D spending on Industry 4.0 technologies from the current 30 per cent to 50 per cent by 2022.[133] However, government investment in R&D is relatively small compared with private R&D investment (table II.4).

About three quarters of the R&D efforts in the Republic of Korea are led by the private sector, with close to 90 per cent of that proportion being focused on manufacturing.[134] The Government offers tax incentives and cheap loans to large conglomerates, such as the Samsung Group and LG Corporation, to engage in expensive and risky R&D.[135] For example, since 2017 up to 30 per cent of R&D expenditures on the development of AI technologies, robotics, 3D printing, flexible displays, hyperplastics and few other technologies have been tax deductible.[136]

However, in recent years, the Government has played a more active role in providing research direction and investment, as evidenced by the various initiatives and projects outlined in the Internet of Things Research and Development Strategic Report.

Table II. 4. Government and private research and development investment scale comparison, 2016

(Millions of United States dollars)

	Broadcasting, communications and networks	Software and content	Internet of Things	Big data and the Cloud	Information security
Government investment (A)	3 719	5 353	695	505	1 494
Private investment (B)	14 716	12 115	3 502	1 513	2 499
Ratio B/A	4.1	2.5	4.8	2.5	2.2

Source: R&D Investment Review Bureau, Ministry of Science and ICT (March 2018). Government R &D Investment Direction in 2019, p. 67; Available in Korean language from http://msip.go.kr/SYNAP/skin/doc.html?fn=e0b5d09aa0f98d1143480c7c7e70db30&rs=/SYNAP/sn3hcv/result/201805/

(ii) Education

The Republic of Korea has expanded software education across all levels of education. In 2015, the Ministry of Education revised the national curriculum to make software education a mandatory subject in elementary, middle and high schools by 2018.[137] In 2017, to build capabilities for the fourth industrial revolution, the Ministry of Science, ICT and Future Planning formulated a plan to increase the number of "software-centred universities" to 20.[138] The aim is to nurture talent and strengthen the capacities of students, businesses and society in building and using IT software.[139]

(iii) Regulation

The Republic of Korea is one of the toughest jurisdictions in the world for data protection and privacy compliance. It has strong legislation and imposes severe penalties for data protection breaches. The Personal Information Protection Act (PIPA) and the IT Network Act are the central acts governing data protection and privacy. They are supplemented by sector-specific regulations. PIPA, enacted in 2011, "is a comprehensive and omnibus data privacy statute".[140] It regulates the collection, usage, disclosure and other acts (recording, storage and retention) of processing personal data and sensitive personal data by public and private sector entities, including foreign companies that target users in the Republic of Korea.[141] It puts forward several basic principles of personal information security, such as preventing harm, purpose limitation and data minimization.[142] It requires personal information processors to notify data subjects and obtain their consent before processing personal data, to make public its privacy policy and to take the technical, managerial and physical measures necessary to ensure the security of personal information.[143] Personal information processors are also required to comply with the notice and consent requirements as well as the data transfer agreement before personal information can be transferred to a third party or another country.[144]

The IT Network Act, which shares much in common with PIPA in terms of its statutory structure and general overarching principles on data privacy matters, regulates mainly the collection and processing of personal data by information and communication service providers.[145] However, it further requires information and communication service providers to notify users and obtain their consent when accessing information in their mobile communication devices. It requires some large businesses to periodically notify users of the details of using, providing and entrusting personal information. It also concerns the deletion or blocking of users' personal information, such as bank account numbers, when the Korea Internet and Security Agency or the Korea Communications Commission requests that such be done.[146]

Regulation also encourages access to and use of public data. In 2013, the Act on Promotion of the Provision and Use of Public Data was enforced to ensure citizens' right to use public data and to facilitate the private sector's use of public data.[147]

The Government has eased legislation to foster the development of robotics, 3D printing and fintech industries. For example, in 2016 the Electronic Financial Transactions Act was amended to lower entry barriers for fintech startups,[148] and in early 2017, the Government announced deregulation in AI, virtual reality and fintech sectors to stimulate their growth.[149] The Government has also designated the cities of Sejong and Busan as test beds for "smart cities" experimenting with regulatory "sandboxes" for various new technologies within a specified urban area.

To enhance cybersecurity, the Act on the Protection of Information and Communications Infrastructure, enacted in 2001, establishes the basis for building, operating and supporting information-sharing and analysis centres to analyse cyberthreats.[150] The IT Network Act prohibits and strictly punishes any unauthorized intrusions to information and communication networks; requires information and communication service providers to take measures necessary to prevent security incidents; and stipulates the creation of a pre-inspection system of information security and obligations to report security incidents.[151] Enacted in 2015, the Act on Cloud Computing Development and User Protection requires cloud computing service providers to "notify incidents, user information leakages and service termination to users and the Minister of Science, ICT and Future Planning".[152] It also prohibits the disclosure of user information to a third party without the consent of the user concerned or for any purposes other than the stated purpose.[153]

(iv) Institutional setting and key actors

Frontier technology policy in the Republic of Korea is coordinated at the highest level and is a priority policy for the Government. The Presidential Committee on the Fourth Industrial Revolution, established in October 2017, is the apex body concerning all government policies on the fourth industrial revolution and the implementation of those policies.[154] Its establishment was an effort to engage in a whole-of-government approach towards promoting the fourth industrial revolution.

There are several other bodies which have been created to address specific aspects of frontier technology policy. For example, the Intelligent Information Society Bureau, established in 2016, consists of civil servants from different ministries and private sector experts tasked with drafting a master plan for the intelligent information society.[155] The bureau facilitates cross-ministry coordination and seeks specialized knowledge from the

private sector. Several other councils have been established to coordinate government policies in the areas of e-government (the Government 3.0 Execution Council), open data (the Open Data Strategy Council) and industry-government-academia cooperation (the Global Council of Public and Private Sectors for the Internet of Things). A number of technical centres have also been set up to provide technical assistance. For example, the Open Data Center was established to provide technical and legal advice on the provision of public data.[156] The Internet of Things Innovation Center was established to support the training of Internet of Things entrepreneurs, partnerships and the expansion overseas of small and medium-sized firms.[157]

Private actors have historically played a central role in the Republic of Korea's technological advancement and continue to do so in frontier technologies. Large conglomerates are investing in AI-related businesses, conducting and supporting R&D in frontier technologies. For example, SK Telecom Co., Ltd., KT Corporation, Samsung and LG Electronics joined the 5G Strategy Promotion Committee, a high-level public-private consultative body, to develop new business models for the integration of 5G mobile networks and industries.[158] In late 2015, Samsung Electronics worked closely with the Ministry of Trade, Industry and Energy to develop and commercialize factory robots. Led by the Republic of Korea's Software Policy and Research Institute, the Artificial Intelligence Research Institute was established in late 2016 with investment from seven companies, including Naver Corporation, Samsung Electronics, SK Telecom, LG Electronics, KT, Hyundai Motor Company and Hanwha Life Insurance.[159] In 2017, SK Telecom established an AI business unit to expand its voice-recognition digital assistance business, while LG Electronics established two laboratories dedicated to AI and robotics technologies.[160] Samsung has established AI R&D centres in France, the Republic of Korea and the United States.[161]

(vi) International collaboration

Cybersecurity and data protection are key areas of cooperation for the Government of the Republic of Korea. It is collaborating with the United States Government to jointly develop AI-based technologies that could detect, analyse and prevent threats in cyberspace.[162] In June 2016, the Republic of Korea's Internet and Security Agency established the Cybersecurity Alliance for Mutual Progress, a global alliance consisting of 40 countries, to promote a safe cyberworld and build trust through information-sharing and cooperative action.[163] The Republic of Korea also built the Asia Privacy Bridge with China; Hong Kong, China; and Japan to develop a data protection system suited to Asia.[164]

The Republic of Korea has joint research projects with the European Union on the Internet of Things, cloud computing and 5G networks.[165] It has also enhanced policy cooperation with leading economies in 5G (China, Japan, the European Union and the United States) to create an ecosystem that integrates 5G and other industries, such as automobile, manufacturing and medicine.[166]

(c) Key messages

1. Frontier technology policy is a primary policy directive of the Government of the Republic of Korea coordinated through a high-level presidential committee. It has a human-centric approach aimed at improving the quality of life and spurring economic growth. It has developed multiple sector-specific and technology-specific plans to achieve these aims.

2. The Republic of Korea is building its frontier technology capabilities through large investments in R&D and incentivizing private sector investments in focus areas. It has also eased regulations in such sectors as fintech and AI in order to stimulate their growth.

3. The Republic of Korea is nurturing software and IT skills to prepare its workforce for the future. It has mandated software education across all levels of school education and is increasing the number of software-focused universities.

4. The Republic of Korea has very stringent regulations on personal data protection and privacy. The Personal Information Protection Act is comprehensive and widely applicable to public and private sector entities, including foreign companies that target users from the Republic of Korea. Several pieces of legislation have been promulgated to solidify cybersecurity at the national level, but there is no framework that regulates cybersecurity in a uniform manner.[167]

4. Singapore

(a) Introduction and key policies

The Government of Singapore has introduced strategic mission-driven policies to support the development and adoption of frontier technologies. These policies are focused on improving the quality of life through better delivery of public sector services and leveraging frontier technologies for the development of specific industries. For example, the Intelligent Nation 2015 (iN2015) Masterplan is a blueprint for smart city development in Singapore.[168] Initiatives were launched in 2014 under that master plan to improve service delivery in health care, towns and estates, urban environment, transport and the financial sector by harnessing digital technologies (table II.5). The Infocomm Media 2025 and the Infocomm Media Industry Transformation Map are aimed at leveraging frontier technologies for the development of digital and media industries, and simultaneously building human capital (table II.5). The Government has also implemented the Cybersecurity Strategy to provide a secure cyberspace and protect essential services from cyberthreats (table II.5).[169]

Table II. 5. Frontier technology-related policies, Singapore

Frontier technology	Policy, strategy, plan
Multiple	Intelligent Nation Masterplan (2005)
Multiple	Smart Nation initiatives (2014)
Multiple	Infocomm Media 2025 (2015)[a]
Multiple	Infocomm Media Industry Transformation Map (2017)
Multiple	Research, Innovation and Enterprise 2020
Advanced IT	National Cyber Security Masterplan 2018

a) Singapore's Infocomm Media refers to the ICT sector, telecommunications and media.

(b) Frontier technology policy architecture

(i) Strengthening research and development collaboration and investing in infrastructure and business

Singapore has strengthened R&D collaboration between the Government, academia and industry and within government agencies to enable real-life application of frontier technologies. It is also investing heavily in the development of the necessary digital infrastructure to leverage frontier technologies and facilitate their use by businesses.

In 2017, the Singapore Data Science Consortium and the AI Singapore programme were started. The former was established to strengthen government-academia-industry data science and R&D collaboration, enable industry to access the latest data science technologies, nurture data science professionals and provide innovative solutions to address real-world challenges.[170] It is a national partnership of research institutes and universities, namely the National Research Foundation, National University of Singapore, Nanyang Technological University, Singapore Management University and the Agency for Science, Technology and Research (A*STAR), that engages local enterprises (startups, SMEs and large businesses) in six sectors (finance, manufacturing, logistics, transport, health care, customer and retail).[171, 172] The AI Singapore programme was launched to boost Singapore's AI capability, broaden the adoption and use of AI and machine learning within the industry and use AI to solve economic and social challenges.[173] It is driven by a government-wide partnership with an investment of $150 million Singapore dollars over five years.[174]

There are also several programmes to increase the adoption of frontier technologies by businesses. For example, the SMEs Go Digital programme provides such enterprises with advice on the use of digital technologies to achieve internal efficiencies, cost reductions and better service provision.[175] The AI Business Partnership Programme helps local companies adopt AI solutions to address their business problems by pairing them with AI solution providers.[176] The programme co-funds 50 per cent of qualifying costs for suitable partnership projects to a maximum of $74,500 Singapore dollars per project.

Singapore spent $1.4 billion in FY 2016 on high-value infrastructure projects, such as network equipment, cabling and the Government Data Centre's core infrastructure. This spending is directed towards laying the foundation for a smart nation and digital government, and accounted for 66 per cent of the technology budget.[177] In FY2018, Singapore increased funding by 18 per cent (compared with FY 2017) to $335 million for the Info-communications Media Development Authority to develop a dynamic digital economy and a cohesive digital society.[178]

(ii) Education and training

The Government has implemented a series of education and training programmes to raise the digital skills of local employees and recent university graduates (table A.7 in the annex) and has heavily subsidized courses on frontier technologies. It has targeted multiple groups and areas – civil servants, sector-specific employees and technology or skill-specific training. An example is the Tech Skills Accelerator, in which the Government has invested $110 million to support upskilling and/or skills development of employees in ICT. The aim is to create 20,000 training places by 2020 (table A.7 in the annex). Another example is the Lee Hsien Loong Interactive Digital Media Smart Nation Award, introduced in 2017 to honour polytechnic students whose completed such media projects could contribute to the Smart Nation initiatives.[179]

(iii) Regulation

The Personal Data Protection Act (PDPA) 2012, which came into effect on 2 July 2014, governs the collection, use and disclosure of personal data by organizations.[180] It requires an organization to obtain the consent of an individual before collecting, using or disclosing his or her personal data and collect, use or disclose personal data only for appropriate purposes.[181] In addition, it requires an organization to keep personal data in its possession secure from unauthorized access, collection, use, disclosure, copying, modification, disposal or similar risks.[182] It also limits the transfer of personal data outside of Singapore unless such personal data can be protected in a manner comparable to the protection offered under PDPA.[183] Its provisions are not as stringent as legislation in Japan and the Republic of Korea for several reasons. First, PDPA does not introduce the concept of sensitive personal data, which generally entails more stringent regulations for storing and usage. Second, it has limited scope because it does not apply to personal data-processing activities of the public sector or any organization acting as an agent of a public agency.[184] Third, PDPA contains an extensive list of exemptions that allow organizations to collect, use or disclose personal data without consent and allows for the concept of deemed consent.[185]

The landmark Computer Misuse Act, which was enacted in 1993 to introduce specific offences and penalties targeted at computer crimes, has been amended by the Government several times in order to remain effective in a rapidly evolving cybercrime landscape.[186] In 2013, the Act was amended to include cybersecurity measures; it was renamed as the Computer Misuse and Cybersecurity Act (CMCA).[187] The amendments "provide[d] the government with greater ability to work with stakeholders to take timely actions against cyberthreats to Singapore's Critical Information Infrastructure (CII)".[188] One of the key amendments was to allow the Minister of Home Affairs to issue a certificate to authorize or direct any person or organization to take measures necessary to prevent, detect or counter cyberthreats to Singapore's national security, essential services, defence or foreign relations.[189] In 2017, CMCA was amended to "tackle the increasing scale and transnational nature of cybercrime, as well as the evolving

tactics of cybercriminals".[190] In 2018, CMCA enabled the regulation of CII to be strengthened and the new position of Commissioner of Cybersecurity to be created with significant authority to prevent and respond to cybersecurity incidents in Singapore.[191]

Singapore has introduced regulatory sandboxes and accreditation schemes to spur innovation. To encourage innovative financial products and services, the Monetary Authority of Singapore in 2016 introduced a regulatory sandbox for financial institutions and non-financial players.[192] Similarly, the Land Transport Authority in early 2017 introduced a regulatory sandbox to allow autonomous vehicle trials to take place on public roads in Singapore.[193] The Accreditation@SG Digital programme certifies promising Singapore-based technology companies involved in AI, the Internet of Things, immersive media and cybersecurity to establish their credentials, thereby increasing trust and opening new market opportunities.[194]

(iv) Institutional setting and key actors

Singapore takes a whole-of-government approach towards Smart Nation programmes. Its policies and execution are directed at the highest level through the Smart Nation and Digital Government Office. That office was created in May 2017, directly under the Prime Minister's Office, to accelerate the implementation of key Smart Nation projects.

The Government Technology Agency of Singapore (GovTech) is the implementing agency of the Smart Nation and Digital Government Office. It is responsible for building Smart Nation infrastructure, platforms and services by deploying frontier technologies, such as the Internet of Things, and sensors.[195] Collectively, the Smart Nation and Digital Government Office and GovTech form the Smart Nation and Digital Government Group tasked with applying smart technologies to improve citizens' lives, develop digital platforms for Smart Nation initiatives and drive digital transformation in the public sector.[196]

Different committees have also been formed to deal with specific frontier technologies. For example, the Internet of Things Technical Committee was formed in 2013 to develop standards in such areas as system interfaces, sensor networks, data management and security.[197] Other technical committees are focused on blockchain and distributed ledger technologies, cloud computing standards, e-financial services, health informatics and identification technology.[198]

The Cyber Security Agency was established in 2015 under the Prime Minister's Office to lead the cybersecurity master plan and provide centralized oversight of national cybersecurity functions.[199] It has been working closely with the Smart Nation Programme Office to integrate cybersecurity-by-design into the Smart Nation project.

(v) International collaboration

Singapore works in collaboration with other ASEAN countries on promoting smart cities and with Australia on research and innovation.

As the Chair of ASEAN in 2018, Singapore proposed the creation of an ASEAN smart cities network to use technology as an enabler to achieve smart and sustainable urban development. A concept note was released in April 2018 to highlight some of the core elements of the proposed network, which included crafting an ASEAN smart cities framework and developing action plans that member cities would undertake from 2018 to 2025.[200] In the 10 ASEAN member States, 26 cities have been named pilot cities for the proposed ASEAN smart cities network.[201]

In 2015, Australia and Singapore signed the Joint Declaration on the Comprehensive Strategic Partnership to enhance cooperation in different areas, including science and innovation. Singapore's National Research Foundation and A*STAR and Australia's Commonwealth Scientific and Industrial Research Organisation are involved in a five-year research collaboration project worth $37 million; funding is provided by both countries.[202] The partnership also encourages cooperation among technology startups from both countries.[203] In 2017, both countries agreed to "increase collaboration and joint funding to promote advanced manufacturing and data science".[204]

(c) Key messages

1. Singapore takes a whole-of-government approach to frontier technologies directed from the highest level of Government. It intends to improve the quality of life in the country by enhancing public sector service delivery and to foster growth by supporting business use of frontier technologies.

2. Singapore is building its frontier technology capabilities by facilitating their application and use by businesses. It has invested in a strong and enabling digital infrastructure and in strengthening R&D collaboration between Government, academia and industry. To further support businesses in developing and adopting frontier technologies, it has instituted regulatory sandboxes and accreditation schemes.

3. Singapore is focusing on upskilling and reskilling its recent university graduates and existing workforce to prepare them for the changing nature of work. It has subsidized training programmes in several frontier technology areas, particularly in ICT.

4. Singapore has less stringent personal data protection rules than Japan and the Republic of Korea. It leans towards encouraging the use of personal data by business. Nevertheless, it has strengthened cybersecurity through amendments to legislation and the introduction of the new Cybersecurity Act.

D. Comparative assessment of the four countries

Over the past few years, the Governments of China, Japan, the Republic of Korea and Singapore have formulated a wide range of policies to facilitate the development and adoption of frontier technologies. It is too early to assess the impact of these policies. However, different global indices are already measuring the readiness or ability of these countries to develop and adopt frontier technologies (figure II.2), and each of them is developing competencies in specific areas related to frontier technologies.

China has made significant progress in digital innovation, particularly AI. In 2017, two of its universities, Chinese Academy of Sciences and Tsinghua University, were among the top 10 in a ranking of the universities with the most frequently cited research papers in the AI field.[205] In 2017, seven Chinese startups, such as ByteDance (or Bytemod Pte., Ltd.), Face++ Cognitive Services and UBTECH Robotics, were listed in CB Insights' AI 100, a list of the most promising private companies applying AI algorithms across industries.[206]

Japan's highly competitive research, development and applied technology capabilities position it as a global leader in the field of robotics.[207] It is the world's predominant industrial robot manufacturer having delivered 52 per cent of the global supply in 2016.[208]

In the Republic of Korea, the robotics industry enjoys steady growth. Domestic sales and exports of robots have increased, and the country has the highest robot density in manufacturing globally (figure II.1).[209] The Republic of Korea is also a world leader in the implementation of open government data strategies.[210] It scores the highest on the OECD OUR Data Index, reflecting the Government's efforts to increase data availability and accessibility.

Singapore has the potential to become a regional AI hub. Industrial Internet of Things solution providers, such as Accenture, United States-based Emerson Electric Co., Japan's Yokogawa Engineering Asia Pte., Ltd. and Sumitomo Chemical Co., Ltd., have set up solution or research centres in Singapore.[211] Singapore's investment in ICT infrastructure, its pro-business regulatory environment and its protection of intellectual property make it the second most cloud-ready country in the Asia-Pacific region.[212] It also ranks second in terms of automation in the manufacturing sector, with a robot density of 488 robots per 10,000 employees.[213]

Governments in these four countries are vision setters. They set out the overarching framework for developing and applying different types of frontier technologies (e.g. AI and the Internet of Things), or for developing specific sectors (e.g. smart manufacturing) or employing holistic approaches (e.g. Japan's Fifth Science and Technology Basic Plan, or STBP). They involve multiple ministries, industries and academia in the identification and implementation of frontier technology and innovation priorities.

They have also established new institutions to deal with the development and application of various frontier technologies. Some are cross-ministerial in nature to facilitate better communication, coordination and cooperation. The Presidential Committee on the Fourth Industrial Revolution in the Republic of Korea and the Smart Nation and Digital Government Office in Singapore are examples of institutions that employ a whole-of-government approach in coordinating and implementing their national strategies on frontier technologies. Other institutions are cross-sectoral in nature to ensure that specialized knowledge, skills and judgment of experts from corporations, non-governmental organizations and academia can be applied to a specific area to accomplish the desired results. For example, the Advisory Board on Artificial Intelligence and Human Society in Japan "consists of 12 members with various backgrounds in fields such as engineering, philosophy, law, economics, and social sciences"[214] to resolve ethical and social issues caused by developing and deploying AI technologies.

1. Building capabilities in frontier technologies

The Governments of China, Japan, the Republic of Korea and Singapore are investing in and supporting frontier technologies. They are encouraging R&D by directing public financing to these areas, investing in new research centres and offering subsidies and tax incentives to encourage private sector investment in R&D. Many research centres or national laboratories have been established in partnership with large technology companies, such as Alibaba and Tencent in China, Fujitsu Ltd. and Toshiba Corporation in Japan, and Samsung and LG in the Republic of Korea.

The private sector in all four countries also actively contributes to R&D and the commercialization of frontier technologies. Large firms in China, Japan and the Republic of Korea have established their own research laboratories and infrastructure, built open innovation platforms and provided financial support for research in frontier technologies. Many of them also collaborate with universities or startups overseas to conduct AI-related research. The Government of the Republic of Korea is also supporting businesses to encourage them to adopt and use frontier technologies. In Singapore, some firms pursue research in AI by collaborating with AI Singapore. There have also been efforts to attract businesses involved in AI and support the commercialization of AI technology, for instance through the Accreditation@SG Digital programme.

Figure II. 2. Country readiness to take advantage of frontier technologies

Automation readiness

Conducted by The Economist Intelligence Unit (2017). It assesses how well-prepared countries are to leverage the opportunities and manage the risks of intelligent automation. It features the following three categories: innovation environment, education policies and labour market policies

12

China performed well in the labour market category, due in part to its strong policy support for students transitioning into the workplace.

4

Japan tops the ranking in the innovation environment category, as its Government provides strong support for AI research.

1

The Republic of Korea ranks highest in the index overall, with strong scores across all three categories. To support AI and robotics innovation for automation, it set aside $150 million in 2017 to fund AI-related research.

3

Singapore delivered top performance in the labour market category, as it has many promising initiatives in continuous education and labour market policy.

Source: The Economist Intelligence Unit, The Automation Readiness Index: Who is Ready for the Coming Wave of Automation Infographic, The Economist (2018). Available at http://www.automationreadiness.eiu.com/static/download/infographics.pdf.

Autonomous vehicles readiness

Conducted by KPMG (2018). It evaluates each country's capacity to adopt and integrate autonomous vehicles according to four categories: policy and legislation, technology and innovation, infrastructure, and consumer acceptance.

16

On infrastructure, China has the second-highest density of electric charging stations, but this is weighed down by low scores on technology infrastructure.

11

On technology and innovation, Japan has the highest number of autonomous vehicles-related patents adjusted for population. It intends to expand the export of intelligent vehicles and infrastructure via public-private partnerships.

10

The Republic of Korea carried out autonomous vehicles demonstrations during its 2018 Winter Olympics, and its K-City facility, opened in October 2017, is intended to be the world's largest testbed for self-driving cars.

2

Singapore ranked No.1 in policy and legislation and consumer acceptance. Its 2017 amendment to the Road Traffic Act allowing self-driving cars to be tested on public roads helped Singapore achieve a maximum score on regulation.

Source: KPMG International, Autonomous Vehicles Readiness Index: Assessing Countries' Openness and Preparedness for Autonomous Vehicles, KPMG International Cooperative (2018). Available at https://assets.kpmg/content/dam/kpmg/xx/pdf/2018/01/avri.pdf.

Global innovation index

Conducted by Cornell University, INSEAD, and the World Intellectual Property Organization (2017). It identifies which countries respond best to the opportunities and challenges of innovation by assessing each country according to three pillars: innovation input, innovation output and innovation efficiency.


22


14


11


7

China, Japan, the Republic of Korea and Singapore have been identified as innovation leaders. Though a stronger pan-Asian innovation network is emerging, few collaborative R&D projects exist between the Asian leading nations, with their top innovation clusters concentrated at either the firm or country level.

Source: Dutta, Soumitra et al., The Global Innovation Index 2017: Innovation Feeding the World (10th edition), Cornell University, INSEAD, and the World Intellectual Property Organization (2017). Available at https://www.globalinnovationindex.org/userfiles/file/reportpdf/gii-full-report-2017.pdf

Digital evolution index

Developed by the Fletcher School at Tufts University (2017). It captures both the current state and the rate of digital evolution across four categories: supply conditions, demand conditions, institutional environment, and innovation and change


36

Break out

China is low-scoring in its current state of digital advancement, but is evolving rapidly.


15

Stand/stall out

Japan is at the border between stand out and stall out.


7

Stall out

The Republic of Korea enjoys a high rate of digital advancement, but exhibits showing momentum. It faces the challenge of a 'digital plateau'


6

Stand out

Singapore is both highly digitally advanced and exhibits high momentum. It is a leader in driving innovation, but faces challenges in sustaining consistently high momentum.

Source: Bhaskar Chakravorti, and Ravi Shankar Chaturvedi Digital Planet 2017: How Competitiveness and Trust in Digital Economies Vary Across the World, The Fletcher School,Tufts University (July 2017). Available at https://sites.tufts.edu/digitalplanet/files/2017/05/Digital_Planet_2017_FINAL.pdf

2. Addressing the future of work

Governments are paying attention to the development of skills that form the foundation for the future economy based on frontier technologies. They have employed multiple approaches, developing core skills at all levels of education, including specialized higher education programmes and upskilling programmes for targeted groups.

Japan and the Republic of Korea are focusing on IT and software education in primary and secondary schools, as well as in higher education. They have reformed their curricula and made programming and software education a compulsory subject in school. In China, programming and AI education are progressively being offered to primary and secondary students. China is also increasing provision of AI education in universities and introducing AI skilling in vocational education and for businesses. Singapore is providing a wide range of training programmes on different frontier technologies to suit the needs of employees working in different industries. The Government encourages employees to reskill and upskill through the provision of different financial incentives, including subsidies, bonuses and monthly stipends.

While frontier technologies have the potential to accelerate productivity, there are concerns regarding the potential of machines to replace humans, both in terms of jobs and decision-making. Consequently, government policies (e.g. Japan's Society 5.0, the Republic of Korea's I-Korea 4.0 and Singapore's Smart Nation) put emphasis on creating a people-oriented society that taps the full potential of frontier technologies to improve citizens' quality of life and foster a cohesive society.

3. Personal data protection and privacy

The Governments of China, Japan, the Republic of Korea and Singapore pay attention to personal data protection and privacy. They have promulgated legislation that sets out compliance requirements for different entities regarding the collection, storage, use, transfer and disclosure of personal information. The Republic of Korea has the most stringent and the most comprehensive data protection law among the four countries. By contrast, Singapore has more permissive data protection provisions. For example, while data protection laws in China, Japan and the Republic of Korea differentiate general personal information from sensitive personal information and set out specific requirements to handle sensitive personal information, the data protection law in Singapore does not address the concept of sensitive personal information.

Countries' growing dependence on frontier technologies to develop and transform their economies and societies have made them more vulnerable to cyberattacks given their greater reliance on Internet-based interactions. According to the Asia-Pacific Defense Outlook 2016: Defense in Four Domains, Japan, the Republic of Korea and Singapore were nine times more vulnerable to cyberattacks than other Asia-Pacific economies due to their heavy reliance on Internet-based interactions.[215] Governments have thus taken proactive steps to strengthen their cybersecurity capacities. Japan has strengthened its industrial cybersecurity capacity by collaborating and exchanging best practices with Germany, while the Republic of Korea has collaborated with the United States to develop AI-based technologies that can detect, analyse and prevent cyberthreats. Singapore has established the Cyber Security Agency to lead cybersecurity policies and ensure the adoption of cybersecurity-by-design practices in its Smart Nation project. Meanwhile, the Governments in China, Japan, the Republic of Korea and Singapore have promulgated cybersecurity laws to safeguard their critical information infrastructure and information and communication networks from unauthorized access, interference or destruction.

E. Contributions to the Sustainable Development Goals

Public policies can ensure that countries harness the wide range of opportunities frontier technologies afford for the achievement of the Sustainable Development Goals and mitigate their risks.

1. Opportunities

Frontier technologies offer significant potential to generate economic growth through increased productivity and the creation of new markets. Frontier technologies offer strengths and capabilities (scale, speed and the ability to cut through complexity) that are complementary to human skills,[216] and can help improve the performance of businesses and industries. Most policy instruments introduced by the four countries have been focused on building the necessary elements for generating economic growth through the development of new industries and markets. These have included policies to develop the knowledge and skills required by these new industries and to create an enabling environment for them to flourish.

Frontier technologies can also improve public sector service delivery, education and health-care services. Singapore is using frontier technologies to improve government service provision through its Smart Nation initiatives. For example, Smart Health Video Consultation is implemented in several hospitals to enable discharged patients or patients with mobility issues to consult their doctors from home.[217] Data mining, AI and machine learning can process and analyse much larger clinical data sets to provide patients with more accurate and personalized treatments. Frontier technologies can improve education through the use of AI combined with learning management software to facilitate individualized approaches to student learning, enabling students to learn at their own pace.[218] In Japan, AI-assisted applications ("apps") have been widely used in schools to help students improve their oral English-language skills.[219]

Frontier technologies can address other social challenges, such as scarcity of water and energy, increased industrial waste, pollution and poorer public health. Incentivizing or mandating the application of frontier technologies in manufacturing can help companies improve energy efficiency. By using AI, sensor networks and system apps to track energy usage in real time, analyse energy performance data and identify optimum operating conditions.[220] For example, LS Industrial Systems Co., Ltd., one of the largest cable makers in the Republic of Korea, automates most of its production through robotics and ICT technologies, thus saving about 60 per cent of power costs.[221]

Smart-city initiatives can move cities in an eco-friendly and sustainable direction through the use of big data, sensors, wireless networking technologies and other smart devices to improve urban management and achieve energy efficiency. For example, the Green Horizon project, a partnership between IBM (International Business Machines Corporation) and Beijing's Environmental Protection Bureau, uses real time data from optical sensors and machine learning to furnish accurate predictions on where pollution was generated and how it was spread.[222] As a result, deadly airborne pollutants were cut by 20 per cent in less than a year.[223]

2. Risks

Frontier technologies also entail risks. Adoption and diffusion of AI, robotics and other forms of smart automation could lead to labour market disruption and job loss, potentially exacerbating inequality.[224] In this context, in anticipation of potential negative impacts, the four countries have introduced policies to equip students with skills required for the digital economy and to support relevant skills training for the existing workforce.

Frontier technologies also give rise to new concerns associated with trust and ethics. Countries have sought to address personal data protection, privacy and cybersecurity in different ways. As a consequence, greater inter-agency and cross-country cooperation and standardization may be required.

F. Key messages

1. Governments in the four countries have facilitated the development and adoption of frontier technologies through investments in R&D, encouraging the development of firm capabilities in frontier technologies and supporting an enabling ecosystem (infrastructure, standards and adaptive regulation) for frontier technologies. Partnerships between Government, industry and academia have been crucial to advance R&D and innovation capabilities in frontier technologies.

2. In the context of high uncertainty, the role of the Government in building the capabilities of frontier technology and directing its use has been crucial. In addition to the above-stated policies, Governments have also encouraged development of frontier technologies by adopting them in order to improve government service delivery. Countries such as Japan and the Republic of Korea have also promoted a human-centric approach, directing the focus of frontier technologies towards addressing social and environmental problems in alignment with the integrated approach of the Sustainable Development Goals.

3. The four countries are building on existing industrial and economic competitive advantages to develop competencies in frontier technologies. For instance, China and the Republic of Korea are building on their manufacturing capabilities to develop smart manufacturing, while Singapore encourages capabilities in frontier technologies to support its fintech industry and improve government services.

4. To take advantage and prepare for potential risks posed by new technologies, the four countries have strengthened public sector understanding of and capacity in frontier technologies across various ministries, including through coordination mechanisms.

5. The Governments of all four countries have initiated policies to mitigate the risks posed by the changing nature of work. They are supporting skill development and modifying curricula to nurture talent for the future frontier technology-powered economy. They are also encouraging businesses to use frontier technologies to provide new economic and employment avenues.

6. Policies on personal data protection, privacy and cybersecurity require further consideration and have been frequently updated to keep pace with technological developments. Countries have sought to balance potential risks to privacy with the utility of personal data in different ways. However, greater inter-agency and cross-country cooperation and standardization may be required.

Chapter III. Public service innovation

A. Introduction

In recent times, Governments across the world have announced innovation agendas and launched dedicated units. Specialized government ministers have even been appointed with a remit to rethink public services. This change has been driven by circumstances: Governments face increasing challenges, ranging from rising citizen expectations to the increasing complexity of global challenges and cost-cutting pressures.

New opportunities become available with advances in technology. For example, when modern computing power is combined with big data, public services can be more personalized, targeted and efficient. School curricula can adapt to a child's progress through school,[225] and precision medicines can be created using an individual's genomic sequence.[226]

Public service innovation is defined as public sector entities "introducing new approaches to improve the quality of public services and better respond to society's needs."[227] For the purposes of this report, the public sector is taken to mean all government entities and publicly owned corporations across the central, subnational and local levels.

In using this definition, this chapter contains analysis of public service innovation through case studies highlighting Governments' use of new tools, techniques, processes and technologies in public service delivery to achieve social, economic and environmental objectives.

Public sector innovation comes in multiple forms and can be categorized based on the type of innovation, the drivers of the innovation or the modality of innovation (figure III.1).

Public sector innovation refers to "both the content of these services and the instruments or processes used to deliver them".[228] Three main types can be distinguished:

(a) Process innovation refers to innovation improving the quality and efficiency of processes in public service delivery. Process innovation can be administrative or technological where the former introduces management innovations while the latter leverages technology for improving public service delivery;

(b) Product or service innovation refers to creation of new public services or products. Its distinction from technological process innovation is sometimes difficult to illustrate. The key difference is in its objective to create new products and services as opposed to using technology to improve existing services;

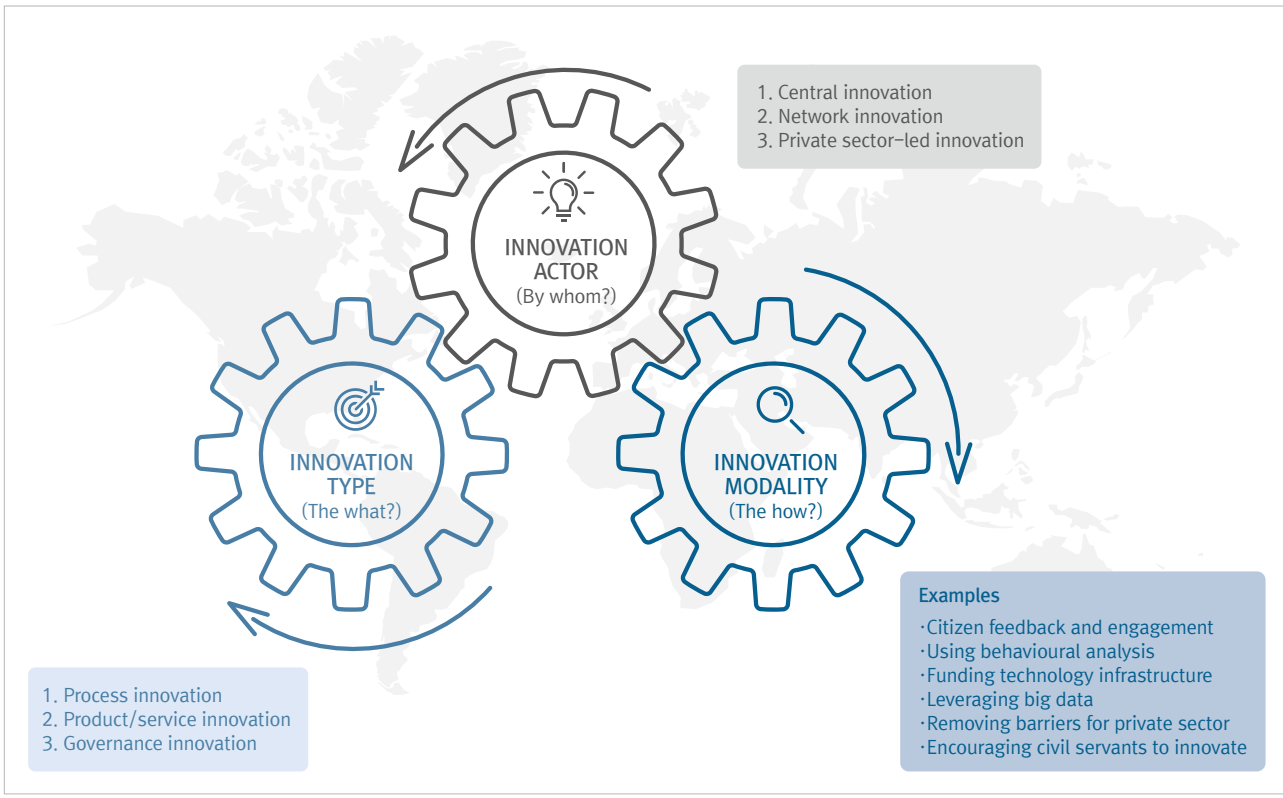
(c) Governance innovation goes beyond creating new products or processes towards developing new governance frames and forms that address specific societal problems. Increasing citizen input into public service delivery is an example of a governance innovation.

Public service innovation may be driven by different organizations, and three categories can be distinguished based on its origin:

- Central innovation refers to any innovation coming from the heart of Government, including from national strategies and delivery units, government digital services and innovation labs;
- Network innovation refers to innovation coming from within the public or social sector but not as part of a national strategy or a central unit. Local government and civil society provide the majority of these examples;
- Private sector-led innovation refers to innovations from the private sector pitched to the Government. While the above two approaches can outsource delivery to the private sector, private sector-led innovation refers exclusively to innovations formed outside the Government, which have been adopted by the public sector.

The third aspect of public sector innovation is the modality, that is, the techniques and methods, used to innovate. For example, using behavioural nudges in programme design or encouraging civil servants to innovate are examples of modalities of public sector innovation.

Figure III. 1. Public sector innovation: a framework



This chapter contains discussions on developments in public sector innovation in China, Japan, the Republic of Korea and Singapore. Such developments are presented based on who drives the innovation (central, network or private sector). Several examples are introduced of Governments innovating in the delivery of public services, and unique country factors are analysed that enable them to do so. The four countries discussed in this chapter specialize in different types and sources of innovation depending on the innovation need, operating context and the resources available. Public sector innovation can have positive implications for achieving national sustainable development goals. The chapter also contains a brief discussion of how public sector innovation has contributed and can contribute towards the achievement of the Sustainable Development Goals by 2030.

B. Country experiences: public sector innovation in China, Japan, the Republic of Korea and Singapore

1. China

China's public sector innovation is characterized by a combination of a strategic vision, openness to experimentation and active private sector participation. Significant public sector innovation is decentralized, with cities and city governments being the primary test beds for public sector innovation. The private sector plays an important role in China's public sector innovation ecosystem by pitching ideas directly to Government. This combination of vision, experimentation and private sector participation has enabled the country to rapidly progress in terms of results in the United Nations E-Government Survey,[229] rising from 78th to 63rd between 2012 and 2016.

(a) Central innovation

Central innovation in China is focused on improving processes for efficient service delivery. In addition, China also promotes ambitious governance innovation intended to improve accountability.

The Internet Plus strategy, set out in 2015, gives impetus for reforming public service and leveraging technology to improve public service delivery. The goal is to promote "better information sharing between government departments, so that the public and businesses need to make fewer visits to government departments to get things done, find procedures simpler, and find the service satisfactory".[230] The 2018 United Nations eGovernment rankings[231] show progress in this area.

Another central innovation is social credit, which uses behavioural economics to stipulate access to public services. In 2014, the State Council called for a "nationwide ranking system to rate the reputations of individuals, businesses, and government officials".[232] This scheme is designed so that every Chinese citizen would be trailed by a file compiling data from public and private sources by 2020, and for those files to be searchable by fingerprints and other biometric characteristics.[233] Currently, this public programme is being implemented as pilots in a few cities.[234] However, private companies such as Alibaba have built opt-in schemes, such as Sesame Credit, which uses buyer loyalty and criminal records to determine users' ability to purchase goods and services.[235]

This example highlights the trade-offs inherent in some public sector innovation initiatives. While the use of personal data has the potential to increase accountability and improve service delivery, it also poses privacy and civil liberty concerns.

(b) Network innovation

City governments have driven public innovation outside the central Government (network innovation) in China through the piloting and scaling of new products, services and technological processes. The Smart City strategy accounts for the bulk of network innovation.

The strategy has three key pillars: creating a competitive industrial environment; enabling an attractive living environment for citizens; and setting innovative management systems for the Government to use.[236] These systems combine public and private sector innovation but are led by the Government. A smart city interministerial coordination working group was convened in April 2016 and has selected 100 new cities for experiments.

One area of network innovation is traffic management. For example, the Hangzhou City Brain project, carried out in partnership with the e-commerce platform Alibaba and hardware manufacturer Foxconn Technology Group, uses camera systems placed across the city and combines their data with artificial intelligence to track road conditions in real time.[237] Alibaba claims that in reporting traffic violations the system has an accuracy rate of 92 per cent and has increased traffic speed by 15 per cent.[238] The system also has potential as an urban planning tool in the long term. It can learn traffic patterns and make recommendations on new roads, bus routes or traffic-light configurations.[239]

Public safety is the second area of network innovation. Facial recognition technology, combined with vast amounts of citizen data, is being used in "predictive policing" models in Xinjiang Province.[240] Feeds from surveillance cameras are combined with travel records, bank statements, travel records and data even on religious orientation in order to monitor individuals.[241] This demonstrates how technology is changing public safety techniques. However, it also raises ethical concerns, including issues of privacy and algorithmic bias.

Citizen services comprise the third area of focus in network innovation. In Xi'an, which has seen extensive migration over the past decade, big data analytics is used to track the population, identifying from what place new citizens come, what kind of jobs they perform and the services they will require from the Government.[242]

The use of facial recognition, as in the examples from Xinjiang Province and Xi'an, and certain other public sector innovations also raise concerns about the trade-offs between improving public service delivery and issues of privacy and civil rights.

(c) Private sector-led innovation

While the private sector is crucial for all smart city initiatives, what sets China apart is the extent to which private companies pitch solutions that replace State systems and address citizen "pain points". Private firms have developed a suite of new products and improved processes to make public service delivery more efficient.

Large service and payment providers, particularly Alibaba (which runs the e-payment platform AliPay) and Tencent (which runs the messaging platform WeChat) are at the forefront of private sector-led innovation. For example, AliPay has rolled out City Services (online services that enable the payment of utility bills, such as for gas, water and electricity, as well as traffic fines and taxes), replacing the face-to-face system operated by government authorities.[243] Other typical city services include making payments through such systems – AliPay is accepted on public transport systems in 50 cities across China – rather than using traditional swipe cards. The company planned to make AliPay available in 100 cities by the end of 2018. Another, less common, application is the ability to register through the system for a divorce appointment with City Hall.[244]

Meanwhile, AliPay competitor WeChat is making gains in the digital identity space. The city of Guangzhou is conducting trials on the use of WeChat to host a digital ID card, which would enable users to access government services online. This system was accredited by the Ministry of Public Security; following trials in Guangdong Province, it will be expanded across the country.[245] Many countries around the world are experimenting with digital identity systems, but this is the first example of the private sector taking the initiative. WeChat Pay is also used in Guangzhou's health-care system, enabling people to pay for their prescriptions and have medicines delivered to their home.[246]

China's tight linkage between the public and private sectors is due to formal relationships and informal networks. Many technology firms have established Communist Party committees, which review compliance with national goals.[247] According to one scholar, regulators are considering taking board seats and a 1 per cent stake in Alibaba and Tencent.[248]

(d) Unique factors

(i) Leveraging data abundance

A unique factor enabling public sector innovation in China is the large amount of data that technology companies, and consequently the Government, have available to them. WeChat has more than 1 billion users while the taxi service Didi Chuxing has 500 million users.[249] This latter provider can now anticipate when and where people will want to travel with 85 per cent confidence 15 minutes ahead of time.[250] These same algorithms have the potential to build predictive public services.[251]

(ii) Central role of the private sector in driving innovation

The central role of the technology sector is one of the unique factors that characterizes public service innovation and the important role of the private sector in it. Many Governments prefer to build their services in-house, but China has used its private technology sector to power the majority of public service innovations. However, the private sector is one of the unique factors that characterizes public service innovation, and this has also brought to the forefront trust and privacy issues. The slim dividing line between the State and the private sector in China makes oversight more problematic.

2. Japan

Japan's public sector innovation goals have a mission-oriented focus on addressing systemic social and environmental problems facing the country, such as health-care reform to support an ageing demographic, electricity and energy reforms following the Fukushima Daiichi nuclear disaster, and transportation and tourism reforms to support the 2020 Olympic Games. For example, the pace of public service innovation has been hastened in preparing for the Olympics, and minds have been focused on how to showcase the country's strengths to millions of new visitors. Ambitious objectives have been set nationally and locally with this hard deadline even for aims that do not relate to the Olympics.

Central innovation in Japan is focused on a national strategy to use frontier technologies in public service delivery with an ambitious declaration to become the "World's Most Advanced IT Nation".[252] This has contributed to Japan's improvement from the 18th to 10th place in the United Nations eGovernment ranking between 2012 and 2018.[253]

Network innovation is city-driven, with mayors using innovation to brand their cities to national and global audiences. The private sector is less involved in public service innovation. However, some areas, such as disaster recovery, illustrate the potential for partnering with and benefiting from private sector involvement.

(a) Central innovation

In Japan, digital public services are run by the Office of Information Technology, which is located in the Cabinet Secretariat. Within the civil service, the Government Chief Information Officer sets the delivery strategy, while departments are responsible for creating and building specific projects.[254]

The Government's plan to be the world's most advanced IT nation forms the core of the central innovation strategy for public sector innovation. The Government established the deadline for the 2020 Olympics to use data analytics and AI in eight key sectors for both improving processes and introducing new services.[255] These are: digital government; health care; medical and nursing care; tourism; finance; agriculture; manufacturing; disaster prevention and mitigation; and mobility. Notable initiatives include a new national identity system; a platform to share data and information during disasters; and plans to reduce government operating costs by 30 per cent by simplifying systems.[256]

AI use is prominent in Japan's central innovation strategy and is being used to augment the country's shrinking workforce. For example, the Japan Patent Office is using AI to automate "cumbersome" tasks in patent, trademark and design applications.[257] The Ministry of Health, Labour and Welfare is using AI to accelerate its drug discovery process, sifting medical research for promising ideas.[258] Finally, the Government is using AI to draft responses to parliamentary questions by using past answers as a template.[259]

Biometrics also plays a key part in the country's 2020 vision, with plans for a fingerprint payment system for tourists. Trials have been conducted in key tourist hotspots by the Ministry of Economy, Trade and Industry to reduce reliance on cash.[260]

Public tendering provides further opportunities for innovation, with blockchain technology being used to create a simpler bidding process. The Ministry of Internal Affairs and Communications will build a platform that enables the sharing of data between agencies so that businesses can use existing tender applications to support their new application rather than having to draft each one from scratch.[261]

Robotics is also set to play an increasing role; the Ministry of Economy, Trade and Industry has set aside $18 million to subsidize 24 companies working on nursing-care robots, such as self-driving toilets and robotic bears to lift elderly people into bed.

(b) Network innovation

As is the case in China, cities form the basis of Japan's network innovation. Some of the key initiatives of city governments include supporting an ageing demographic, boosting tourism and becoming more environmentally friendly.

For example, in terms of health care, Kita City ward in Tokyo is conducting trials on AI to support nursing claims and streamline the benefits process for elderly residents.[262] Meanwhile, the city of Iruma is using design to enable elderly citizens to retain their independence through the use of QR code stickers which can be affixed to fingernails, enabling the police to access information on them if they get lost.[263]

Tokyo has used the forthcoming Olympic Games to set out a vision for a "hydrogen society",[264] which will involve installing hydrogen charging points on streets for fuel-cell cars, and the Olympic Village will be run solely on hydrogen power.[265] The car manufacturers Honda, Nissan Motor Co., Ltd. and Toyota have agreed to fund one third of the costs of the fuel stations.[266]

While cities currently operate separately from the national innovation agenda, this situation is likely to change with advancement of the smart city strategy.[267]

(c) Private sector-led innovation

The private sector is keen to align itself more closely with the Government and to increase the opportunities for private sector-led innovation. The Japan Business Federation of large companies has reached out to the Government asking for problem statements that industry could address. At the end of 2018, the country was to conduct trials on "agile procurement", where a tender is not based on concrete specifications but on broader requirements. Tenders are also split into small-sized chunks so that a project could evolve if specifications change. Procurement reform will enable crowdsourcing, where challenges are published and citizens and industry alike propose their ideas to address them.[268]

Disaster recovery systems are unique examples of private sector-led innovation, helping the country to learn from the 2011 tsunami and the Fukushima nuclear disaster. Fujitsu has partnered with the International Research Institute of Disaster Science to build two systems: tsunami flooding simulations and evacuation simulations. The initiative to mitigate the impact of tsunamis is based on cutting-edge technologies, including AI and supercomputers.[269] The system was launched in the coastal city of Kawasaki in November 2017. Simulation technology predicts where damage would be concentrated, estimating factors, including wave height and arrival time, by using offshore sensors. Meanwhile, technology that models human behaviour is used with flooding data to plan evacuation routes.

The 2011 tsunami also prompted a rethink of the country's energy industry, creating innovations in the utility sector that have achieved broader public service goals. The semi-nationalized electricity company TEPCO (Tokyo Electric Power Company Holdings, Inc.) has used AI to plan predictive maintenance operations, coping with reduced manpower as the country's workforce ages. It also has plans to install smart meters between 2020 and 2024, enabling citizens to measure their energy consumption and allow for personalized utility bills.[270]

(d) Unique factors

(i) Leveraging an advanced technology sector

Japan has the advantage of having a large and sophisticated technology sector, particularly in terms of ICT hardware, transportation and robotics. This situation enables greater experimentation to meet societal objectives in health care and energy. For example, it is piloting multiple artificial intelligence-based initiatives to reform the work and efficiency of the Government. However, the limited role of the private sector in software and IT services – crucial industries for eGovernment work – can limit this advantage.[271]

(ii) Establishing clear milestones and targets

The deadline in preparing for the 2020 Olympics has established a clear milestone for innovation objectives, which has led to investment of political and financial capital in public service innovation at both the national and local levels. Further, the mission-orientation of public sector innovation has led to greater coherence between social and environmental aims and public service innovation in Japan.

3. Republic of Korea

The Republic of Korea is a global leader in digital public service provision, consistently scoring in the top three of the United Nations eGovernment rankings over past surveys.[272] Despite the effectiveness of service delivery in the Republic of Korea, it was noted in the March 2018 Innovation Master Plan that "the level of citizen trust in government and transparency remains low".[273]

This situation has motivated strong inclusivity and citizen engagement focus in public sector innovation. The Government of the Republic of Korea has mobilized citizens to find gaps in service delivery, while the private sector is expected to innovate and provide solutions to these flaws. The public sector acts as a facilitator in the process, which also marks a pivot in the Government's focus away from efficiency and economic growth towards "innovation that makes a real difference in citizens' lives",[274] with emphasis on network participation and building communities.

(a) Central innovation

The Republic of Korea is strongly focused on streamlining processes, promoting open data and standards. It has launched an initiative to prevent duplication of government services and platforms. Another initiative is the Open Data scheme, in which large amounts of open data are published to create new commercial opportunities. There has been a focus on common standards to make it easier to share data, with emphasis on financial transactions, e-procurement, taxation and business registration systems.[275] According to OECD, this can "add value in the private sector, foster innovation and empower citizens' decision-making".[276] The Republic of Korea scores the highest in the world on the OECD OURdata Index, a measure of data availability, accessibility and government support for the reuse of data.

Additionally, the Republic of Korea is piloting new products and services using big data to improve the targeting and planning of public services. For example, a health-care project is providing elderly people in the countryside with wearable devices that monitor their blood pressure and heart rate. Testing this technology enables the Government to determine whether and how it can support an ageing demographic and enable personalized home care.[277]

The Korean Centers for Disease Control and Prevention is using international roaming data by partnering with telecommunication companies to track people who have recently visited countries with disease outbreaks.[278] This activity occurred after the outbreak in 2015 of Middle East Respiratory Syndrome (MERS), which forced 17,000 people to be held in quarantine, infected 186 persons and killed 36 Koreans.[279]

The Government is also committed to using robotics for public service delivery. The Ministry of Trade, Industry and Energy has announced a $449 million plan to use robots in public safety, health care, tourism and logistics.[280] Specialist robots have been created to be dropped by drone into large fires to search for survivors;[281] and hospitals will trial robots to transport materials and assist with patient rehabilitation. The Republic of Korea also used robots to guide visitors at the 2018 Winter Olympics.[282] As in Japan, these technologies are still in their nascent stages, so while they are innovative they have less impact in the short term than process changes or data analytics projects.

(b) Network innovation

Network innovation in the Republic of Korea comes from two key thrusts: open government initiatives to encourage citizen-led ideas for delivering local solutions, and experimentation at the local level.

There are a number of participatory initiatives using technology to gather ideas and reshape public service delivery. For example, in 2017 President Moon Jae-in launched the "Gwanghwamoon 1st Street" initiative, a 100-day government programme that asked citizens for their ideas to reduce corruption, improve efficiency and plug gaps in public service delivery.[283] The People's Transition Office was established to lead the initiative, with the central branch being established in Seoul and local pop-up offices created in almost every municipality, supported by a national crowdsourcing website.[284] The project received 180,706 suggestions, and more than 1,700 of them were integrated into government policies.[285] Some of these suggestions have been implemented. For example, one proposal recommended combining the fire station, public library and police station together in the municipality of Wirae to improve the facilities in a central building rather than maintaining three lower-quality separate outposts. This suggestion has been taken forward by the Ministry of Interior and Safety.[286]

At the local level, Seoul City government has led the way on citizen engagement, believing that "citizens are mayors". A notable innovation is the policy "hackathon", which borrows a software development method in order to develop public services. One such hackathon in 2017 was designed to fast-track approval procedures for "next generation medical devices", assess them on social and clinical benefits as well as on hard scientific evidence.[287] Public competitions also engage citizens and experts in urban planning. The Project Seoul initiative uses a digital platform to seek innovative designs for public projects, with citizens and experts able to vote on their favourite schemes as the tendering process develops.[288]

At the city level, the Seoul Innovation Bureau oversees new approaches to policymaking in the city. One example is the night bus initiative that was first proposed by a citizen communicating through Twitter. The city has used mobile phone data to analyse the location of 3 billion phone calls and discovered the eight most common routes that people take between midnight and 5 a.m.[289] Participatory budgeting forms an important part of the Government's engagement programmes. This method was adopted in 2012 and enables citizens to propose new projects which are voted on at a public meeting. The Seoul Metropolitan Government selects 35 projects a year with an overall budget of $8 million.

Two online channels play a further role in engaging citizens. First, mVoting collects public opinions in real time,[290] enabling citizens to comment on policy decisions, vote in favour or against and propose new ideas. As of 2016, the programme had developed 121 policy initiatives.[291] Second, the Ten Million Imagination Oasis is a platform where citizens can make detailed policy proposals and communicate with officials in real time about their ideas.[292] Successful proposals include Braille signage in the city for people who are visually impaired, new park trails and air quality indicators displayed in city subways. These methods all rely on a highly engaged citizenry with good Internet connectivity. Most importantly, they are successful because the Government visibly acts on suggestions and takes them forward.

(c) Private sector-led innovation

The role of the private sector in public sector innovation is less prominent in the Republic of Korea compared with that of China and Japan, with the Government taking the lead on the strategic direction and industry implementing those ideas.

A notable exception is Songdo, a city built on the outskirts of Incheon. It is a $35 billion project where private developers have created an entire city on reclaimed land, with the ambition of having it become the world's most sustainable city with an emphasis on smart city technology.[293] The development prioritizes public transportation and bicycles over road traffic,[294] while all housing units were built within a 12-minute walk of a bus or metro stop.[295] Almost 40 per cent of the city is green space, while thousands of closed-circuit television cameras are monitored in a central operations room to provide public safety assistance.[296]

Finally, much of the work of the e-Government Bureau is outsourced to the private sector. Unlike many leading digital Governments, there is not a large central team that builds and develops portals and other systems. Other countries which score well in the United Nations eGovernment rankings, such as Australia, Singapore and the United Kingdom of Great Britain and Northern Ireland, have built their own in-house digital teams, but the Republic of Korea outsources the most of its IT projects.

(d) Unique factors

(i) Making a commitment to an open data policy

The first advantage of the Republic of Korea is its prowess in digital government, especially its use of data and data transparency. This stems partially from concerns of both national and city governments with strengthening citizens' trust.

(ii) Using technology to build citizen engagement

Second, the Republic of Korea has used its technology to facilitate greater interaction with citizens. Techniques such as hackathons have been adopted from industry and refashioned to shape policymaking.

4. Singapore

The Government of Singapore provides strong support for central innovation. As a geographically small country with a population of about 5 million people and few natural resources, the Government is forced to place high emphasis on skills, technology and continuous adaptation. This urgency has increased in recent years as the country faces a shrinking workforce due to its ageing population, a "vocal citizenry with rising expectations",[297] and a services-based economy that is being "drastically reconfigured" by technology.[298]

The Government of Singapore has two broad innovation strategies to adapt to these pressures. First, at the central level, it has set out an umbrella strategy for a smart nation[299] that will be built through partnerships with industry and the creation of digital public services. Second, it has an innovation movement that encourages civil servants to come forward with new ideas and techniques for public service delivery.

(a) Central innovation

Central innovation strategy in Singapore is outlined in its Smart Nation vision, launched in November 2014 to maintain the competitiveness of the city-State. The objective of the vision is to leverage technology and process innovation to improve the economy, quality of life and responsiveness of public servants.[300, 301] The Government has outlined a five-point plan to achieve this:

(1) A nationwide network of sensors, called the Smart Nation Sensor Platform, is used to manage a range of public services from utility management to security.[302] For example, facial recognition cameras will be attached to lampposts across the country for public safety, crowd control and traffic predictions;

(2) A new national digital identity system, which is aimed at increasing citizen convenience and productivity by improving transactional security, will enable digital signatures encouraging paperless transactions with the Government;[303]

(3) A "moments of life" strategy will see digital services created around citizen needs rather than departmental structures. For example, a platform for newborn children will combine health-care and education information in one place;[304]

(4) An overhaul of public transport includes plans for driverless cars and trucks on its road network. The Ministry of Transport is currently conducting trials of such systems in ports and the university district;

(5) Prioritized e-payments across the country support industry by replacing cash transactions with mobile payment systems developed in partnership with local banks and industries.

Singapore has also created the Government Technology Agency (GovTech) to build the technology necessary for implementing the Smart Nation strategy. Its mission is to help agencies trial technology platforms quickly and build proof-of-concepts to test new ideas.[305] For example, the parking.sg app launched to allow Singaporeans to pay for parking without using paper coupons was built by GovTech in six months and using only three people to do so.[306] GovTech uses "agile project management" to build these services, continually upgrading projects that are imperfect at launch. This differs from the previous model of creating large-scale tenders that cost more than three to four times and took at least one year to complete.[307]

The Smart Nation vision is driven by the Prime Minister's Office and led by a specialized (dedicated) minister. In 2017, this organization was supplemented by a ministerial committee chaired by the Deputy Prime Minister; it has been given powers to command the budgets of individual agencies to ensure individual agencies meet the technology-enabled vision.

(b) Network innovation

Network innovation in Singapore, for example, comes primarily from government departments and has been prioritized through governance (e.g. appointment of innovation offices) and in processes (e.g. adoption of innovation challenges, behavioural economics, design-thinking and, more recently, strategized citizens' engagement).

Singapore's Public Service Division (PSD) encourages public officers to bring forward their ideas and to innovate in their agencies, as well as develop new strategies for public service delivery.[308] First, the Government has appointed innovation directors in every agency to create an environment that encourages new ideas. These officials are senior civil servants appointed at the director level. They receive regular training from PSD and network to create a community of practice.[309] Singapore GovTech has also followed this model, appointing chief digital strategy officers in the 15 ministries of Government.

Second, it has promoted innovation through the use of challenges and open competitions. The Public Service Division launched an innovation challenge in August 2016 to call for new ideas among civil servants. Rewards of $680 were handed out on the spot and funding was set aside for prototypes with $95,000. GovTech also ran a challenge in 2018, asking employees to put forward 100 new ideas for public service delivery.[310] One idea was to create a new system that generated automatic wills for citizens, which had been prompted by a bereavement suffered by an employee. The innovation, which is being constructed, will auto-complete a citizens' details from their digital identity data and is valid in court, preventing many of the legal and bureaucratic obstacles often suffered during times of bereavement.

Third, the Public Service Division shares examples of key innovation approaches across departments. Data science, design-thinking and behavioural economics are the most prominent tools of innovation in the public sector. For example, the National Environment Agency has used weather data and health-care information, combined with algorithms, to tackle dengue fever.[311] A system was built to predict the location of mosquito breeding grounds, with drones and manpower teams deployed to spray areas with pesticides in advance of any problems occurring.

Behavioural economics is increasingly employed in the design and messaging of programmes. For example, the Health Promotion Board built the Health Hub app[312] that pulls in citizens' health-care records, enabling users to register their activities and diet; it even monitors their step count to encourage citizens to walk more. Citizens who join the programme receive points for shopping vouchers based on the steps they take daily.[313]

Design-thinking is increasingly prominent, and the Ministry of Manpower used it to speed up immigration processes. They redesigned their service centres for foreign workers and tracked the full application process.[314] Similar moves have occurred in Singapore's health-care system where lean and design-thinking principles are used when (re)designing infrastructure. For example, the Tan Tock Seng Hospital has cut waiting times in its outpatient pharmacy by up to 40 per cent.[315]

Citizen engagement efforts have also increased over the past few years, with the dedicated Office for Citizen Engagement and the new Citizens' Jury initiative. For example, a 75-person panel was established to hear evidence about diabetes and discuss possible measures to encourage healthier lifestyles and nudge citizen behaviour,[316] which resulted in citizens calling for higher financial rewards to be given for exercising.[317]

(c) Private sector-led innovation

Singapore has a far smaller domestic technology base than the other countries, and private sector-led public sector innovation is less significant. On the contrary, the Government is supporting private sector innovation through its activities. The Government encourages innovation, particularly in startups and local companies through preferential and agile tendering schemes, crowdsourcing solutions for local challenges and supporting regulatory sandboxes (see chapter I).

Notably, GovTech partners with the Info Communication Media Development Authority of Singapore (IMDA) to run a preferential tendering scheme – Accreditation at IMDA that supports local SMEs. The scheme gives local businesses a charter mark, which allows them to skip key parts of the tendering process, thereby reducing their costs and enabling them to compete with some requirements, such as cash flow.[318]

Second, the Government runs the InnoLeap programme, which is similar to a speed-dating programme. Agencies set out a challenge, such as crowd control in urban squares, and local enterprises pitch how they can solve these problems with novel ideas. In 2018, 20 proof-of-concept schemes were in development.[319]

The Ministry of Finance has encouraged agencies to apply this approach directly to tenders, as is being considered in Japan. The Ministry of Defence crowdsourced local engineers' ideas for new equipment ideas in 2017. However, agile procurement has been slow in view of the complexity of this approach and has taken second place in initiatives to directly build services in-house.

Finally, regulatory sandboxes provide an environment where companies can bend the rules to deliver new products under government scrutiny. The data protection regulator has enabled companies to create personalized services, such as car insurance products, that use greater amounts of citizen data. The sandbox enables the Government to track the growth and popularity of these schemes without making larger changes in legislation. Meanwhile, by reducing privacy restrictions the Ministry of Home Affairs is working with the Singapore Tourism Board to enable hotels to conduct trials of facial recognition technologies.[320]

(d) Unique factors

(i) Maximizing its small size and high population density to test and deploy innovation

Singapore's small size and high population density makes it feasible to experiment and rapidly deploy central innovations. For example, a nationwide sensor is far easier to implement in a small country of 720 sq km than it would be in China with its area of more than 9 million sq km, and digital identity systems are easier to build when there are only 5 million citizens compared with China's population of almost 1.4 billion, for example.

As a city-State, Singapore combines local and national governments, which also allows for quick changes in government structures. For example, the GovTech agency was moved in 2017 directly under the Prime Minister's Office to give it greater clout.[321]

(ii) Providing long-term strategy and high-level support for public sector innovation

The country places strong political emphasis on public sector innovation with buy-in from the Prime Ministerial level. The public is also behind this agenda, as 70 per cent of citizens believe the Smart Nation agenda will improve their lives.

Under increasing pressures to remain competitive, Singapore is building on its long history of public service innovation.

C. Implications for achieving the Sustainable Development Goals

Developments and advances in public sector innovation have implications for achieving the Sustainable Development Goals. The discussion and examples from the four countries illustrate the potential and implications of public sector innovation for achieving the Sustainable Development Goals. Six interlocking themes in public sector innovation are critical for the achievement of the Goals:

(a) **Improving data availability and quality:** Improved data availability and quality are important aspects of achieving and tracking progress on the Sustainable Development Goals. They can improve decision-making, service delivery and ensure better evaluation of policies and programmes. Developments in public sector innovation in the four countries highlight the need for and potential of accurate, comprehensive and timely data sets. For example, China relies on this aspect to create most of its services, ranging from predictive transport systems to divorce registration forms. Similarly, Singapore has used geographical data sets and health-care data to deal with dengue fever. Partnerships have been critical to obtain access to better and more data. For example, the epidemics monitoring system of the Republic of Korea demonstrates the potential of private sector partnerships (e.g. with telecommunication companies) to gather information on travel history.

(b) **Directing development towards sustainability:** Sustainability is a central focus of the Sustainable Development Goals. Governments play a strong agenda-setting role, and through public sector innovation, they are increasingly directing and deploying policies for sustainable development. For example, Japan encourages innovations for more sustainable development, particularly with its reforms following the 2011 Fukushima Daiichi nuclear disaster. The utility company responsible for the nuclear power plant, TEPCO, is innovating with technology to improve service delivery and incentivize consumers to use energy at times of low demand. Tokyo's vision for a "hydrogen society" in 2020 with zero emissions is another example.

(c) **Addressing trade-offs between the Sustainable Development Goals:** The achievement of the Goals will require an integrated approach that considers the trade-offs between different Goals. There are also trade-offs where advancing one Goal may have a negative impact on the achievement of another[322] (e.g. between efficiency and inclusivity or between economic growth and sustainability). Some public-sector innovations, in particular those regarding the use of big data, illustrate these contradictions. With rapid growth of data available to corporations and Governments, the balance between leveraging data for efficient governance and service delivery versus privacy protection has to be carefully considered.

(d) **Increasing inclusivity through participatory governance:** Achieving the Sustainable Development Goals will require innovative policy processes. Public sector innovations, such as the Republic of Korea's national and local citizen engagement projects, or Singapore's Citizen Jury initiative, have shown how participatory and inclusive governance can encourage citizen contributions in policymaking, enable better public service delivery, help identify citizens' needs and enhance the design of public projects. Participation and co-creation are also being encouraged in the design and implementation of STI activities. For example, Japan Science and Technology Agency's MIRAI Program collects proposals for R&D.

(e) **Partnerships:** Partnerships with a broad spectrum of stakeholders, from the private sector to civil society organizations, have been critical to realize public innovation programmes that support the achievement of the Sustainable Development Goals. The country examples portrayed show the potential and avenues of partnerships to support sustainable development in innovative ways. For example, the typhoon warning and evacuation systems piloted in Kawasaki, Japan, shows the potential of industry partnerships in disaster recovery.[323]

(f) **Incorporating new ways of delivering public services through design-thinking, behavioural insights and nudges:** Using behavioural insights and informed nudges have the potential to increase the value and impact of public policies and their contribution to the Sustainable Development Goals.[324] For example, Singapore uses small changes in signage and design to influence citizens across a vast range of areas, from traffic-light crossings to tax payments.[325]

D. Key Messages

Innovation is a relatively new phenomenon in Government, but as these countries show, it is rapidly becoming the new normal. China, Japan, the Republic of Korea and Singapore have different experiences, rationales and instruments for pursuing public sector innovation. While the origin and the types of innovation vary across countries, public sector innovation in these countries has highlighted four strategic features that make public sector innovation meaningful and more likely to succeed.

1. Leveraging strengths

Each of the four countries has developed successful public sector innovations by building on national strengths. China has leveraged its strong technology sector; Japan has utilized its strong city governance, manufacturing industry and the upcoming Olympic Games; the Republic of Korea has used its data capabilities and participatory governance process to build inclusive innovation; and Singapore has used its strong civil service capacity and small size to experiment with and operationalize ambitious projects. Innovation is specific to the local context and can be best encouraged by leveraging local strengths. For example, a country with a large population will be less able to implement new systems as quickly as Singapore; network innovations are particularly relevant in leveraging local strengths.

2. Defining clearly the problem and the role of the public sector

Public sector innovation has proven most effective when addressing clear problems important to citizens or businesses. There are multiple sources which can help define problems and the public sector interventions needed. Frontline agencies may spot them, as Singapore's Ministry of Manpower discovered with its immigration system.[326] Citizens may complain, as they did to the People's Transition Office in the Republic of Korea in 2017,[327] or private companies may spot them, as AliPay did with China's utility bill payment system and WeChat Pay did with public transport payment systems.328

3. Public sector innovation goes beyond technology

This chapter has presented many public sector innovations adopting or guiding technological innovations. However, public sector innovation goes beyond technology, reassessing public education structures (e.g. stabilizing innovation offices), processes (e.g. agile procurement) and frameworks (e.g. sandboxes) to improve public service design and delivery. The impact of new redesigns can arguably be more transformative than the simple migration of existing procedures onto new platforms, such as cloud computing or blockchain, but without any notable change to the service itself.

4. Public sector innovation is transforming the role of government

As the world becomes more volatile, uncertain, complex and ambiguous, the role of government is becoming more of an enabler and less of a singular unit. None of the approaches or case studies mentioned in this chapter were built in isolation; they required strong industry partnerships or buy-in from citizens. Government's role may be voicing public policy problems, providing funding and creating platforms that enable industry and civil society to address them. Cities are increasingly at the heart of public service innovation. China's cities are spearheading vast changes; the Republic of Korea has seen Seoul take the lead on many projects; Japanese network innovation was mostly reliant on cities; and Singapore is able to quickly adapt precisely because it is a city-State. Further, innovation is now permeating the whole of government. Once, innovation was treated with caution in politics, but it is now the new normal. The greatest innovation is government's transition to be a dynamic force that embraces change, adopts new approaches and engages as many outside voices as possible. The solution, it seems, is clear: state the problem and then seek help from as many sources as possible.

Conclusions of the report

STI policies have been fundamental in enabling the socioeconomic transformation of China, Japan, the Republic of Korea and Singapore. As these countries have made rapid advances in their science, technology and innovation capabilities, their STI policies have also evolved both in terms of their objectives and of the policy instruments used to achieve them. These countries are now at the forefront of various technology and innovation domains, driving the development of frontier technologies and adopting them to improve public service delivery.

This section contains a summary of the key findings regarding the historical evolution of STI policies and the current adoption of policies related to frontier technologies and public sector innovation in China, Japan, the Republic of Korea and Singapore. It also contains reflections on how the linkages between STI policies and the 2030 Agenda for Sustainable Development can be further strengthened. The section is concluded with some suggestions on opportunities for regional learning and collaboration.

A. Key findings on the past and present evolution of science, technology and innovation policies in China, Japan, the Republic of Korea and Singapore

The analysis of the past and current evolution of STI policies in the four countries provides four key findings.

1. Different paths but common sequencing of science, technology and innovation policy

While the evolution of science, technology and innovation policies in China, Japan, the Republic of Korea and Singapore has followed divergent paths, employed different instruments and occurred over different time frames, they have common themes. All four countries first focused on facilitating technology transfer and diffusion and on building human resources in science and technology. Subsequently, or in the case of China concomitantly, they supported the development of domestic research capabilities.

2. Science, technology and innovation policy is increasingly mainstreamed and broadened

The scope and objectives of science, technology and innovation policy have been gradually broadened. The earlier focus on science and technology was almost exclusively on supporting industrial development and economic growth objectives. Now social and environmental objectives for inclusive and sustainable growth have been incorporated into them.

Since the 1990s, the mandate of science and technology policy was broadened to include innovation objectives. To support innovation, STI policy was broadened, mainstreamed and started being made a central component of

national development policies.

3. The development of policies and capacities for frontier technologies has become a priority

All four countries are at the forefront of developments in one or several domains of frontier technology. The Governments of the four countries have prioritized frontier technology development as a policy objective and have developed specific policies and support mechanisms to facilitate developments in frontier technology. Governments have identified frontier technologies as crucial to continued economic growth by providing their economies with enhanced productive capacities, as well as addressing some of their pressing social and environmental challenges, such as population ageing and environmental pollution.

The efforts have been focused on leveraging existing technological strengths, investing in building digital infrastructure and R&D, incentivizing private sector firms and creating an enabling environment for them. To effectuate these efforts, Governments have invested in developing capacities in the public and private sectors, including expanding the innovation ecosystem, and in enhancing collaboration between the Government, private sector, academia and civil society.

4. Public sector innovation is encouraged through diverse approaches

Public sector innovation is an important tool to enhance public service delivery and to support the development of technological and innovation capabilities and markets.

The four countries have leveraged their existing strengths to maximize the impact of public sector innovation. For example, China is using its strong technology sector while Singapore is leveraging its small size and operational efficiency to pilot and operationalize ambitious public sector innovations.

The public sector in these four countries has adopted and promoted new technologies to innovate, they they have also fostered innovation beyond merely adopting new technologies. Their governments have also integrated innovation in their public administration more broadly, such as in managing human resources (e.g. establishing innovation offices in Singapore's administration) or new regulatory frameworks (e.g. sandboxes).

B. Science, technology and innovation policies and the 2030 Agenda for Sustainable Development

The report also indicates that there are multiple linkages between STI policies and the 2030 Agenda for Sustainable Development, yet there is scope to strengthen those linkages by:

1. Mainstreaming sustainability and inclusivity goals into science, technology and innovation policy

The initial objectives of STI policy in the four countries were economic growth and building industrial capacity. As the countries developed, their objectives were broadened to include social concerns (e.g. addressing rural poverty through STI policy) and environmental considerations (e.g. tackling pollution through STI policy). Currently, all four countries have plans although to varying degrees on leveraging STI policy for inclusive and sustainable development. This situation represents a shift towards mainstreaming Sustainable Development Goals into STI policies, although there remain much more potential for greater integration.

2. Further leveraging frontier technologies for sustainable development

All four countries demonstrate high readiness in one or several domains of frontier technology and see opportunities to increase productivity and develop new markets. Frontier technologies have also been used to improve public sector service delivery, education and health-care services. Singapore, for example, is using frontier technologies to improve government service provision through its Smart Nation initiatives. There are also examples on how frontier technologies provide opportunities to address social challenges. However, there is scope for policies to further encourage linking frontier technologies to harness these social and environmental opportunities.

On the other hand, the Governments of all four countries have made efforts to mitigate the risks that frontier technologies pose to the achievement of the Sustainable Development Goals. They have strengthened public sector understanding of and capacity on frontier technologies across various ministries, including through coordination mechanisms, and have initiated policies to mitigate the risks posed by the changing nature of work.

3. Adopting innovations in the public sector to further support sustainable development

Governments can tailor public sector innovation to help further the 2030 Agenda for Sustainable Development through different avenues. First, they can do so by adopting a public sector innovation agenda that establishes inclusive and sustainable objectives. Second, they can improve public data availability and quality to enable tracking and achieving progress towards the attainment of the Sustainable Development Goals. Accurate, comprehensive and timely data sets can improve decision-making and service delivery and ensure better evaluation of policies and programmes. Third, they can do so by carefully addressing the trade-offs posed by technology. The use of big data, for instance, requires a careful balance between achieving efficiency and ensuring privacy. Fourth, governments can innovate in the manner they prioritize, design and deliver public services through, for example, adopting participatory governance approaches, fostering partnerships with a broad spectrum of stakeholders from the private to the civil society sectors and conceiving public services differently through design-thinking or the integration of behavioural insights.

C. Opportunities for regional learning, cooperation and common action

This report offers decision makers in the Asia-Pacific region and beyond important knowledge from some of the most advanced economies in the region. However, policy formulation requires further contextualization. The policies adopted by China or any of the other country featured in this report will not necessarily work in another setting. Countries are at different stages of development, face varied socioeconomic challenges and have different assets and technological capabilities. Yet, these cases offer understanding regarding the sequencing of STI policy objectives, policy trade-offs and the range of policy instruments that can be considered to spur innovation.

Opportunities for mutual learning and contextualization can be further encouraged and are particularly valuable in the newer policy arenas of frontier technologies and public sector innovation. In this context, regional cooperation to exchange knowledge in new STI policy arenas will be precious.

Two areas are suggested in this report that may benefit from further exploration and discussion among member States in the Asia-Pacific region.

The first area involves building a greater understanding on how the Sustainable Development Goals can be fully mainstreamed into STI policies: in particular, how STI policies can be designed to leave no one behind; the type of policies that can encourage greater use of frontier technologies for social good and environmental sustainability; and the role of public sector innovation in promoting more inclusive societies.

The second area is concerned with developing a greater common understanding of and response to the trade-offs between privacy and access to data and to managing the risks posed by frontier technologies, including the changing nature of work.

Finally, two areas are identified in the report that may benefit from further intergovernmental discussion and the development of common frameworks among member States in the Asia-Pacific region. The first area concerns addressing the risks of frontier technologies in terms of ethics, data privacy and cybersecurity. The second area involves building a road map for STI policies to support the Sustainable Development Goals.

ESCAP is supporting member States in the Asia-Pacific region in several of these areas. It regularly facilitates intergovernmental dialogues, and its Committee on Information and Communications Technology and Science, Technology and Innovation explores frontier technology policy issues and the promotion of more inclusive innovation policies. ESCAP also conducts research and analysis, publishing reports on frontier technology issues and policy developments in the Asia-Pacific region and analysis on inclusive innovation policies. Through the work of the Asia-Pacific Research and Training Network on Trade on STI policies (ARTNET on STI Policy),[330] ESCAP supports research and training for decision makers in critical policy areas: for example, on making strategic decisions regarding the financing of R&D in frontier technologies, or, together with other partners,[331] on policies that can encourage AI for social good. ESCAP also provides Governments with advisory services in a diverse range of STI policy areas, including inclusive innovation policies and frontier technologies.

Annex

Table A. 1. Frontier technology-related policies and policy objectives, China

Frontier technology	Policy, strategy, plan	Objectives
Smart manufacturing: Made in China 2025	• Action Plan on Implementing the Guiding Opinions of the State Council on Promoting "Internet Plus" (2015-2018)	• Develop a new economic model and facilitate industrial innovations and e-commerce through integrating cyberphysical systems, cloud computing and big data with traditional manufacturing industries
	• Intelligent Manufacturing Development Strategy (2016-2020)	• Upgrade key areas of traditional manufacturing to digital manufacturing • Implement key tasks (setting up intelligent manufacturing standards, establishing industrial Internet and information security systems, and developing industrial software)
	• Development Plan for the Robotics Industry (2016-2020).	• Increase annual production of industrial robots, enhance product functionality and quality to international standards and achieve breakthroughs in critical robot components • Apply service robots to home services, rehabilitation, rescue and public safety
Smart cities	• Notice on Carrying Out National Pilot Smart Cities	• Utilize modern science and technology, and integrate various information resources to improve urban planning, construction and management
	• Interim Measures for the Administration of National Smart Cities	• Set out criteria for cities to apply for becoming pilot smart cities
	• Pilot Index System for National Smart Cities	• Sets up indexes to measure the performance of smart cities
Big data	• Planning Outline for the Construction of a Social Credit System (2014-2020)	• Improve government integrity, the credibility of the judicial system and the trustworthiness of companies and citizens through the establishment of a social credit system
Artificial intelligence	• "Internet Plus" Artificial Intelligence Three-year Action Implementation Plan (May 2016)	• Develop emerging AI industries and create a market worth more than $15.7 billion by 2018 through supporting: platforms for AI resources; innovation in intelligent products; their applications into homes, vehicles and unmanned systems; and deeper integration of AI and robotics
	• New Generation of Artificial Intelligence Development Plan (July 2017)	• Bring AI technology and applications up to global standards by 2020; achieve major breakthroughs in AI theory by 2025; and reach a global leading position in AI theory, technology and application by 2030
	• Three-year Action Plan to Promote the Development of New Generation Artificial Intelligence Industry (2018-2020)	• Support high-end AI products, speed up the industrialization of AI and widen the application of AI
	• AI Standardization White Paper (January 2018)	• Establish a unified and comprehensive set of standardizations

Frontier technology	Policy, strategy, plan	Objectives
Blockchain technology	• Blockchain Technology and Application Development White Paper (2016)	• Identify potential blockchain applications • Support the development and enforcement of blockchain standards
	• Key Points on Informatization and Software Standardization (2018)	• Set up a national technical standardization committee for blockchain and participate in relevant international standardization activities
Intelligent Vehicles	• Intelligent Vehicle Innovation and Development Strategy (January 2018) (in draft stage)	• Adopt an open and inclusive approach to support intelligent vehicle innovation • Establish a national leading group for innovation and development of intelligent vehicle • Improve intelligent vehicle-related regulations and standards to remove market access obstacles • Establish an intelligent vehicle security management system • Protect personal safety and privacy

Source: Ministry of Housing and Urban Rural Development, The Notice on Carrying Out National Pilot Smart Cities (in Chinese) (2012); The State Council, State Council Notice Concerning Issuance of the Planning Outline for the Construction of a Social Credit System (2014-2020) (in Chinese) (2014); Ministry of Industry and Information Technology, The Action Plan on Implementing "The Guiding Opinions of the State Council on Promoting 'Internet Plus'" (2015-2018) (in Chinese) (2015); Ministry of Industry and Information Technology, The Blockchain Technology and Application Development Whitepaper (in Chinese) (2016); National Development and Reform Commission, The Development Plan for the Robotics Industry (2016-2020) (in Chinese) (2016); Ministry of Industry and Information Technology and Ministry of Finance, Intelligent Manufacturing Project Implementation Guideline (2016-2020) (in Chinese) (2016); National Development and Reform Commission, the Ministry of Science and Technology, the Ministry of Industry and Information Technology and the Cyberspace Administration of China, The "Internet Plus" Artificial Intelligence Three-Year Action Implementation Plan (in Chinese) (2016); Ministry of Industry and Information Technology, The Three-Year Action Plan to Promote the Development of New-Generation Artificial Intelligence Industry (2018-2020) (in Chinese) (2017); Ministry of Industry and Information Technology, Interpreting the Three-Year Action Plan to Promote the Development of New-Generation Artificial Intelligence Industry (2018-2020) (in Chinese) (2017); The State Council, Notice of the State Council Issuing the New Generation of Artificial Intelligence Development Plan (in Chinese) (2017); The National Standardization Management Committee, The AI Standardization White Paper (in Chinese) (2018); Ministry of Industry and Information Technology, Key Points on Informatization and Software Standardization 2018 (in Chinese) (2018); National Development and Reform Commission, Strategy for Innovation and Development of Intelligent Vehicles (in Chinese) (2018).

Table A. 2. Frontier technology-related policies and policy objectives, Japan

Policy, strategy, plan	Objectives
Fifth Science and Technology Basic Plan (2016-2020)	• Support super smart society (or Society 5.0) • Develop 11 systems: optimizing the energy value chain; building a global environment information platform; maintaining and upgrading of an efficient and effective infrastructure; attaining a resilient society against natural disasters; creating intelligent transport systems; developing new manufacturing systems; building integrated material development systems; promoting integrated community care systems; developing hospitality systems; creating smart food chain systems; and constructing smart production systems
Comprehensive Strategy on Science, Technology and Innovation (2016) (annual identification of priority initiatives under the Fifth Science and Technology Basic Plan)	• Develop databases as a foundation for the creation of new value and services • Promote data utilization • Promote intellectual property strategies and international standardization • Promote regulatory and institutional reforms and cultivate social acceptance • Promote capacity development and personal training
Facilitate the fourth industrial revolution (2016)	• Establish a public-private council to lead the fourth industrial revolution • Implement regulatory reforms to simplify administrative procedures and utilize information technology • Promote business streamlining and restructuring of SMEs via the use of data and technologies such as fintech, robots and sensor technologies • Triple the investment from corporations in universities and research institutes by 2025 and establish five world-class R&D centres • Strengthen human resources capacity by providing IT in schools and recruit highly skilled foreign professionals through green card system
Connected Industries Policy (March 2017)	• Identify five priority areas: automated driving and mobility service; biotechnologies and materials; Smart Life; plant/infrastructure safety management; and manufacturing and robotics • Become competitive in global "real data"
Future Vision towards 2030s (May 2017)	• Develop the New Industrial Structure Vision to leverage the Internet of Things, big data, AI and robots to solve problems in the fields of mobility, supply chains, health care and lifestyle • Develop approaches in each field to gain global markets and generate economic growth in the short, medium and long term

Source: Cabinet Office, Society 5.0 (2014); Ministry of Foreign Affairs of Japan, 2016 Growth Strategy Japan (2016); Prime Minister of Japan and His Cabinet, Japan Revitalization Strategy 2016 (2016) and "Growth Strategy 2016" toward Nominal GDP 600 Trillion Yen (2016); Ministry of Economy, Trade and Industry, Overview of the Concept Framework "Connected Industries" and Connected Industries' Tokyo Initiative 2017 (2017).

Table A. 3. Frontier technology-related policy and policy objectives, the Republic of Korea

Frontier technology	Policy, strategy, plan	Objectives
Fourth industrial revolution	• People-centred Plan for the Fourth Industrial Revolution to Promote Innovative Growth (I-Korea 4.0)	• Improvement of people's quality of life through solving social and environmental challenges through the fourth industrial revolution • Sustain economic growth through creation of new industries • Prepare for future social changes associated with the fourth industrial revolution, including skills development and social protection
Intelligent robots	• First master plan (2009-2013)	• Nurture the robotics market through infrastructure building, production development and promotion
	• Second master plan (2014-2018)	• Expand the robotics industry into other manufacturing and service sectors, integrate advancements in robotics technology and facilitate robot network convergence
	• Third master plan (2019-2024)	• Expand public demand for robots through the use of more service robots in the public sector and the development of smart factories • Strengthen suppliers' capacity by building 10-15 advanced robot commercialization research centres, AI/ICT convergence centres and humanoid robot research centres
	• Intelligent Robot Industry Development Strategy (2018)	• To further expand the robotics industry through: - Boosting industry sales to $6.21 billion by 2022 through an Intelligent Robot Industry Development Acceleration Strategy - Promoting collaborative robots in manufacturing with industry, academic and research institutions - Developing AI platforms for robots with telecom companies, robot manufacturers and research institutions
Smart manufacturing	• Manufacturing Industry Innovation 3.0 strategy (2014)	• Promote smart factories through: - Creation of new manufacturing featuring industrial convergence - Enhancement of the major segments - Advancement of industrial infrastructure for innovation - Set up 10,000 smart factories by 2020 to facilitate convergence between software and hardware technologies with an investment of $972 million
Advanced IT and AI	• Plan for the Advancement • of the Intelligent IT • Industries (2016)	
	• Mid- to Long-term Master Plan in Preparation for the Intelligent Information Society (2016)	• Establish a world-class infrastructure for intelligent IT • Promote the application of intelligent IT to all industries • Reform and strengthen the social support system (e.g. welfare services) to ensure that citizens can enjoy the benefits of the intelligent information society
	• Intelligence Information Society Fourth Industrial Revolution Medium- to Long-term Comprehensive Response Plan (2016)	• Create new value for data resources • Invest in R&D in intelligent IT • Develop key AI technologies
Internet of Things	• Master Plan for Building the Internet of Things (2014)	• Foster the development and use Internet of Things services through: - Developing an open platform for Internet of Things in collaboration with the private sector - Promoting open innovation - Developing and expanding products and services through collaboration with global businesses - Developing customized strategies for start-ups, SMEs and large businesses

Frontier technology	Policy, strategy, plan	Objectives
Internet of Things	• Internet of Things Information Security Road Map (2014)	• To guide government actions in developing cybersecurity standards and best practices • Prescribes - That security would be embedded in seven Internet of Things application categories - That the Secure Dome project would develop nine core security technologies aligned with Internet of Things characteristics - Internet of Things convergence security, proof-of-concept projects
	• Three-year Execution Plan for Internet of Things Information Protection Road Map (June 2015)	
	• K-ICT Strategy (2015)	• Includes Internet of Things-related objectives, such as: • Establishing large-sized IoT test complex (healthcare, smart city) • Developing the "sensor industry" • Cultivating domestic IoT start-ups and ventures to become global enterprises
Fintech	• IT-Finance Convergence Support Plan (2015)	• Reorganize the offline-centred financial systems • Support the growth of fintech
Cloud computing	• Information Protection Measures for Vitalization of Cloud Services (2015)	• To enhance user protection and credibility of cloud computing services
	• K-ICT Cloud Computing Development Plan (2016-2018)	• To build momentum for the growth of the cloud industry by identifying three strategies and nine tasks
	• 2017 K-ICT Cloud Computing Support Plans	• To implement cloud computing in the public sector
Others	• 2016 Future Growth Engine Action Plan	• To develop smart cars and 5G mobile communications through different investment plans
Smart and open Government	• Smart Government Implementation Plan (2011-2015)	• To provide personalized and integrated services for people anytime and anywhere through the use of smart technologies (e.g. smart phones and cloud computing)
	• "Government 3.0" policy (June 2013)	• To promote a more transparent, competent and people-oriented Government through opening and sharing government-owned data with the public
	• Open Data Master Policy Plan (2013-2017)	• To open up public data and build an open data ecosystem

Source: The Government of the Republic of Korea and Presidential Committee on the Fourth Industrial Revolution, People-Centered "Plan for the Fourth Industrial Revolution" to Promote Innovative Growth I-Korea 4.0 (2018); Ministry of Trade, Industry and Energy, Development of a Fully Fledged Robotics The Industry through Convergence with Other Industries (2014); Jonny Kim, New and Emerging Trends in Korea's Robot Industry, Korea Trade-Investment Promotion Agency (2017); Government of the Republic of Korea Interdepartmental Exercise, Mid- to Long-term Master Plan in Preparation for the Intelligent Information Society: Managing the Fourth Industrial Revolution (2016); Ministry of Science, ICT and Future Planning, Master Plan for Building the Internet of Things (IoT) (2014); Joshua New and Daniel Castro, Why Countries Need National Strategies for the Internet of Things (2015); Korea Internet and Security Agency, 2015 Korea Internet White Paper (2015), 2016 Korea Internet White Paper (2016), and 2017 Korea Internet White Paper (2017); Ministry of Public Administration and Security, Smart Government Implementation Plan (2011-2015) (2011); Ministry of the Interior and Safety, Government 3.0 (n.d.); Open Government Partnership, Republic of Korea National Action Plan on Open Government Partnership (2014).

Table A. 4. Frontier technology-related policy and policy objectives, Singapore

Policy	Objectives
Intelligent Nation (iN2015) Masterplan (2005)	• To adopt a 10-year plan for smart city development in Singapore • To transform Singapore's economy, Government and society and develop a globally competitive infocomm industry through ICT
Smart Nation initiatives (2014)	• To harness digital technologies to improve living, create more job opportunities, foster innovation and growth and build a stronger community • Five key strategic national projects were identified: - National Digital Identity framework - e-Payments - Smart Nation Sensor Platform to deploy sensors - Smart Urban Mobility to improve public transport through autonomous vehicles - Moment of Life to provide citizens with seamless public services around key moments of life (e.g. birth and marriage)
Infocomm Media 2025 (2015)[a]	• To guide the development of infocomm media (ICM) over the next decade • Identified three strategic thrusts: - Data, advanced communications and computational technologies - Nurture an ICM ecosystem to develop Singapore-made products - Connect people through ICM • Priority development was given to six technology areas: big data and analytics; Internet of Things; future comms; cybersecurity; cognitive computing/advanced robotics; and immersive infocomm media
Infocomm Media Industry Transformation Map (2017)	• To develop the digital economy through: - Building capabilities in four frontier technologies (i.e. AI and data analytics, Internet of Things, immersive media and cybersecurity) - Strengthening the core of the ICM sector - Guiding SMEs and the workforce to adopt digital technologies to improve efficiency and productivity
Research, Innovation and Enterprise 2020	• To grow industry R&D and innovation capabilities and their innovative capacities by prioritizing public funding in: - Advanced manufacturing and engineering - Health and biomedical sciences - Urban solutions and sustainability (e.g. self-driving vehicles) - Services and digital economy (e.g. autonomous technologies, real time analytics, Internet of Things health-care devices and data mining)
National Cyber Security Masterplan 2018	• To foster a secure and resilient national infocomm environment through: • Enhancing the security of critical infrastructure • Adopting security measures among businesses and individuals • Growing Singapore's pool of infocomm security experts

Source: Infocomm Development Authority of Singapore, Innovation. Integration. Internationalisation. Report by the iN2015 Steering Committee (2006); Infocomm Development Authority of Singapore, National Cyberscurity Masterplan 2018 (2013); Central Policy Unit, Research Report on Smart City (2015); Ministry of Communications and Information, Infocomm Media 2025 (2015); Research, Innovation and Enterprise Secretariat, Research, Innovation and Enterprise 2020 (2016); Infocomm Media Development Authority, Infocomm Media Industry Transformation Map (2017); Smart Nation and Digital Government Office, Smart Nation (2018).

[a]) Singapore's Infocomm Media refers to the ICT sector, telecommunications and media.

Table A. 5. New institutions to carry out fourth industrial revolution initiatives, Japan

Institution	Mandate
Public-Private Council for the Fourth Industrial Revolution (Established in 2016)	• Established under the Headquarters for Japan's Economic Revitalization within the Cabinet • Established to serve as a command centre to undertake reform • Oversees: - Robot Revolution Realization Council - Strategic Council for AI Technology - Council for Promotion of Human Resources Development to Respond to the Fourth Industrial Revolution • Responsible for: - Identifying priority areas and formulating strategies for each priority area - Accelerating regulatory reforms - R&D - Provision of funds - Human resource development
Robot Revolution Realization Council (Established in 2014)	• Established in the Prime Minister's Office • Charged with formulating the New Robot Strategy (a five-year action plan to broaden robot utilization by 2020)
Strategic Council for AI Technology (Established in April 2016)	• Established under the direction of the Prime Minister • Promote R&D in AI technology • Manage five national research and development agencies • Coordinate with industries that utilize AI • Develop a road-map for the development and commercialization of AI
Advisory Board on Artificial Intelligence and Human Society (Established in May 2016)	• Established under the initiative of the Minister of State for Science and Technology Policy • To examine ethical, legal and social issues associated with developing and deploying AI technologies and how these issues can be resolved • Consists of members from different professional backgrounds (economics, engineering, law, philosophy and social sciences)

Source: The Headquarters for Japan's Economic Revitalization, New Robot Strategy (2015); Prime Minister of Japan and His Cabinet, "Growth Strategy 2016" toward Nominal GDP 600 Trillion Yen (2016); Strategic Council for AI Technology, Artificial Intelligence Technology Strategy (2017); Center for Data Innovation, How Governments Are Preparing for Artificial Intelligence (2017), Advisory Board on Artificial Intelligence and Human Society, Report on Artificial Intelligence and Human Society (2017)

Table A. 6. Private sector initiatives in frontier technology development, Japan

Company	Actions
Toyota Motor Corporation	- Established in 2016, the Toyota Research Institute in Silicon Valley is set up to conduct research in frontier technologies - Collaborates with world-class universities (e.g. MIT, Stanford and the University of Michigan) to accelerate AI research and innovation - Established in March 2018, together with two Japanese auto parts suppliers, the Toyota Research Institute-Advanced Development in Tokyo develops fully integrated, production-quality software for automated driving
Honda Motor Company Ltd.	- Founded Honda Innovation Lab Toyko in 2016 to strengthen its R&D for AI technology - Founded R&D Center X in 2017 to conduct R&D in robot technology, mobility systems and energy management
Hitachi Ltd.	- Established in 2016, the Hitachi University of Tokyo Laboratory conducts research in a broad range of fields related to the Society 5.0. vision
Mitsubishi Electric Corporation	- In 2017, the firm spent $1.94 billion to conduct R&D in AI, smart mobility, automated vehicle navigation systems, networked smart appliances at home and the world's first 5G base stations
Dwango Co., Ltd.	- Founded Dwango Artificial Intelligence Laboratory to develop deep learning technologies and "advance research on cognitive architectures for integrating multiple machine learning devices"
Recruit Holdings Co., Ltd.	- Restructured the Recruit Institute of Technology in April 2015 as an AI research centre to realize global open innovation through collaboration with Israeli and United States AI startups

Source: Recruit Holdings, Recruit Restructures Recruit Institute of Technology as Artificial Intelligence Research Laboratory (2015) available at: https://recruit-holdings.com/news_data/release/pdf/20150415_02.pdf
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Table A. 7. Frontier technology-related education and training programmes, Singapore

Education and training programmes	Objectives and financial incentives
Massive Open Online Course in data sciences	Organized by the Infocomm Development Authority Offered to 350 local employees who worked in health-care, education, finance and IT sectors in 2014 An 80 per cent subsidy on the $613 fee and a $500 bonus were given to participants who completed this 10-module course
Specific courses and training on data science	Offered by the Singapore Data Science Consortium to address the current shortage and demand of experts in data science Starting from 2017, 10,000 civil servants will receive data science training offered by the National University of Singapore over the next five years
Fintech training sessions and networking activities	Provided by the FinTech Innovation Lab established by the Monetary Authority of Singapore for the fintech community
New Skills Future Series (October 2017)	Training programmes in eight priority and emerging skills areas (data analytics, advanced manufacturing and cybersecurity) to upskill existing employees Up to 70 per cent course fee subsidy for Singapore citizens and permanent residents
Tech Skills Accelerator (TeSA)	In FY 2018, the Government will invest additional $145 million to create an additional 20,000 training places by 2020 to support employees' skills development in frontier technology
AI Apprenticeship Programme (AIAP)	Starting in April 2018, the programme provides full-time training to recent university graduates with three months of AI coursework and six months of on-the-job training Apprentices receive a monthly stipend of $2000 to $3500 during the training period

Source: Grade Chng, 'IDA Dangles $500 Bonus for 350 Attending Online Course', Straits Times (10 August 2014). Available at https://www.straitstimes.com/singapore/ida-dangles-500-bonus-for-350-attending-online-course.
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