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THE ROLE OF SCIENCE, TECHNOLOGY, AND INNOVATION POLICIES IN THE INDUSTRIALIZATION OF DEVELOPING COUNTRIES

Lessons from East Asian Countries

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The Role of Science, Technology and Innovation Policies in the Industrialization of Developing Countries

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Abbreviations

ADB	Asian Development Bank
AHRDP	Automotive Human Resource Development Programme
AI	Artificial intelligence
APEC	Asia-Pacific Economic Cooperation
ASEAN	Association of Southeast Asian Nations
BIOTEC	National Center for Genetic Engineering and Biotechnology
BOI	Board of Investment
BUILD	BOI Unit for Industrial Linkage Development
CAS	Chinese Academy of Sciences
CDM	Clean Development Mechanism
CDMA	Code division multiple access
CIP	Competitive Industrial Performance Index (CIP)
CLMV	Cambodia, Laos, Myanmar and Vietnam
CPC	Communist Party of China
CPCCC	Chinese People's Political Consultative Conference
DIP	Department of Industrial Promotion
EEC	Eastern Economic Corridor
EOI	Export-oriented industrialization
EPB	Economic Planning Board
FDI	Foreign direct investment
FL	Foreign licensing
FYP	Five-Year Plan
GHG	Greenhouse gas
GPNs	Global production networks
GPTs	General purpose technologies
GRI	Government-funded research institute
GVCs	Global value chains
HAN	Project Highly Advanced National (HAN) Project
HDD	Hard disk drive
HDDI	Hard Disk Drive Institute
IBRD	International Bank for Reconstruction and Development
IJV	International joint venture
IoT	Internet of Things
IPR	Intellectual property rights
ISI	Import substitution industrialization
ITAP	Industrial technology assistance programme
JICA	Japan International Cooperation Agency
KAIST	Korea Advanced Institute of Science and Technology
KIST	Korea Institute of Science and Technology
KITA	Korea International Trade Association
KOSEF	Korea Science and Engineering Foundation
LCRs	Local content requirements
LDCs	Least developed countries
M&As	Mergers and acquisitions
MHESI	Ministry of Higher Education, Science, Research and Innovation
MNCs	Multinational companies
MOI	Ministry of Industry
MOST	Ministry of Science and Technology
MOSTE	Ministry of Science, Technology and Energy
MTEC	National Center for Metals and Materials Technology
NECTEC	National Electronics and Computer Technology Center
NEDP	National Economic Development Plan
NESDB	National Economic and Social Development Board
NESDP	National Economic and Social Development Plan
NEV	New electric vehicle
NIEs	Newly industrialized economies
NISTEP	National Institute of Science and Technology Policy
NRCT	National Research Council of Thailand
NRF	National Research Foundation of Korea

NSDP	National Supplier Development Programme
NSTC	National Science and Technology Council
NSTC	National Science and Technology Policy Committee
NSTDA	National Science and Technology Development Agency
NTRM	National Technology Road Map
NXPO	Office of National Higher Education Science Research and Innovation Policy
ODM	Original design manufacturing
OECD	Organisation for Economic Co-operation and Development
OEM	Original equipment manufacturing
R&D	Research and development
RoK	Republic of Korea
SMEs	Small and medium-sized enterprises
SOEs	State-owned enterprises
S&T	Science and technology
STDB	Science and Technology Development Board
STEPI	Science and Technology Policy Institute
STI	Office National Science Technology and Innovation Policy Office
STI	Science, technology and innovation
TAI	Thailand Automotive Institute
TISTR	Thailand Institute of Scientific and Technological Research
TPP	Technology Promotion Plan
UNCTAD	United Nations Conference on Trade and Development
UNFCCC	United Nations Framework Convention on Climate Change
UNIDO	United Nations Industrial Development Organization
WIPO	World Intellectual Property Organization
WTO	World Trade Organization

Summary

Technological change is well understood as a major determinant of industrial development and economic growth (Kim 1991; Kim and Dahlman 1992; Nelson and Winter 1982; UNIDO 2015). Industrial development is understood as a process of upgrading technological capabilities, resulting in increased productivity and the upgrading and diversification of industrial activities, thereby improving industrial competitiveness. Technological capabilities are generally defined as the ability to create, absorb and mobilize knowledge and develop new technologies as part of the production and industrial innovation processes. However, due to so-called "market failure"—originating from knowledge as public goods—and "system failure"—a lack of interactions among actors with the tacit nature of knowledge—these capabilities cannot be sufficiently nurtured without proper coordinating activities, which justify policy intervention by governments in both developed and developing countries.

From developing countries' perspective, the inherent problem is not just about the sub-optimal level of research and development (R&D) as the traditional market failure approach indicates, nor the inefficiency of R&D and other innovation activities as the system failure approach does. It is about the lack of both innovation capabilities and learning opportunities available for developing countries, as the "capability failure" approach contends (Lee 2014). This observation suggests the importance of leveraging the experiences of developing countries that have successfully industrialized in order to identify possible mechanisms to create and promote policy learning, thereby informing areas where governments in latecomer developing countries may wish to intervene—through appropriate industrial policies to systemically tackle gaps in technological capability accumulation.

However, as documented in this report, learning mechanisms and industrialization opportunities for developing countries change over time, as do the drivers of industrial development. This is evident from the early successful industrialization experiences of Germany and the United States to industrialize, or catch up with, the United Kingdom

in the 19th century. To a large extent, the success of both countries occurred thanks to their ability to enter markets with new technologies, products and economies of scale. In the 20th century, "late" industrialization by East Asian countries was characterized by the "learning of borrowed technologies" with "the absence of new technology" (Amsden 1991, p. 283). Therefore, careful consideration should be granted to the specific strategies adopted by East Asian countries in the last century that may be applicable to the industrialization efforts of currently developing countries, particularly at times when new technological, economic and social challenges—such as digital transformation, climate change and inequality—are emerging. This new set of enabling conditions makes the current group of developing countries confront "twin challenges" in pursuing industrial and economic development while addressing and incorporating the issues of inclusiveness and sustainability.

Digital transformation is strongly connected to inclusive aspects of industrialization. It draws attention to issues of economic and technological divides, as well as job replacement by hardware or software in both developed and developing countries. It also links industrial catch-up by developing countries to considerations around so-called "digital divides" and, accordingly, "development divides", due to unequal accessibility and affordability, skills and literacy for using digital technologies as well as outcomes and values thereof (Scheerder et al. 2017; van Dijk 2020). Does digital transformation merely enlarge the gap of technological capabilities between developed and developing countries, deteriorating the industrializing efforts of developing countries? Or does it provide new windows of opportunity for developing countries to pursue industrialization? Although we have been witnessing some empirical cases of both opportunities and imbalances, it may be too early to tell which will dominate and how they will eventually unfold in full scale. Nevertheless, it is imperative to closely monitor and analyse the phenomenon, examining its implications for developing countries' industrial development.

Climate change poses tremendous environmental risk to the lives of human beings as well as the prospects for achieving sustainable development. It is now widely accepted as a global trend that shapes an exogenous socio-technical landscape for industrialization, significantly destabilizing the current socio-technical regime and pressuring a transition to a more sustainable one (Geels 2002). As the global community recognizes climate change as an urgent and imperative matter, both developed and developing countries should pursue more sustainable and resilient development. From this perspective, addressing climate change introduces the notion of directionality in industrial and economic development; in other words, it may add additional challenges to the industrial upgrading of developing countries. Moreover, inclusive dimensions can be incorporated into addressing sustainable industrial development—particularly in terms of jobs, wages, balanced geographic development, smaller firms, women's rights, etc.

Lastly, inequality has worsened across the world, driven by both global and country-specific factors, in particular, technological progress such as digital transformation. Inequality often leads to the polarization of social and political sides, which is widely regarded as a threat to economic development and growth. Inequality should be alleviated by securing inclusion and sustainability to support healthy economic growth on a national scale.

This report provides empirical evidence based on case studies of three East Asian economies: the Republic of Korea (RoK), the People's Republic of China (China) and Thailand. The course of each country's technology development was carefully analysed, organizing development into distinct stages and focusing on the linkage between demand-side and supply-side policies. The main findings from the country case studies are as follows.

FINDINGS FROM THE ROK

Science, technology and innovation (STI) has played a major part of the RoK's industrial development strategies throughout the country's industrialization.

Technology introduction stage:
Demand-side approach prevailed with STI policies considered as key tools for the implementation of industrial and economic policies. The RoK established STI-related institutions. Newly established government-funded research institutes (GRIs) supported the private sector as contracting intermediaries for sourcing foreign technologies.

Technology internalization stage:
Demand-side approach continued but with more emphasis on STI policies, providing required indigenous technologies to facilitate industrial upgrading. GRIs led national R&D programmes, in collaboration with the private sector as an innovation intermediary, while the government created markets for technologies.

Technology creation stage:
Demand-side approach continued, but the main policy target shifted from large conglomerates to small and medium-sized enterprises (SMEs) and ventures, where market failure is pronounced. GRIs and universities filled the gap of suboptimal R&Ds in basic research.

FINDINGS FROM CHINA

While heavily dependent on trading markets for technology in order to source foreign advanced technologies, China began to nurture indigenous innovation capabilities with a demand-side approach beginning in the early 2000s. From the early 2010s, China positioned itself as an innovation powerhouse based on a strong science and technology (S&T) foundation, competing at the world frontier in new emerging industries.

Technology introduction stage:
Despite the recognition of the importance of STI, STI policies had not been well aligned with the needs of industry. Instead, the Chinese government was heavily dependent on trading markets for technology to absorb foreign advanced technologies, which resulted in minimal success between the 1980s and 1990s.

Technology internalization stage:
STI policies began to be aligned with industrial development strategies, stressing indigenous innovation capabilities, but also in tandem with continuous technology transfer efforts through international joint venture (IJV) arrangements based on foreign direct investment (FDI).

Technology creation stage:
China aims to compete in high-tech and new emerging industries based on its world-class S&T system. Strong university-GRI-industry collaboration is observed, with private companies leading national R&D programmes in new digital sectors.

FINDINGS FROM THAILAND

In general, STI policies in Thailand have not been associated with industrial development strategies in the course of the country's industrialization process. Without indigenous technological capabilities, an investment-led strategy seems to have its limits, keeping Thailand in a "middle-income trap." Since the early 2010s, the R&D inputs in Thailand have taken off, led mainly by the private sector, but the results remain to be confirmed.

Technology introduction stage:
Thai government was dominated by industrial, trade and investment policies with limited interest in STI policies until 1980 when the government began to show interest in STI policies, adopting mainly a supply-side approach.

Technology internalization stage:
Thai government began to recognize the importance of STI as a tool to tackle its structural weaknesses, stressing a demand-side approach at the policy design level. However, STI policy at the implementation level remains fragmented and inefficient.

POLICY IMPLICATIONS

Based on these three country case studies, the following policy implications— in terms of STI policy design and implementation—are relevant for other developing countries in their pursuit of industrial development.

- **Key STI indicators are useful in diagnosing technology development.**
  STI indicators of R&D inputs and outputs were useful for understanding different technology development stages of a developing country.

- **STI policies should be demand-driven.**
  STI policies should be closely aligned with demand-side industrial policies as they are complementary to each other.

- **Investment-led growth has its limits.**
  The Thai case in particular demonstrates the limitations of investment-led growth strategies to sustain a country's industrial development. It has failed to sustain economic growth without indigenous technology development efforts.

- **Utilization of foreign technologies never diminishes.**
  Although indigenous technology development efforts should be at the center of STI policies from the technology internalization stage, utilization of foreign technologies should continue to serve as one of the most important mechanisms to source technologies.

- **A coordinating mechanism of STI policies with the support of high-level leadership is critical.**
  Both the RoK and China have had the full support of high-level leadership; however, while Thailand does have a policy coordinating body, lack of the prime minister's support demonstrates the contrasting outcome.

- **Creating markets facilitates industrial upgrading.**
  A government's intervention in creating markets can facilitate industrial catching-up and leapfrogging. Interventions can reduce technology and market uncertainties of domestic R&D.

The main policy conclusion from our analysis of three East Asian countries' efforts to implement successful STI policies can be summarized by the following three key principles:
(1) demand-driven approach throughout the process of industrial development;
(2) strong commitment to indigenous innovation efforts from technology internalization stage; and
(3) a government's ability to reflect on and adapt to changing environments.

The over-arching theme of these principles is the increasing need for the government's active involvement in its industrial development, although not to the level of a "developmental state" (Amsden 1989; Lall 1992; Chang 1994). Considering the contemporary challenges discussed in this report—digital transformation, climate change and inequality—as well as the conventional challenges of industrial development, it is imperative for developing countries to play a more active role in addressing the "twin challenges" to secure both inclusive and sustainable industrial development.

1. Introduction

This report provides an updated review of literature on industrial and STI policies in the context of developing countries' approaches towards inclusive and sustainable industrial development. The main objective is to document the evolving linkages between industrial policies and STI policies over the course of industrial development in developing countries in East Asia. Section 2 reviews the most recent successful industrialization efforts by East Asian countries in the second half of the twentieth century. It documents how those countries were able to create synergies between industrialization and technological capability-building to tackle windows of opportunity for catching up with already industrialized economies—and frames domestic efforts with those targeted learnings from foreign advanced technologies throughout different stages of the industrialization process.

Section 3 reviews three contemporary challenges that novel approaches to industrial policy must confront, including digital transformation, climate change and inequality. The discussion considers how these three challenges can impact developing countries' inclusive and sustainable industrial development prospects. Against this backdrop, the section discusses conventional as well as changing rationales for industrial and STI policies, in addition to their implications for developing countries.

Section 4 offers an in-depth examination of the experiences of three East Asian countries: Republic of Korea (herein: "RoK"), the People's Republic of China (herein: "China") and Thailand. The section closes with a summary of empirical findings and provides policy implications.

2. Traditional mechanisms of technological learning in developing countries

Industrial development is a process of accumulating technological capabilities (Lee et al. 1988; Kim and Dahlman 1992; Amsden 1989) as primary determinants of structural change, upgrading and industrial competitiveness (Lall 1992; Kim 1999). Technological capabilities enable developing countries to create windows of opportunity to achieve technological and productive catch-up. In this regard, successful industrial policy for developing countries is more than a dichotomous decision on the choices between general (functional or horizontal) and selective (sectoral or vertical) policy measures. Instead, it is a dynamic process of promoting and creating opportunities for technological learnings from advanced economies by implementing a mix of timely policies that are suitable for a specific time and context. Amsden (1991, p. 285) argues:

> *Market forces and the state have divided the labor of disciplining East Asian business. During an industry's import substitution phase, the state has typically been the disciplinarian while during its early export phase, that role has fallen to the market. Then during an industry's "neo-import substitution phase," when subsidizing R&D and shifting into a higher-quality market segment come on the agenda, the state's dominant role resumes-as became evident by the late 1980's in Taiwan, South Korea, Singapore, and even Hong Kong… The disciplinarian of business activity has thus shifted over time, from simply a competitive market structure in the first industrial revolution (by the United Kingdom), to Schumpeterian gales of technological change in the second industrial revolution (by Germany and the United States), to an interaction of market forces and state intervention in late industrialization (by East Asian countries).*

This section begins by discussing the learning mechanisms of developing countries at the early stage of industrialization, based on the transfer of borrowed technologies from advanced foreign countries. These mechanisms are mainly drawn from the success of late industrialization in East Asian countries such as Japan and the RoK during the second half of the twentieth century. We then continue to explore how East Asian countries were able to exploit windows of opportunity for learning from borrowed technologies after the early stage of industrialization, considering incentives and motives for international technology transfer.

2.1 Learning mechanisms of developing countries at the initial stage of industrialization

By transferring matured technologies to developing countries, an advanced firm in a developed country is able "(1) to prolong the life cycle of products that are becoming obsolete in the home market,
(2) to find new, growing markets, and
(3) to ensure its own survival by relocating production segments to developing countries where labor costs are lower" (Kim 1997, p. 223).

Developing countries can take advantage of the international transfer of these borrowed technologies to learn how to upgrade their technological capabilities. In the early stages of industrialization, latecomer firms' learning activities mainly occur not in their laboratories (mainly R&D) but on their shop floors (innovation) using borrowed technologies from advanced economies (Amsden 1989).

In **Table 1**, Kim (1991) provides four categories of technology transfer mechanisms between developed and developing countries based on factors of market mediation and the role of foreign suppliers. Cell 2 identifies learning by using of capital goods imported while Cell 3 lists self-learning through secondary documents or disassembling/reassembling of foreign products. The modes in Cells 1 and 4 have become more important and popular with the emergence and proliferation of global production networks (GPNs) in the form of FDIs and technical assistance through original equipment manufacturer (OEM) and original design manufacturer (ODM) contracts (Hobday 1995a).[1]

Table 1 Modes of foreign technology transfer

Market mediation	Role of foreign suppliers: Active	Role of foreign suppliers: Passive
Market mediated	*Formal mechanisms* (FDI, FL, M&A, turnkey plants, consultancies) **CELL 1**	*Commodity trade* (standard machinery transfer) **CELL 2**
Non-market mediated	*Informal mechanisms* (technical assistance of foreign buyers and vendors through OEM, ODM contracts) **CELL 4**	*Informal mechanisms* (reverse engineering, observation, trade and technical journals, etc.) **CELL 3**

Source: Kim (1991) elaboration based on Fransman (1985).

Note: FDI … foreign direction investment; FL … foreign licensing; M&A … mergers and acquisitions; ODM … original design manufacturer; OEM … original equipment manufacturer.

1 In 1980s, RoK companies benefitted strongly from fierce competition in the US consumer electronics market between US and Japanese companies. Struggling with price competition against Japanese companies, US electronics companies provided RoK companies such as Samsung and LG electronics with ODM contracts, offering full technical support and market guidance to their RoK counterparts. Products manufactured in RoK factories were sold under the US companies' brand in the United States, which was mutually beneficial to both countries.

However, heavy reliance on joint venture arrangements involving FDI from multinational corporations (MNCs) is risky. While FDI may provide additional mechanism of technological learning, developing countries may lose domestic technological capabilities. If MNCs buy domestic companies with R&D capabilities and then centralize the R&D function at headquarters in an industrialized country, firms in developing countries may lose ground on technological learning, and simply provide local production capacity for their parent MNCs.

Technology transfer is not a once-and-for-all affair. Efforts around "internal technology capability-building" from borrowed technologies should be included in order to take full advantage of the foreign technologies transferred (Bell and Pavitt 1993; Rosenberg 1982). Those internal capabilities are needed to understand, adapt and improve transferred technologies, and to make the right, informed decision about candidate foreign technologies that will be acquired at a later stage.

2.2 Windows of opportunity for learning after the initial stage of industrialization

Forerunners in advanced economies are generally eager to transfer their matured technologies to firms in developing countries through various transfer forms as shown in Table 1. However, they may become reluctant to transfer their immature technologies—especially when firms in developing countries start being considered potential competitors in a global market. Still, we argue that opportunities for technological learning through technology transfer from forerunners do exist in firms in developing countries.

Based on Lee's (2014) discussion on three windows of opportunity for latecomers' leapfrogging, and that of Park's (2016) on windows of opportunity for technology transfer, we present four possible "windows of opportunity for technological learning" for developing countries after the early stage of industrialization. Lee (2014) suggests
(1) business downturns in industry cycle and
(2) governments' interventions on institutions and regulations,

while Park (2016) presents
(3) firm heterogeneity of origin and
(4) competition among forerunners as opportunities for leapfrogging.

We exclude here Lee's (2014) discussion on the emergence of a new techno-economic paradigm, which was the main argument of Perez and Soete (1988). While this may create an opportunity for latecomers to invest in a new technology trajectory and for incumbents lock-in to an old technology trajectory, it does not mean that it automatically gives firms in developing countries opportunities for technological learning from forerunner incumbents.

Some industries have innate industry/business cycles (boom and decline) due to a mismatch between market demand and product supply (Mathews 2005; Lee 2019), a phenomenon that is intrinsic to specific industries (Lee 2019). Such industries include flat panel displays, semiconductors, steel industries and so forth, where a substantial amount of preemptive investments is required to meet future demand (Shin 2017). These industries tend to cycle through booms and downturns—and it is the latter that forces comparatively weak forerunners to fall into bankruptcy to become an M&A target, to go to market with cheaper costs, or to participate in the market for knowledge, that is the market for technology transfer. Firms in developing countries, on the other hand, can penetrate a new industry (industry diversification) with lower costs and better access to knowledge.

Government interventions in institutions and regulations can also create learning opportunities for local firms in developing countries. Policies involving local content requirements, joint ventures, standard setting and government operation of intellectual property rights (IPRs) fall into this category. These policies may promote FDI from forerunners that need to secure new markets for continued growth. Examples include the telecommunication equipment industry in China and the RoK (Mu and Lee 2005), the pharmaceutical industry in India (Guennif and Ramani 2012), and, in more recent years, the solar PV and wind turbine industries in China (Lema and Lema 2012; Tan and Mathews 2015; Gandenberger and Strauch 2018). It is important to note that this approach works primarily in countries with large domestic markets so that the government has more negotiating power in sourcing foreign advanced technologies.

Firms' heterogeneous knowledge bases also provide opportunities for technology transfer. There may exist specialized suppliers in advanced economies that are not direct competitors against final producer firms in developing countries. These specialized suppliers can emerge in later stages of the industrial cycle when the market's size is big enough and differentiation of production process can be acquired (Stigler 1951; Rosenberg 1976). Specific industries in advanced economies may encourage partnerships with specialized supplier firms in developing countries. For example, Hyundai Motors, an automobile producer, collaborated with Ricardo, a specialized car engine design company located in the United Kingdom when Hyundai acquired engine design capabilities (Lee et al. 2005). Another example is the partnership between VAI, the Austria-based engineering company in the steel industry, and RoK's POSCO, among the top five steel producers in the world. POSCO successfully commercialized the FINEX (fine iron ore reduction) process based on VAI's embryonic COREX process, which was a proven technological concept but had yet to yield commercial viability until POSCO's involvement.

Some companies in advanced countries may decide to remain in their business despite their new technological capabilities, as these capabilities may bring them new market opportunities. In this case, firms with new technologies require collaboration with neighboring incumbent companies equipped with complementary technological capabilities to prove the commercial feasibility of their own new technologies. Such examples are ample. When US cable TV equipment maker General Instrument (GI) developed digital TV signaling technologies, it chose to cooperate with TV producers rather than expand its business into the digital TV market. GI proved the commercial feasibility of digital TV based on a joint project with Samsung Electronics, a TV producer that successfully mastered GI's digital TV technologies and penetrated the digital TV market (Lee et al. 2005). In addition, small venture companies in advanced economies, which sometimes fail to secure finance until they identify market opportunities, are often interested in partnerships with other incumbents for their survival. When Samsung decided to join the semiconductor industry, it quickly acquired Dynamic Random Access Memory (DRAM) design technologies from a small US company that was struggling at the time and desperately needed infusion of R&D investments (Kim 1997).

Lastly, competition among forerunners can create different windows of opportunity for technology transfer (Soete 1985; Steinmueller 2001). New entrants (venture companies) in advanced economies can provide opportunities for technology transfer to developing countries that are in the early stages of a new industry. It is not uncommon that these technology-based venture companies struggle to maintain sufficient cash flow until the market creation of their technologies is realized and until they are willing to provide their technologies in return for financing. Further, some firms in advanced countries are successful in technology development but not in market competition. These firms are eager to reap their investments in technology development with technology transfer; if not, they may be a target for M&As from firms in developing countries. These are the firms pursuing aggressive strategies to seek required capabilities outside their country boundaries, that is, outward FDI. [2] Examples of M&As abound: Chinese Geely's acquisition of Swedish car maker Volvo, Indian Tata Group's acquisition of Jaguar Land Rover UK, etc.

Another opportunity can be created when there is standard-setting competition among forerunners. They have incentives to attract as many ally companies as possible in order to assure their technologies as a national/indus-

2 Motives of outward FDIs by MNCs include market-seeking, resource-seeking, efficiency-seeking and asset-seeking strategies (Wladimir 2015).

try-dominant standard. In this regard, forerunners provide not only opportunities for technology transfer, but also at relatively lower—or even no—cost. The partnership between ETRI, one of the RoK's GRIs specializing in electronics and telecommunications, and Qualcomm, the US-based mobile communication venture company, together commercialized CDMA (code division multiple access) technology, which was only technically proven in concept at the time of the bilateral partnership and required further R&D for commercialization (Song 1999).

2.3 Indigenous technological capability-building and government intervention

Over the course of industrialization, the need for and importance of indigenous R&D capabilities increases, together with learning, through borrowed technologies. Effective adoption of foreign technologies is conditional on a sufficient level of absorptive capabilities, which can be acquired mainly through indigenous R&D efforts (Bell and Pavitt 1993). And stronger bargaining power during the negotiation of contracts for technology transfer can be leveraged through sufficient local technological capabilities on the technology buyer's side. The importance of domestic technological capabilities becomes more pronounced when developing countries accumulate sufficient technological knowledge and begin to compete against advanced countries in emerging sectors. If the technologies that developing countries require through technology transfer are insufficiently mature in advanced countries, several technology options may compete for a dominant technology in the future—in some industries as a form of technology standard. Hence, it is critical for a government or a company in a developing country[3] to select the right technological trajectory among their technology licensing options, given the resource and capacity constraints to explore all technical options. This risk of technology uncertainty can be resolved, even if only partially, through sufficient technological capabilities to search, evaluate and select the right technology path to further market development—which can be attained only through indigenous R&D efforts. In short, learning through borrowed technologies and indigenous R&D efforts are not mutually exclusive. Developing countries require both for successful industrial upgrading.

By contrast, if the technologies that developing countries require are at the emerging stage of a new industry (in advanced economies), two kinds of uncertainties may engulf developing countries' path to industrialization: technology uncertainty and market uncertainty (Park 2016). How? At the emerging stage, technologies that are expected to be licensed will be very primitive in both technical and commercial terms. Several possible technology trajectories for a new market opportunity generally exist and they compete for each other. A latecomer government or firm faces the risk of choosing between alternative technological paths to guide R&D investments towards becoming technologically competitive at later stages of development. Sometimes those R&D efforts may bear no commercial success even if the chosen technology path is technically competitive or superior (consider Sony's Betamax failure in the home video industry). Even if the hurdle of technological viability is overcome, firms must contend first with market creation and then fierce market competition. This is where government intervention is most appropriate. Governments in developing countries can intervene with policy measures, such as a public-private partnership in an R&D consortium for technology uncertainty or single standard-setting and public procurement for market creation in order to resolve market uncertainty (Lee et al. 2005; Song 1999).

3 This depends on which entity has initiative in driving a new technological trajectory.

2.4 Barriers to international technology transfer

Regarding barriers to transferring technology from advanced to developing countries, Rosenberg (1982, p. 270) contends that:

> *The transfer of industrial technology to less developed countries is inevitable. Indeed, as we have seen, the process has already been going on for about a century and a half, and there is no compelling reason to believe that it will stop … Thus, a historical perspective suggests that the central questions are not whether industrial technologies will be transferred, but rather when it will happen, where it will happen, which technologies will be transferred, how they will be modified in the process, and how rapidly this process will occur.*

In practice, international technology transfer from advanced to developing countries continues to occur, even taking into account the World Trade Organization (WTO) regime as well as strong enforcement of intellectual property rights (IPRs) and trade-related aspects of intellectual property rights (TRIPS) since the 1980s, which mainly constrain government intervention in developing countries. Looking again at Table 1, we can argue that in Cells 2 and 3, it is difficult for forerunners in developed countries to stop latecomers from learning—as, by definition, the role of foreign technology suppliers is absent or weak. By contrast, as shown in Cells 1 and 4, where foreign technology suppliers are more active, the possibility to hinder transfer mechanisms is low. Restrictions on FL, FDI and OEM/ODM contracts will only weaken competitiveness to the detriment of forerunners. Some may argue that the recent increase in techno-nationalism encourages nearshoring or reshoring of the production of global value chains (GVCs). However, Lema et al. (2021) recently reported an intense use of GVCs in the ICT sector, though with some geographical and sectoral differences, such as a small decrease in hardware and a slight increase in the software sector.

3. Contemporary challenges: The role of industrial and STI policies

3.1 Changing rationales for policy intervention

Rationales for both industrial and STI policies have changed over time and differ by country. A traditional argument in favor of them hinges on a government's ability to redirect resources to enhance the competitiveness of a sector or to restructure industries to achieve higher productivity and welfare effects.[4] A policy rationale that has driven this approach is that the government should address market failures, which are particularly significant in developing countries (**Table 2**, Framework 1). According to Roth (2008), efficient markets exist only if the markets are thick, free of congestion and safe. In other words, for an efficient market to exist, there must be a sufficient number of transacting parties (buyers and sellers), an adequate amount of information about transactions (information on which transacting parties are the best possible choice), and mechanisms to protect transactions. Well-functioning institutions are required to enhance the chances that these conditions are put in place, which can be a challenging task for many developing countries.

Recently, the market failures argument for industry policy has faced challenges from multiple quarters. Today's type of industrial policy takes a more comprehensive approach and targets more proactive and transformative goals. In Europe, for example, the "new" approach aims to address horizontal issues over a variety of industries, promote framework conditions and attend to the specific needs of a particular sector altogether (Aiginger 2007). Aiginger calls this form of new industrial policy a "matrix type" because both horizontal policy and complementary, vertical (or sector-specific) policy are offered in a combined way.

The multiple layers of failures in the realm of STI policies has brought concepts of innovation systems into consideration (**Table 2**, Framework 2). Innovation systems were conceptualized to understand performance differences in innovation among different countries, particularly—but not exclusively—between Japan and Western countries (Freeman 1995). The three main components of innovation systems are actors, networks and institutions. Actors include not only firms but also universities, governments and intermediary organizations. Networks include both formal and informal networks, such as R&D collaboration, joint venture informal meetings and others (Edquist 2005). Institutions span rules, regulations, laws, social norms and customs related to broad socioeconomic activities, including R&D institutions. Innovation systems whose boundaries are delineated by national borders are called national innovation systems (NIS). Today, the systems approach is the starting point for the formulation of policies that aim to address multiple layers of failures.

Current debates increasingly focus on the mobilization of industrial and STI policies to meet global challenges, including the imminent need to address digital divides, economic inequality, environmental threats and healthcare risks. For example, Chang and Andreoni (2016) point out that shorter technological cycles, digitalization and the need to address grand, long-term challenges such as climate change should take a central place in making invest-

4 For a discussion on different definitions of "industrial policy", see Warwick (2013) and Aiginger and Rodrik (2020).

Table 2 Three frameworks for government-driven innovation policy

	Framework 1: Innovation for growth	**Framework 2:** National systems of innovation	**Framework 3:** Transformative change
Conceptual foundation	• Significance of the residual in the economic growth	• Localized knowledge spillover, absorptive capacity, social capability of entrepreneurship and cumulative and path-dependent nature of technological change	• Social and environmental challenges
Rationale/ justification for policy intervention	• Market failure • Mission-oriented research	• Coordination failure • Insurgence of East Asian economies • Focusing less on funding pre-competitive R&D and more on learning between the actors in the system	• Directionality failure • Policy coordination failure • Reflexivity failure
Innovation model	• Linear model	• National system of innovation approach • Triple Helix model	• Sustainability transitions • Deliberating and exploring these social and environmental goals and underlying values and embedding them in processes of systemic change
Actors	• Clear division of labour and responsibility	• Interaction among actors for creating knowledge	• Inclusive deliberation processes for co-production of values
Policy practices	• Direct subsidies and financing science • Favourable tax treatment • Strengthening and extending intellectual property protection • Education for research careers	• Policies that aim to improve the coordination and alignment among different actors in innovation systems (such as conditional funding, foresight as a coordination and communication tool) • Greater role of agency and a greater interest in entrepreneurship • Education and training of the workforce with the aim of supporting the absorptive capacities	• Active involvement of users • Need for anticipation, experimentation, learning and the formation of bridging networks and alliances • New institutional arrangements and governance structures that cut across governments, markets and civil society

Source: Authors' adaptation from Schot and Steinmueller (2018b).

ment decisions (**Table 2**, Framework 3). They also summon attention to three features in the global economy that affect industrial policy in developing countries:
(1) transformation of the global production system;
(2) financialization of the global economy; and
(3) global coordination of policies propelled by multilateral agreements such as those from the WTO and bilateral free trade agreements (a so-called "new form of imperialism").

In the same vein, Aiginger and Rodrik (2020) propose 10 general principles for new industrial policy. As shown in Table 3, key aspects include the importance of manufacturing, systemic nature of both policy and sectoral growth, desirability of a high road strategy, establishment of directionality in technical progress, societal goals and the existence of information uncertainty driving public-private collaboration.

Table 3 10 general principles for new industrial policy

1. Manufacturing remains crucial for growth and well-being
2. Industrial policy has to be systemic, not isolated or delegated to specialists
3. The optimal scale of the industrial sector depends on capabilities, ambitions and preferences
4. Industrial policy has to take the high road
5. Redirecting technical progress and preparing for less growth
6. Societal goals should be paramount, moving beyond the correction of market failures
7. Search process in an unknown territory
8. Asian countries demonstrate how to combine planning with market forces
9. Industrial policy can mitigate populism
10. An international forum for industrial policy shaping responsible globalization

Source: Aiginger and Rodrik (2020).

Contemporaneous rationales for policy intervention advocate for reflection beyond addressing market failures and towards playing more proactive roles in systems transformation. Drivers of this change are manifold. One reason for this is the recognition of the growth potential of STI systems, as described by Aghion et al. (2009, pp. 691–692):

> *Technology and innovation policy for growth is widely accepted, but it immediately becomes politically controversial when its implementation goes beyond the support of "exploratory" and "far from-commercialization" research, and enters into specific details that are perceived to have differential effects on particular markets, institutions and industries. There are good reasons for caution in entering those realms, but the growth potential of R&D and innovation is too clear to abandon policy efforts simply because they are difficult to implement or politically charged.*

Mazzucato (2015) also points out the necessity to change policy approaches, from "fixing market failures" to "creating market opportunities." She claims that the roles of the state should be broadened to establish a direction for a society to take. Dosi (1982) states that a technological paradigm "embodies strong prescriptions on the directions of technical change." Thus, STI policies become directionality-setting, and thereby the state bolsters mission-oriented changes in STI and productive systems, similar to what entrepreneurs do in markets (Mazzucato and Penna 2016; Kattel and Mazzucato 2018). However, mission-oriented policies for transformative goals are different from past top-down, state-led policies. Schot and Steinmueller (2018a, p. 1,584) assert their difference as follows:

> *Mission-oriented policies need to be implemented in an open and tentative way and be aimed at transformations. Such mission-oriented policies need to move away from a state-centric view, assuming missions to be the outcome rather than the starting point of the policy.*

In this context, developing demand-side policy instruments is critical. It is well known that public procurement programmes in the United States resulted in incubating the early development of ICT technologies (Mowery et al. 2010). Thus, it is clear that policy instruments expand in the realm of the demand side (Edler 2010; Georghiou et al. 2014). This is relevant as developing countries generally suffer from a lack of demand for intermediate products that integrate high-technology contents because their forward industry sectors are underdeveloped as well. Moreover, demand for commodity-like consumer manufacturing goods is insufficient because of the low income of the general population.

Schot and Steinmueller (2018b) attempt to provide a comprehensive rationale and account for mission-oriented policies by focusing on their growth potential, as well as their role as drivers of forward-looking societal transformation. In order to achieve these goals, "transformative innovation policies need flexibility, experimentation, acceptance of failure, mobilization, circulation, and upscaling of local initiatives, rather than top-down mission driven programme management" (Schot and Steinmueller 2018a, p. 1,584). According to these authors, policy changes are needed to address societal goals such as the United Nation's 17 Sustainable Development Goals (SDGs), technologies adapting to or mitigating climate changes, increased social justice, a fairer distribution of welfare, sustainable consumption patterns and new ways of producing economic growth. This rational is captured in Table 2, Framework 3 through the goal of facilitating societal transforming in a desirable direction. This transformative change, or "Deep Transition", is defined as a "series of connected and sustained fundamental transformations of a wide range of socio-technical systems in a similar direction" (Schot and Kanger 2018, p. 1,055). Schot and Steinmueller (2018b) succinctly define the policies listed in Framework 3 as those focused on "innovation as a search process on the system level, guided by social and environmental objectives, informed by experience and the learning that accompanies that experience, and a willingness to revisit existing arrangements to de-routinize them in order to address societal challenges" (p. 1,563).

Yet any policy prescriptions or frameworks must take into account key features and shifts affecting the global economy. The following sections briefly discuss some of the megatrends that are currently shaping the environment in which industrialization takes place (UNIDO 2021).

3.2 Digital transformation

Digital transformation, in line with the fourth industrial revolution (4IR), is one of the most significant phenomena shaping the future dynamics of businesses, markets and society globally. The rapid expansion of ICTs and the emergence of new general purpose technologies (GPTs)[5] are disrupting the existing industrial foundation and changing the rules of competition within industries (Lee et al. 2021). Due to its disruptive nature, digital transformation provides opportunities for as well as threats to developing countries' industrial development.

Radical technological change may open windows of opportunities for latecomers to catch-up or leapfrog to the next stage of industrial development (OECD 2017 and 2019; Ciuriak and Ptashkina 2019; Choi et al. 2020; Lee et al. 2021). The idea of leapfrogging is that developing countries can bypass heavy investment in previous technological stages and preemptively invest in emerging technologies to catch up with advanced countries (Lee 2019). There are two ways developing countries can capture leapfrogging opportunities in the digital era. First, their antiquated or lack of preexisting infrastructure enables them to directly enter the new industrial era without huge investment in

5 General purpose technologies describe "a collective platform of complementary technologies centering on core technologies such as microchips or artificial intelligence today, and at the same time, the set of rules governing innovation" (Lee et al. 2021).

the earlier industrial stage or making enormous sunk costs (Mühleisen 2018; Ciuriak and Ptashkina 2019; Lee 2019). Second, digital technologies can facilitate technology acquisition through knowledge spillovers (Ciuriak and Ptashkina 2019). Open platforms and free/open software provide firms and governments in developing countries immediate access to vast information and knowledge, which enables them to quickly adopt new technologies. Mobile payments in Kenya, digital land registration in India and e-commerce in China are successful cases of technology areas led by developing countries due to knowledge externalities and low sunk costs (Mühleisen 2018).

However, digital transformation can also pose a threat to latecomer countries. First, the digital gap between advanced and less developed countries may exclude the latter from the digital economy. Developed countries tend to have more resources and capabilities—such as ICT infrastructures, enabling technologies, policy capabilities, etc.—and, accordingly, have more potential for growth by making better use of digital opportunities. Developing countries, especially the least developed countries (LDCs), are more likely to lack basic ICT infrastructure for digital connection. This limited physical accessibility leads to gaps in digital usage, skills and literacy, as well as in value creation and capture from digital technologies, consequentially. In today's digital era, this digital divide may prohibit underdeveloped countries from competing in the increasingly digitalized economy, which could lead to a development divide. Moreover, the recent COVID-19 pandemic has been accelerating the development of the digital economy (UN 2020). Countries with stronger digital capabilities are better able to withstand and take advantage of the pandemic; countries lacking digital capabilities may be further left behind (UNIDO 2021a).

Digital transformation can be a double-edged sword to developing countries, in that it provides opportunities yet also more challenges. A two-step approach should enable them to capture and exploit these opportunities. The first step is to grant them easier access to competitive markets through digital inclusion. This has been a topic of concern over the past few decades. Until around 2010, digital inclusion [6] had mainly focused on technological and economic attributes, such as physical access and collective usage. As technological and economic attributes have dominated throughout most of the period, the corresponding indices used to measure them–*Availability* [7] and *Affordability* [8]–have significantly improved. However, educational, social and persuasive attributes like digital skills, individual usage and entrepreneurial motivation have only been discussed more recently. Hence, there is significant room to improve indices related to these views: *Readiness* [9] and *Relevance*. [10] In the case of the readiness index, the pandemic reversed progress achieved over the past few years (The Economist 2021). Similarly, efforts to improve along the relevance index through better awareness and the rising significance of digital technologies have encountered difficulties due to the insufficiency of content available in many developing countries, which tends to be below user expectations (The Economist 2021). External support should assist developing countries, notably LDCs, break out of the negative feedback loop around digital divides; assistance should address various fields, such as politics, businesses, markets and research, among others.

Once latecomers have secured access to the digital economy, the next step is to build and develop foundational capabilities. Foundational capabilities are "the capabilities to learn new technical and organizational solutions, integrate them into production, organize and commit resources over time for the effective deployment of these new solutions" (Andreoni et al. 2021, p. 334). These capabilities cannot simply be obtained through purchasing foreign advanced technologies, imitating established economic patterns or concentrating resources solely on technological

6 Digital inclusion consists of five different categories: technological, economic, educational, social and persuasive perspectives (van Dijk 2020; The Economist 2020).

7 Availability can be defined as the quality and breadth of available infrastructure required for access and levels of internet usage (The Economist 2017).

8 Affordability can be defined as the cost of access relative to income and the level of competition in the internet marketplace (The Economist 2017).

9 Readiness can be defined as the capacity to access the internet, including skills, cultural acceptance and supporting policy (The Economist 2017).

10 Relevance can be defined as the existence and extent of local language content and relevant content (The Economist 2017).

Table 4 Digital inclusion attributes and indices

Attribute	Primary index	Focus in phase of appropriation
Technological	Availability	Physical access
Economic	Affordability	Physical access, collective usage
Educational	Readiness	Digital skills/literacy
Social	Affordability, Readiness, Relevance	Individual usage
Persuasive	Relevance	Motivation/attitude

Source: van Dijk (2020).

jumps rather than on incremental learning (Lee et al. 2021; Andreoni and Chang 2017; Andreoni et al. 2021). They can be developed and nurtured through the continuous efforts of innovation activities in production, technologies and organizations. In this regard, in-house R&D centres play vital roles as learning repositories (Lee 2019; Andreoni et al. 2021). They enable firms in developing countries to look for various learning channels, absorb foreign knowledge and develop technological capabilities beyond simple purchase or licensing (Lee 2019). Through these learning processes, in-house R&D can create indigenous innovations that are informed by the application of domestic knowledge and practices. By obtaining foreign knowledge on 4IR-related technologies and applying it to local contexts, developing countries can create products and services that fulfill local needs.

Several examples can be found in Asia. GoJek, originally a regional motorbike [11] taxi company in Indonesia, began a call-booking service with 20 drivers in 2010 after recognizing a local problem, that drivers and customers wasted time waiting for and connecting with each other (Pillai 2019). The company launched a mobile application and scaled up their services through the acquisition of engineering startups and the establishment of an R&D centre (Chanchani 2016). Taking advantage of its knowledge of the local market and regulatory environment, GoJek's app turned out to be a breakout success and has now become a decacorn company (a private company valued at $ 10 billion or more) through investment from IT giants such as Google and Tencent (The Jakarta Post 2019). Other successful cases of companies with in-house R&D are Aadhaar, India's biometric ID system, and OVO, Indonesia's payment service company.

11 Ojek is a term for motorbike in Indonesia.

3.3 Climate change

Climate change is one of the most imminent global challenges requiring a collective international response. Like digital transformation, it poses both threats to and opportunities for industrial development in developing countries. Technological innovations in low-carbon and climate technologies are highly concentrated in several advanced countries (Park 2017). Hence, the transition towards low-carbon technologies can be a big barrier to the industrial development of developing countries where technological innovation systems are relatively weak and indigenous technological capabilities to develop and deploy relevant technologies are absent (De Coninck and Sagar 2014; Khosla et al. 2017).

At the same time, the idea of leapfrogging is also applicable to the transition towards low-carbon economies; developing countries can skip and bypass heavy investment in previous carbon-intensive systems, preemptively investing in emerging low-carbon systems. In addition, the international institutional setting of climate change is also favourable to developing countries. The United Nations Framework Convention on Climate Change (UNFCCC) has been making efforts to facilitate international transfer of climate technologies between developed and developing countries; one of these is the Clean Development Mechanism (CDM)[12] under the Kyoto Protocol.

Nevertheless, the effectiveness of the CDM is not straightforward. One branch of the literature argues that the CDM has had a positive impact on facilitating the international transfer of climate technologies (Dechezlepretre et al. 2009; Murphy et al. 2013; Seres et al. 2009; Gandenberger et al. 2016). Their conclusion is largely based on the definition in the IPCC (2000),[13] which considers even the relocation of equipment to developing countries as technology transfer. On the other hand, Das (2011) and Park (2018) conclude that the CDM did not facilitate technology transfer to local companies in host countries, after analyzing its impact on the technological upgrading of local participant companies. These studies emphasized the knowledge flow to local participant companies. Lessons learned from the previous CDM experience should be incorporated into a new carbon offset scheme under the new climate regime that came out of the 2015 Paris Agreement.

There are already successful catch-up cases that demonstrate the value in promoting the sustainable development of low-carbon technology industries, such as the solar photovoltaic and wind turbine industries in several large developing countries like China, South Africa and India during the 2000s (Lema and Lema 2012; Tan and Mathews 2015; Gandenberger and Strauch 2018).[14] These countries aimed to overcome environmental pollution originating from their conventional industrialization processes, and they pursued industrial upgrading and sustainable economic development by promoting the adoption of low-carbon technology systems. Lema and Lema (2012) observe that conventional mechanisms for technology transfer, such as FDI and FL, were utilized mainly at the takeoff stage of new industries in these countries. In contrast, more unconventional technology transfer mechanisms—such as overseas R&Ds (outward FDI), acquisition of foreign firms and the fostering of endogenous technological capabilities—were deployed in the catch-up stage. The latter created absorptive capacity and complemented technology transfer. Government intervention in these countries played a vital role in promoting indigenous technological capabilities and creating domestic markets.

12 Operating since 2006, the CDM is a carbon offset scheme that allows countries to implement projects to reduce greenhouse gas (GHG) in non-Annex I (developing) countries, earn equivalent emission reduction credits and use them to meet their emission reduction targets under the Kyoto Protocol. Developed countries tend to have higher commitments around GHG emissions, thereby fueling incentives to participate in the CDM to offset their emission reduction targets. The CDM presents developed countries with a means to achieve their GHG emissions reduction targets in a cost-efficient manner. For developing countries, it can facilitate both economic development and climate response.

13 "The broad set of processes that cover the flows of knowledge, experience, and equipment for mitigating and adapting to climate change among different stakeholders. These include governments, international organisations, private-sector entities, financial institutions, NGOs and research and/or education institutions. It comprises the process of learning to understand, utilise, and replicate the technology, including the capacity to choose it, adapt it to local conditions, and integrate it with indigenous technologies."

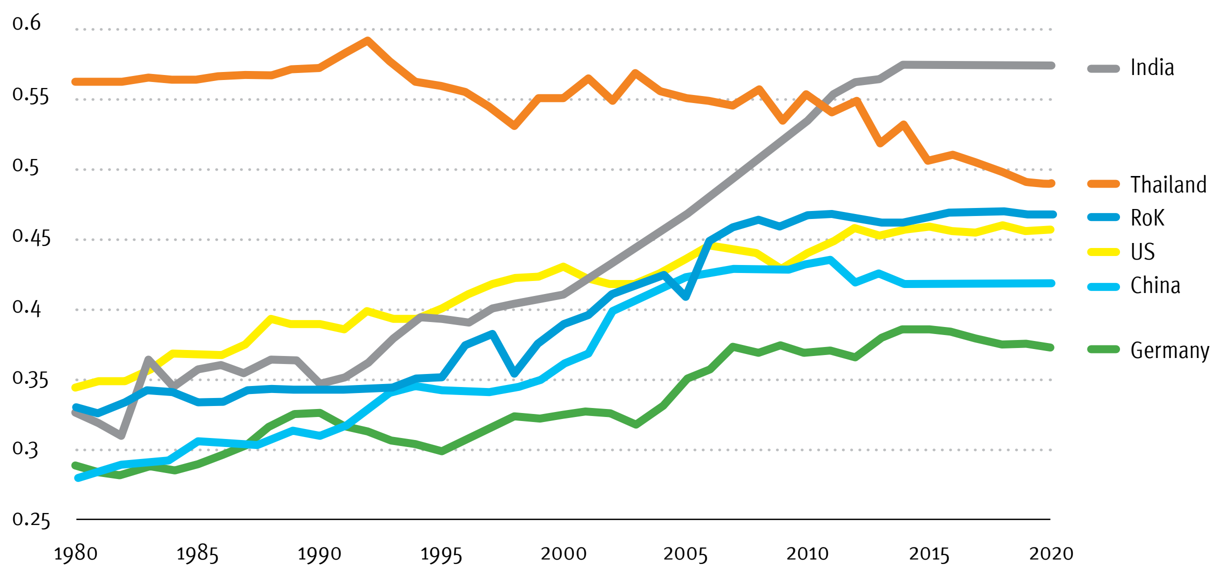
14 China adopted a similar strategy in the field of electric vehicles and batteries in the 2010s.

3.4 Inequality

Inequality is yet another global challenge that affects industrialization in developing countries. Income inequality, measured as the share of the top 10 percent of income earners in national gross income, has worsened globally over the last 30 years according to the World Inequality Database. In 1990, the share of national income held by the top 10 percent of earners in Europe and Asia was below 40 percent. However, it has increased to nearly 50 percent in those regions based on the latest data. Income inequality in the United States has also increased, from 38.6 percent in 1990 to 45.5 percent in 2010.

Figure 1 illustrates the trend in income inequality in several countries since 1980. India exhibits a sharp increase over the past 40 years, while most of the other countries represented in the figure, including the RoK, the United States and China, show mild increases for the same period. On the other hand, the income equality of Thailand has improved, though the level of income inequality as shown by the index is still higher than other countries.

Figure 1 Income inequality, selected countries, 1980 – 2010



Source: Reconstructed with data from the World Inequality Database.
Note: Income inequality is the share of the top 10 percent's income of the total national income.

Inequality responds to both global and country-specific factors. Technological progress and globalization are the main global factors. In particular, technological progress has contributed to skills development, which is a key driver of labour productivity. In Western Europe and the United States, however, technological progress has also translated into a hollowing out of middle-class jobs, a phenomenon known as job polarization, and has led to income inequality (IMF 2021). Country differences in terms of economic development, financial integration, redistributive fiscal policies and the liberalization and deregulation of labour and product markets also contribute to explaining inequality between and within countries (IMF 2021).

The multifactorial nature of inequality leads to a complex set of negative outcomes, threatening economic growth and development. Income inequality often causes the polarization of social and political views, which usually hinders social cohesion and ultimately leads to bleak economic growth prospects (IMF 2021). Growth, inclusiveness and sustainability have diverse and multidirectional feedback loops. Sternfels et al. (2021) documents the interaction of these three elements. Growth is an engine of prosperity and well-being and can form the basis for more inclusive and sustainable economies. Inclusion determines opportunities for productive work and life satisfaction for all; it creates diverse kinds of demand that further propel growth. Finally, sustainability is a prerequisite for long-term growth that is fair for current and subsequent generations (Sternfels et al. 2021). Inclusion can be enforced by sustainable economic growth; jobs and income generation strengthen inclusion. For example, there are around 200 million young people of working age in Africa and this will increase to 1 billion by 2050. If we provide adequate education and training, including digital skills, to young people, they can enter the middle class and the skill gaps with the rest of the world can be closed (Sternfels et al. 2021).

4. Review of technology development experiences in selected East Asian countries

Country case studies were carried out for three East Asian countries: the RoK, China and Thailand.[15] Key indicators related to the economic, industrial and STI competitiveness of these three countries are presented in **Table 5**. In terms of income per capita, China and Thailand are categorized as upper-middle-income countries while the RoK is categorized as a high-income country. On the other hand, in terms of innovation performance, the RoK and China lead journal publication and patent registration activities while Thailand lags behind.

ANALYTICAL FRAMEWORK AND DIFFERENTIATING STAGES IN EACH COUNTRY

The main purpose of the country case studies is to identify the role of STI policies and their relationships to industrial and economic policies in the course of the industrial development of developing countries. Drawing on Kim and Dahlman (1992), here we define in a narrowed manner STI policy as direct and indirect policy instruments promoting technological development (supply-side policies), and industrial policy as direct and indirect policy instruments creating market needs for technologies (demand-side policies). We consider three aspects of STI and industrial policies: the level of technology development, source of technology and market mechanism of technologies.

According to Lee et al. (1988), an evolutionary path of technological development in developing countries can be organized into three stages: technology introduction, technology internalization and technology creation. This

15 One of the limitations of the case studies is that it is difficult to draw implications of the previously discussed contemporary challenges of digital transformation, climate change and inequality on the experience of East Asian countries as their industrial development occurred mainly before the emergence of the challenges. Where available, this report aims to include recent policies in response to these challenges from the analysed countries.

Table 5 Selected economic, industrial and STI competitiveness indicators for the RoK, China and Thailand

Country		RoK	China	Thailand
GDP (current 2020 $ billions)		1,630.5	14,723	501.8
Per capita GNI (current 2020 $ billions)		32,860	10,610	7,050
Country category by income (World Bank, 2020)		High-income	Upper-middle-income	Upper-middle-income
Trade openness (%, 2020)		70.1	34.5	97.9
High-tech ratio of manufacturing exports (%, 2019)		32.4	30.8	23.6
Gross expenditure on R&D (% of GDP, 2018)		4.81	2.19	1.11
Journal publication	Numbers	1,196,961	6,589,695	199,226
	World ranking	13th	2nd	44th
Patent registration	Number (by resident, %)	125,661 (94,852, 75.5%)	452,804 (360,919, 79.7%)	3,121 (172, 5.5%)
	World ranking	4th	1st	38th
UNIDO CIP Index (2020)		3rd	2nd	24th

Source: World Bank (2021), Scimago (2021), WIPO (2020), UNIDO (2021b).
Note: Journal publication numbers were calculated by Scimago with data between 1996–2019.
CIP ... competitive industrial performance; **GDP** ... gross domestic product; **GNI** ... gross national income; **R&D** ... research and development; **RoK** ... Republic of Korea; **STI** ... science, technology and innovation.

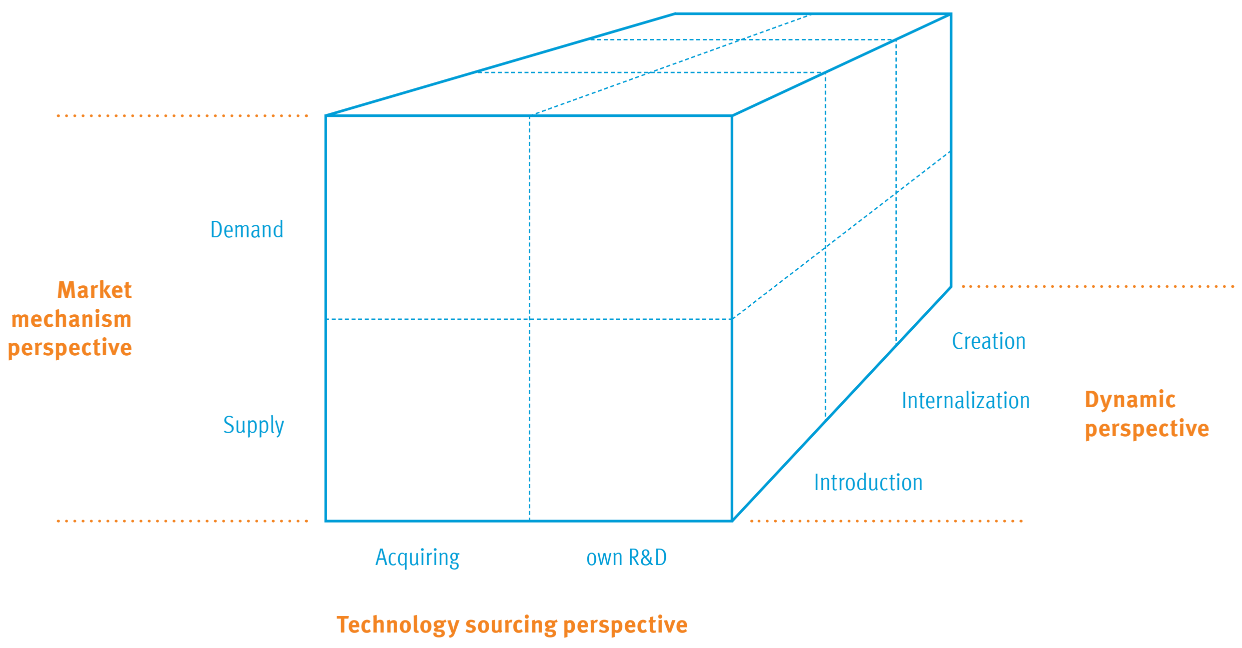
categorization is based on the industrialization experiences of East Asian countries. Initially, these countries began their industrialization by importing mature technologies, and gradually achieved industrial progress by assimilating and adapting foreign technologies in tandem with local R&D. Finally, they achieved the level of creating their own technologies. This three-stage approach is useful in that different policy instruments can be identified at different stages, since the role and content of STI policies evolve over the course of technological development in a developing country.

In terms of the source of technology required to promote industrial development, two elements are considered: foreign technologies and domestic technologies. As discussed in Section 2, learning from foreign technologies was one of the main characteristics of East Asian "late" industrialization miracles (Amsden 1991). Therefore, policies to facilitate international technology transfer are a very important component of a technology sourcing strategy in developing countries. These policies include a variety of formal and informal modes of technology transfer presented in **Table 1** earlier in this report. In addition, in order to fully take advantage of the potential of foreign technologies, developing countries should employ local R&D efforts to absorb and assimilate these technologies and eventually to develop their own technologies.

As for the market mechanism of technologies, it is important to note that demand and supply policies of technologies are complementary to each other. Demand policies to promote a specific industry cannot be successfully implemented without the provision of sufficient technology capabilities. Similarly, supply policies to develop technological capabilities will be of no use if there are no market needs.

In this regard, in analysing the case studies, we have constructed an integrative analytical framework (**Figure 2**), adapted from Kim and Dahlman (1992), that is comprised of three dimensions: market mechanism perspective, technology sourcing perspective and dynamic perspective.[16] The market mechanism perspective has two elements: demand-side policies creating market needs for technology and supply-side policies providing technological capabilities. Technology sourcing covers different measures to source technologies, from acquisition of foreign technology and domestic R&D efforts to utilize imported technology, to, eventually developing own technology. In our analysis, we identify specific policy measures aimed at acquiring foreign technologies and developing domestic technologies at different stages in each analysed country. The dynamic perspective is composed of three stages: technology introduction, technology internalization and technology creation. This perspective can serve to provide not only common findings and implications for developing countries in general, but also specific findings and implications for developing countries at different stages of their development.

Figure 2 Integrative analytical framework



Source: Authors' adaptation from Kim & Dahlman (1992).

16 The dynamic perspective in Kim and Dahlman's original framework has three stages: mature, consolidation and emergence—the reverse evolutionary process of industrialization in advanced countries. Therefore, the terms of the stages do not provide much sense in terms of the level of technology development and related STI policies in developing countries.

In operationalizing the framework, we first apply a time element, the dynamic perspective, to each country. It is important that we differentiate technology development stages of each country in a consistent manner according to the framework. To do so, we looked at significant changes in economic, industrial and STI policies, as well as STI indicators such as R&D inputs and corresponding outputs for each country. Through the lens of the market mechanism perspective, we chronologically present important demand-side and supply-side policies introduced by each country at each stage of technology development. In addition, particular focus was placed on policy measures for sourcing foreign technologies and developing indigenous technologies, per the technology sourcing perspective.

In the next sections, we present the rationales and results of differentiating technological development stages for each country, then analyse in greater detail the experiences of the three East Asian countries.

THE REPUBLIC OF KOREA

Changes in industrial and STI policies and related quantitative indicators over the course of the RoK's industrial development are shown in **Table 6** and **Figure 3**. We can see that there has been a rapid increase in national R&D expenditure, number of researchers, invested R&D budget and number of R&D centres by the private sector since the 1980s. It is clear that these indicators really took off in the early 1980s. Importantly, the private sector ratio within the gross expenditure of R&D overtook that of the government beginning in 1981, which demonstrates the dedication of the private sector to indigenous technology development. In the case of patent applications (**Figure 4**)—a proxy for R&D outputs—the surge also occurred in the late 1980s but with some time lag. The number of patent applications by residents overtook those by non-residents in 1993.

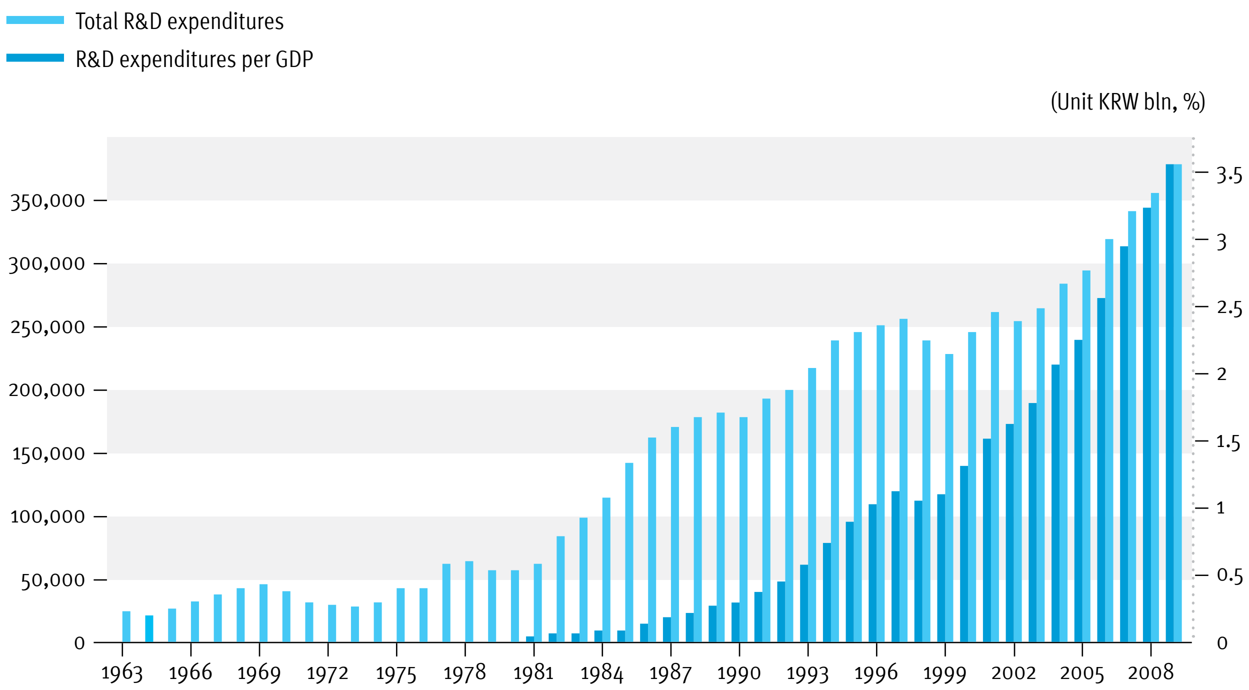
Table 6 Selected R&D indicators in the RoK, 1971 – 2001

	1971	1976	1981	1986	1991	1996	2001
R&D expenditure/GDP	0.32*	0.42	0.59	1.52	1.71	2.22	2.28
Government vs private ratio	68:32	64:36	42:58	19:81	19:81	26:74	27:73
Researcher per 1,000 population	0.08	0.33	0.54	1.33	1.68	2.18	2.88
Corporate R&D centres	1	n/a	53	290	1,201	2,610	9,070

*GNP applied

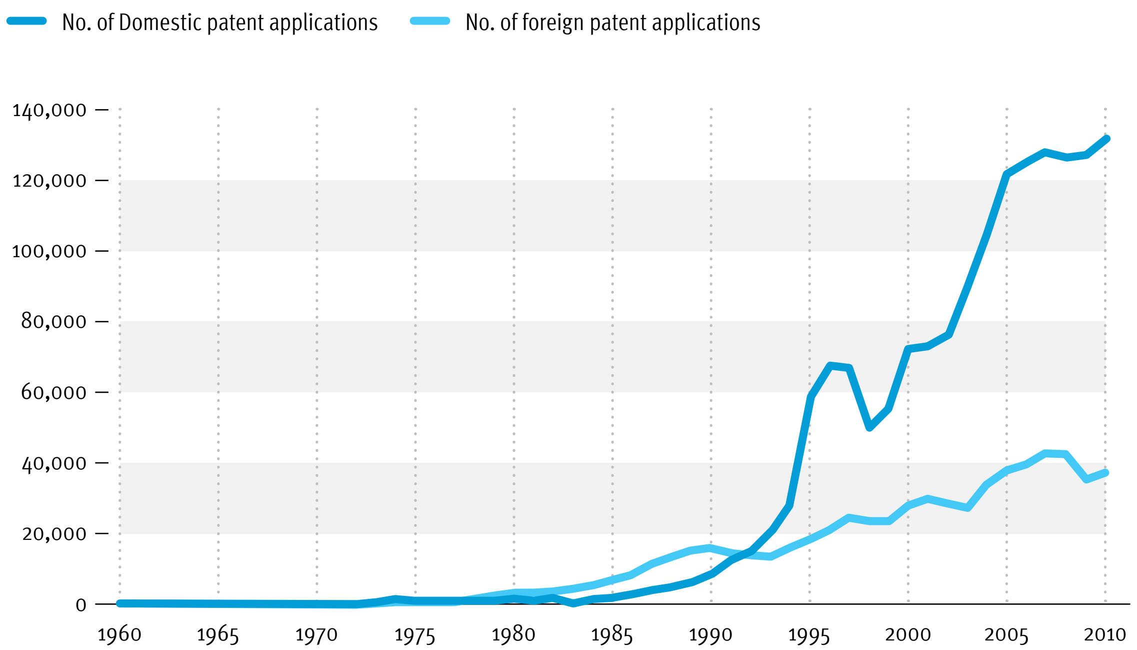
Source: Authors' elaboration. Additional data added from Kim and Dahlman (1992).
Note: **GDP** … gross domestic product; **GNP** … gross national product; **R&D** … research and development.

Figure 3 Total RoK R&D expenditures (KRW billions) and their share of GDP (%), 1963 – 2008



Source: Shin and Lee (2012).
Note: GDP … gross domestic product; KRW … RoK won; R&D … research and development.

Figure 4 Number of patent applications in the RoK, nationals and foreigners, 1960 – 2010



Source: Shin and Lee (2012).

The country's technological capabilities have significantly improved since 2000, as evidenced by the evolution of the technology balance of payments [17] in Table 7. Under 0.1 before the 2000s, the technology balance of payments began to dramatically improve, reaching 0.23 in 2001, 0.41 in 2011, and 0.77 in 2019. In other words, we can observe another type of takeoff in terms of technology exports over technology imports. In addition, the amount of technology trade experienced an exponential, ten-fold growth during this stage. The increase in these figures offers two important implications. First, the increase of technology exports relative to technology imports attests to the dramatic improvement of the RoKs technological capabilities during the technology creation stage. Second, steady growth in both technology exports and imports implies the need to actively mobilize foreign and domestic technologies to maintain a country's international competitiveness.

Table 7 Technology balance of payments, $ millions, in the RoK, 1981 – 2019

	1981	1986	1991	1996	2001	2006	2011	2016	2019
Technology exports (A)	11.8	11.7	35.2	108.5	619.1	1,897	4,032	10,687	13,756
Technology imports (B)	107.1	411.0	1,183.8	2,297.2	2,642.7	4,838	9,900	14,842	17,876
Technology balance of payment (A/B)	0.11	0.03	0.03	0.05	0.23	0.39	0.41	0.72	0.77

Source: Korea Industrial Technology Association (2020).

Considering the evolution of the RoK's technological capabilities, then, its industrialization can be divided into three periods:
(1) the technology introduction stage, which began in 1961 when South Korea developed its first Five-Year National Economic Development Plan (herein: "NEDP") and lasted until 1980;
(2) the technology internalization stage, which lasted until 1997 and the outbreak of the Asian economic crisis; and
(3) the technology creation stage, which has been in progress since 1998.

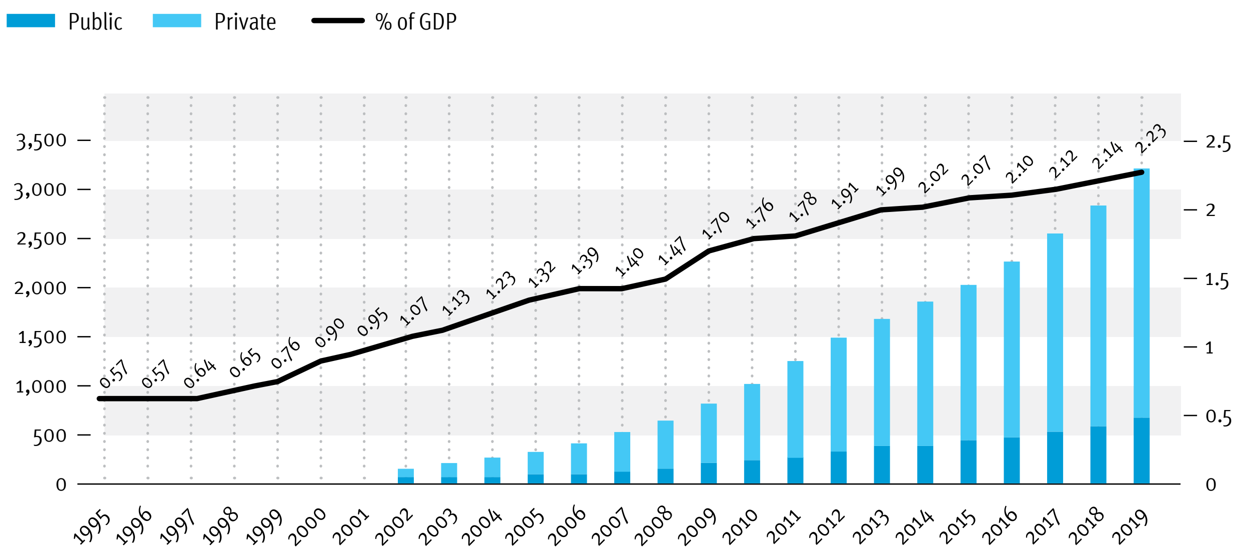
THE PEOPLE'S REPUBLIC OF CHINA

Taking into consideration changes in policies and key quantitative indicators that were accompanied by leadership change, several studies have divided the development path of China's technology innovation after the Reform and Opening-Up Policy into three or four stages (Choi et al. 2020; 陈劲 et al. 2013; 陈劲 2020). The results of an analysis of these previous studies confirm that China began accumulating technological capabilities mainly through foreign technology imports by the late 1990s, as well as through major investments in indigenous technology devel-

17 The technology balance of payments measures receipts and payments of disembodied international technology transfers: license fees, patents, purchases and royalties paid, know-how, research and technical assistance (OECD 2010).

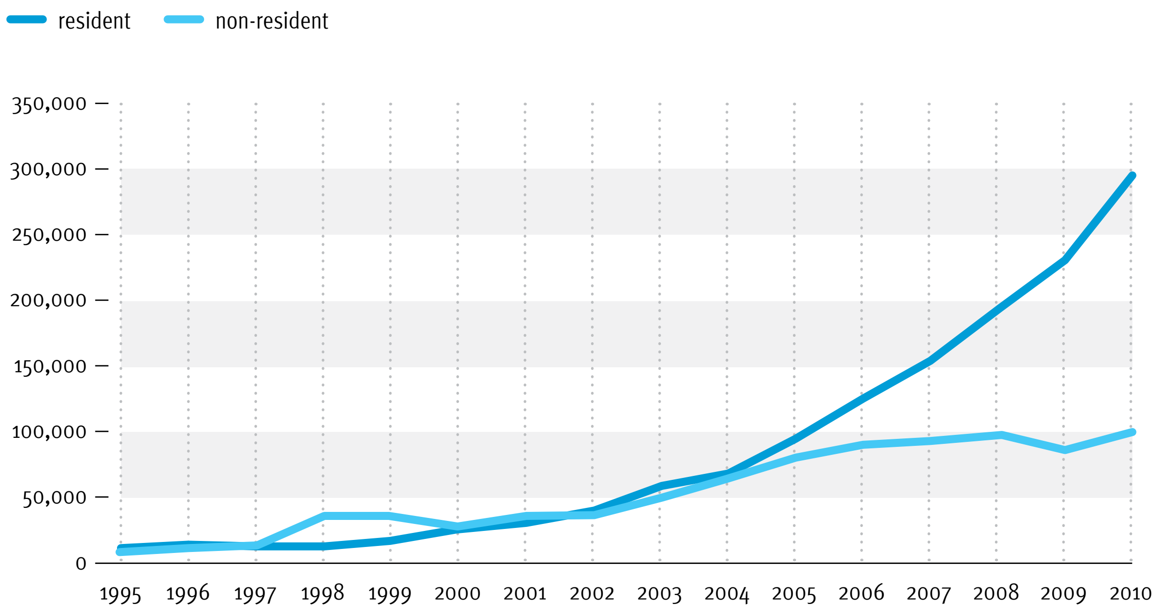
opment since its accession to the WTO in 2001. As outlined in **Figures 5** and **6**, it is clear that takeoffs in R&D inputs and outputs similar to those of the RoK have also occurred.

Figure 5 Total R&D expenditures ($ billions), by sector and by share of GDP (%) in China, 1995 – 2019



Source: MOST (Ministry of Science and Technology) and Fu (2015).
Note: Data for R&D expenditure by sector not available between 1995 and 2001.
GDP … gross domestic product; R&D … research and development.

Figure 6 Number of patent applications in China, by resident and non-resident, 1995 – 2010



Source: Data extracted from WIPO statistical country profiles.

4. Review of technology development experiences in selected East Asian countries

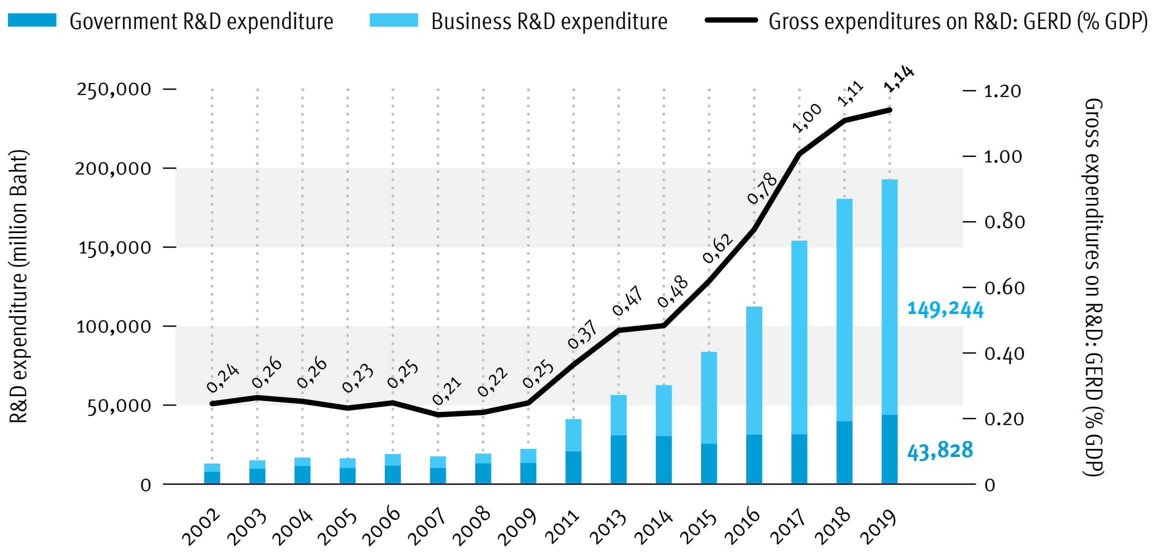
Another major shift in policy and world-leading R&D performance occurred during China's leadership change in the early 2010s. During that period, China began to emerge as a leading industrial powerhouse, introducing policies to promote new and emerging strategic industries in which China aims to compete directly with advanced countries, such as in the fields of artificial intelligence (AI), 5G, quantum technologies and so forth. China's gross R&D expenditure reached 80 percent of that of the United States in 2019, and the country ranked second after the United States in terms of the top 1 percent of highly cited papers in 2018 (NISTEP 2021).

Thus, China's industrialization can also be divided into three periods:
(1) the technology introduction stage (1978 – 2001),
(2) technology internalization stage (2002 – 2011) and
(3) technology creation stage (2012 – present).

THAILAND

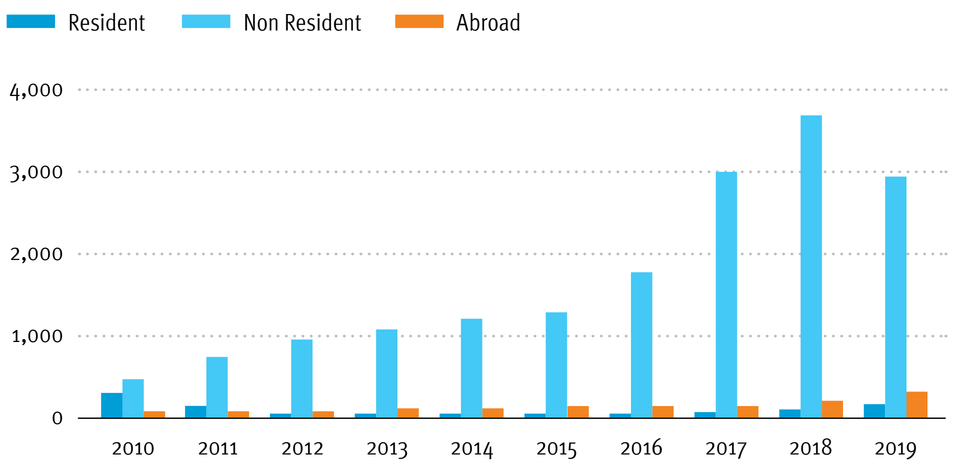
Thai industrial development began with the development of the National Economic and Social Development Plan (herein: "NESDP") in 1961. Unlike the RoK and China, which developed and accumulated their technological capabilities through the aforementioned three evolutionary stages, Thailand seems to be trapped in the beginning of its technology internalization stage. The main reason for this is that the takeoff of R&D only recently occurred. As shown in **Figure 7**, R&D expenditures as well as their value as proportion of GDP began to take off since the early 2010s and, most importantly, R&D expenditures of the private sector are leading the trend, overtaking those of the public sector since the early 2010s. However, as shown in **Figure 8**, there is to date no takeoff nor overtaking by Thai nationals in the number and composition of patent activities. Considering the several-year time lag in R&D output in both the RoK and China, it is therefore necessary to monitor whether there will be a similar takeoff and overtaking in Thailand in the coming years.

Figure 7 Total R&D expenditures (THB millions), by sector and share of GDP (%) in Thailand, 2002 – 2019



Source: NXPO (2021).
Note: GDP … gross domestic product; GERD … gross domestic expenditures on research and development; R&D … research and development.

Figure 8 Number of patent grants to residents, non-residents and applicants located abroad in Thailand. 2010 – 2019



Source: WIPO statistical country profiles.

In consideration of such differences, we adopted a phased approach presented by the World Bank (1993) and the OECD (2021), which divides Thailand's industrial development into the following three periods, reflecting major shifts in the country's industrial and STI policies:
(1) the import substitution industrialization (ISI) period (1961 – 1980);
(2) export-oriented industrialization (EOI) period (1981 – 1996); and
(3) economic recovery and moderate growth period (1997 – present).

According to the dynamic perspective in the framework presented in **Figure 2**, the first two periods (1961 – 1996) belong to the technology introduction stage and the last period (1997 – present) belongs to the technology internalization stage.

4.1 The Republic of Korea

INTRODUCTION

Despite its poor endowment of natural resources, the RoK has emerged as one of the few countries to achieve unprecedented success in rapid industrialization and economic development. It used to be one of the least developed countries in the world, with just $ 79 in per-capita income when it embarked on its industrialization process in the early 1960s (Hwang 2011). By the 1980s, however, the RoK began to be recognized as one of a group of newly industrialized economies (NIEs) in East Asia (Amsden 1989). And in 2020, the RoK became the 10th largest economy in the world amid the COVID-19 pandemic and was reclassified from a Group A economy (Asian and African countries) to a Group B (developed economies) economy by the United Nations Conference on Trade and Development (UNCTAD).[18] As illustrated in **Table 8**, the RoK's industrial structure has continuously evolved over the past five decades, reflecting changes in its top 10 export products. In the 1960s, exports were driven mainly by raw materials, such as iron ore, tungsten and silk. In the 1970s and 1980s, the country pursued industrial diversification and upgrading, shifting its focus from light to heavy industries and electronics. In 2020, high-tech products—including semiconductors, automobiles and auto parts, petrochemicals, displays, steel and mobile phones—account for 58.0 percent of Korea's exports (KITA 2021).

The RoK's success in building a strong industrial and technological base also reflects positively in the country's resilience against external shocks. For example, the first and second oil shocks in the 1970s, and later the Asian economic crisis of 1997, dealt heavy blows to the country. Nevertheless, the RoK managed to overcome these hardships and sustain a steady path towards achieving its current level of industrial development. And strong collaboration across the government and between the government and the scientific community and industry, built over many years, helped the RoK to respond and manage the spread of the COVID-19 epidemic (Andreoni 2021). To a large extent, the country's pandemic response was made possible by the substantive technological capacities accumulated over the course of its industrialization and that are discussed in this section.

Key drivers of the RoK's successful industrialization include steady investments in STI by the government as well as the private sector, along with successful implementation of an export-oriented industrialization (EOI) policy under strong state leadership (Amsden 1989; Cherif and Hasanov 2019). In fact, the South Korean government is currently spending more than 4 percent of its GDP on R&D, which is the second-highest in the world after Israel. As result, as of 2019 the RoK ranks 12th globally in terms of the number of scientific publications and 5th in share of global IP5[19] patents, which are key indicators for national STI competitiveness (UNESCO 2021).

Table 8 Top 10 export products of the RoK, 1960 – 2019

Rank	1960	1970	1980	1990	2000	2011	2019
1	Iron ore	Textiles	Textiles	Textile products	Semiconductors	Ships	Semiconductors
2	Tungsten ore	Plywood	Electronics	Semiconductors	Computers	Petrochemical products	Automobile
3	Raw silk	Wigs	Iron/steel products	Footwear	Automobiles	Semiconductors	Petrochemical products
4	Anthracite	Iron ore	Footwear	Ships	Petrochemical products	Automobiles	Automobile parts
5	Cuttlefish	Electronics	Ships	TV/VTR	Ships	LCDs	FPD & sensors
6	Live fish	Fruits/ vegetables	Synthetic fibers	Iron/steel products	Wireless telecom eq.	Wireless telecom eq.	Synthetic fibers
7	Natural graphite	Footwear	Metal products	Synthetic fibers	Synthetic fibers	Automobile parts	Ships & related parts
8	Plywood	Tobacco	Plywood	Computers	Iron/steel products	Iron/steel products	Iron/steel products
9	Rice	Iron/steel products	Fish	Audio	Textile products	Synthetic fibers	Wireless telecom eq.
10	Bristles	Metal products	Electrical goods	Automobiles	TV/VTR	Computers	Plastics

Source: Korea International Trade Association.(2021).

18 The Hankyoreh, UNCTAD classifies RoK as a developed economy, https://english.hani.co.kr/arti/english_edition/e_international/1002230.html (accessed 26 August 2021).
19 The five largest intellectual property offices in the world are in the United States, European Union, Japan, RoK and China.

This section divides the RoKs industrialization process into three stages, in consideration of the characteristics of technologies mobilized in the country's industrial deepening process. The first stage began in 1961, when the country developed its first NEDP, and lasted until 1980. During this stage, RoK acquired technological capabilities mainly through importing capital goods from overseas. At the same time, the country also protected its infant industries and heavily promoted exports. The second stage—which lasted until 1996, before the outbreak of the Asian economic crisis—is often characterized as a period of high growth, driven by nurtured capabilities through indigenous R&D along with foreign technology imports. In the last stage, from 1997 to the present, the RoK has finally joined the ranks of developed countries by successfully creating indigenous technologies in high-tech industries.

TECHNOLOGY INTRODUCTION STAGE (1961 – 1980)

After the Korean Civil War (1950 – 1953), the RoK government relied on foreign aid (grants), mainly from the United States, as its major source of income. In fact, the ratio of foreign aid in the Korean government's total revenue surged to 86.8 percent in 1957 (Kim 2017). Displeased with the country's heavy dependence on foreign aid, however, the United States changed its support policy in 1958, moving away from grants to loans. As a result, aid from the United States diminished, further deteriorating the RoK's trade deficit, forcing the government to launch a new economic development plan capitalizing on the support from the US government. This section covers the country's technology introduction stage of the 1960s and 1970s. In the 1960s, the RoK embarked on industrialization efforts through foreign technology introduction, while exporting mainly light-industry products such as textiles, garments and footwear. In the 1970s, the export focus shifted to heavy industries like steel, petrochemicals, shipbuilding and electronics (Kim and Dahlman 1992).

Early industrialization based on export promotion policy

In 1961, the Economic Planning Board (EPB) of the RoK government developed the country's first NEDP, with the support from the US government. The NEPD introduced targeted production outputs and investment plans by industry for the period 1962 – 1966. The RoK originally pursued an ISI strategy led by the first NEDP to reduce its dependence on foreign resources. However, the country was soon faced with difficulty in securing foreign currency while having unexpected export success in some sectors. As a result, the government quickly switched to an EOI policy in 1964, through currency depreciation, with amendments to the first NEDP (Kimiya 2008; Kim 2021). Capitalizing on the country's cheap labour, government intervention focused on supporting the production and export of products from labour-intensive light industries like garments, textiles, footwear and wigs.

Table 9 Foreign technology transfer to Korea, $ millions, 1962 – 1989

Source	1962 – 1966	1967 – 1971	1972 – 1976	1977 – 1981	1982 – 1986	1987 – 1989
Foreign direct investment	4.4	218.6	879.4	720.6	1,766.5	3,433.2
Foreign licensing	0.8	16.3	96.5	451.4	1,184.9	2,130.3
Technical consultancy	–	16.8	18.5	54.7	332.3	679.0
Capital goods imports	316	2,541	8,841	27,978	44,705	52,155

Source: Kim and Dahlman (1992).

A monthly export promotion meeting related to exports, attended by more than 200 members, including ministers and private-sector leaders, was established in 1962 as a mechanism to review export performance and related policies for export expansion. It was initially chaired by the prime minister; however, the chairmanship moved to the president in 1965 to express the country's full commitment to exports. Involvement at the highest level of power signaled that export performance was a top priority and made the monthly meeting one of the most powerful government coordination and policy monitoring mechanisms during this period (Kim 2021). The president continued to chair the meeting until 1979 when the dictatorship ended.

Lacking a homegrown technological base, RoK had to turn to foreign sources to secure a stable supply of required technologies. As shown in Table 9, foreign technologies were introduced mainly through importing capital goods or turnkey plants, while FDI and FL were limited due to the tight control of the RoK government [20] (Kim and Dahlman 1992).

With the early export success in light industries, the government signaled its intention to promote heavy and chemical industries, encouraged by the political context of the time. The Nixon Doctrine, announced by US President Richard Nixon in 1969, hinted at the possibility of a phased withdrawal of the American troops stationed in Korea, highlighting the need for the country to develop its defense industry on its own initiative. In addition, the first oil shock in 1973 as well as wage increases made the RoK pay serious attention to high value-added heavy and chemical industries, which could earn higher foreign exchange (Oh 1996). Against this backdrop, the Korean government officially announced its drive to develop heavy and chemical industries as part of the third NEDP (1972 – 1976) and made selective investments in six designated strategic industries: industrial machinery, steel, petrochemicals, shipbuilding, automobile and electronics. Most of the facilities for these heavy and chemical industries were constructed through turnkey contracts with foreign suppliers and vendors. Unlike light industries, which are based on cheap labour, heavy and chemical industries often require massive early investments in facilities as well as operational know-how, but also offer several opportunities such as productivity gains from new vintage technologies, economies of scale and learnings of sophisticated technologies.

The RoK government adopted various policies to encourage local companies to participate in the government-led EOI efforts by offering incentives that could offset risks arising from pursuing new businesses. A series of direct incentives were introduced, including financial support (such as government guarantees for foreign loans with low interest rates) for business diversification of high-performing exporting companies; protection of domestic final product markets for local companies by imposing high tariffs on imports; and exemption or reduction of tariffs on imported capital goods.

At the same time, the government adopted, as a disciplinary measure, the mandatory evaluation of firms' export performance. Evaluation results informed the government's decision on which firms would earn the opportunity to enter new industries with the provision of favorable incentives. This disciplinary measure, in tandem with fierce international competition, made RoK exporting companies maintain their focus on improving technological competitiveness. The disciplinary regulations exerted strong economic and social influence under the supervision of the authoritarian government when most RoK companies were lacking capital accumulation (Amsden 1989).

20 Throughout its early industrialization process, the RoK government had been stubborn to maintain local ownership in promoting the private sector due to its earlier experience of Japanese colonial rule.

During this stage, inter-firm mobility of human resources within industries played an important role in developing and diffusing problem-solving and production capabilities (Kim 1980). Many local latecomers that entered domestic markets in later industrialization phases could attract talent from forerunners, which automatically expanded production capabilities of all market participants. The success of local companies in subsequent export markets then opened even bigger markets, which again attracted more latecomers. A similar flow of talents from forerunners to latecomers followed, which led to the enhanced production capabilities of all RoK industries. An influx of engineers from state-owned enterprises (SOEs) to private companies also served as an important mechanism for diffusing production capabilities (Kim and Dahlman 1992).

Demand-side approach from the beginning of industrialization

The most noticeable characteristics of the RoK's early industrialization are the government's leading role as a developmental state with close links between industrial and STI policies. The government's role in industrialization was quite similar to the active role played by the governments of Western European countries in their catching-up to the United Kingdom, as argued by Gerschenkron (1962), in mobilizing financial resources and disciplining business activities (Amsden 1989; Lall 1992; Chang 1994). In addition, the role of technology as an important enabler of industrial development was fully recognized by the RoK government since its initial stage of industrial policy design and implementation.

Two key factors contributed to the recognition of the importance of technology in industrialization process—and, therefore, to the systematic linkages between industrial and STI policies. First, under the threat of a military confrontation with North Korea, a political situation unique to the Korean Peninsula, the RoK government considered securing a technological competitiveness imperative as a core part of national defense power. Second, in the early 1960s, the government had been frustrated by the United States Operations Missions to the Republic of Korea (USOM/K, the US agency in charge of aid to Korea) repeated rejection of its loan proposals to import capital goods for the development of heavy industries (typically, ISI-based projects). The agency cited RoK's lack of operational know-how of the imported equipment as a key reason for its refusal. This made the country recognize the importance of S&T. Fully aware of the importance of technological self-reliance, the RoK government developed the first Five-Year Technology Promotion Plan (herein: "TPP") under the newly established Bureau of Technology Management (EBP) to secure (foreign) technology as well as talent to enable the implementation of its first NEDP. After being briefed on the first NEDP, then-president Park Chung-hee made the following comments, which eventually became the main contents of this initial TPP (Hong et al. 2013, p. 24).

> *"… We are about to build new factories, but can we do that with existing technology and a current pool of engineers? If not, please tell me how we can tackle this."*

Institution-building for STI policies

Even at the technology introduction stage, then, the RoK government instituted an S&T policy to better support the country's industrialization process. The first TPP specified various policy efforts, including the supply of scientists and engineers, the promotion of foreign technology imports, the enactment of S&T-related laws, and the establishment of a government ministry and agencies in charge of S&T. Based on the TPP, the Science and Technology Promotion Act was enacted in 1967 and the Ministry of Science and Technology (herein: "MOST") was established in 1968, with a core function at this stage to support and align the country's industrial diversification towards heavy and chemical industries.

In 1966, the Korea Institute of Science and Technology (KIST), the country's first government-funded research institute (GRI), was founded with the financial assistance of the United States. In the early 1970s, six additional GRIs specializing in six heavy and chemical industries were established to build S&T capacity in those strategic industries—a clear attempt to align with the government's policy of promoting heavy and chemical industries. However, RoK companies that were concentrating their efforts on production using imported mature technologies were able to source the needed expertise directly from foreign machinery suppliers or product purchasers. In the case of OEM, foreign companies' informal guidance and consultation on product specifications and quality also helped RoK companies solve production-related problems. Under such circumstances, S&T demand for GRIs and their R&D activities from the private sector were relatively moderate. GRI researchers, mostly graduates of foreign universities with prior experience at foreign research institutes, were equipped with research capabilities rather than industry-needed problem-solving capabilities, causing a mismatch between supply and demand of talent (Kim and Dahlman 1992). Accordingly, these GRIs transformed their main roles to support the needs of the industrial sector—from providing research capabilities of S&T to helping private companies with adoption and assimilation of foreign mature technologies. Examples of GRIs' services include feasibility studies on technologies to be imported and negotiations of technology transfer contracts with foreign counterparts.

The government also promoted enhancement of human resources in heavy and chemical industries through the establishment of a long-term plan for demand and supply of S&T engineers (1971 – 1981) and the Korea Advanced Institute of Science (KAIS), the first graduate school specializing in engineering, in 1973. In 1977, MOST initiated government funding for basic science research activities at the school by establishing the Korea Science and Engineering Foundation (KOSEF), later restructured into the National Science Foundation of Korea (NRF). By this time, the foundational institutions underpinning STI policies had been gradually established: MOST as a ministry, KAIS as a research-oriented engineering school, KOSEF as a funding agency, as well as 16 sector-specific GRIs with the enactment of several S&T related acts.

In the corporate sector, the government's export-oriented policy gave birth to "chaebols", large corporate groups unique to the RoK context. In the export-oriented strategic industries selected by the RoK government, only large corporates were poised to take on such risks as large-scale capital investment and tough competition in the export market, while taking advantage of the government's protection of domestic markets and support for technology imports. The dissemination of production capabilities and problem-solving skills through inter-firm mobilization of field workers implies that RoK's accumulation of S&T capabilities in its late industrialization stage was driven by on-site learning led by private companies (Kim 1980; Kim and Dahlman 1992). Various modes of learning—including reverse engineering-based learning, visits to turnkey plant suppliers and training at their sites, and learning by imitating—turned out to be very effective in building capacities for achieving production targets.

During the technology introduction stage, private companies' interest in *internal* R&D investment was rather limited. With the enactment of the Technology Development Promotion Act in 1972, the country was able to establish an institutional framework for proving financial support, including subsidies for technology development and tax incentives for technology development reserve fund. Until the late 1970s, however, RoK companies' technology development activities remained low. There was only one corporate R&D centre in 1970, and most corporate R&D centres were concentrated in light industries such as textiles, food, agriculture, etc. until the mid 1970s. Beginning in 1979, however, corporate R&D centres began to increase in technology-intensive industries such as steel, electronics, automobiles, chemicals and shipbuilding with the government's strong encouragement (Hong et al 2010).

Building on this period of early industrialization—with increases in government funding policies to support the private sector and technology skill-building and instruction at the educational level, as well as an increased focus on heavy industries—the country experienced a major turnaround in the 1980s, when it entered the technology internalization stage.

TECHNOLOGY INTERNALIZATION STAGE (1981 – 1997)

Although RoK companies reached “late industrialization” mainly through learning, assimilation and adaptation from foreign mature technologies, they successfully produced competitive export goods, ranging from light to heavy and chemical industries in the 1960s and 1970s. However, in the aftermath of the second oil shock, and following the country’s massive investments in heavy and chemical industries in the 1970s, fueled by foreign loans, RoK suffered the triple hardships of an increased trade deficit, rising foreign debt and high inflation. In 1980, the country recorded its first negative economic growth, – 2.7 percent. In addition, the developed world began enforcing a free trade regime based on a neoliberal doctrine, calling on developing countries to open their markets and comply with intellectual property rights (IPR) protection. Pressured by these moves in developed countries, RoK realized that its reverse engineering-based technology catch-up was no longer a valid option and began to develop its indigenous technologies.

This section reviews the period when the RoK shifted its policy stance from industry-focused to technology-oriented. During this stage, which took place before the outbreak of the Asian economic crisis, the country managed to sustain its growth by nurturing indigenous technological capabilities through rapid increases in R&D investments by both the public and private sectors.

Shift of industrial policies from sectoral (industry) to functional (R&D)

Soaring oil prices in the aftermath of the second oil shock of 1979 dealt a major blow to the RoK economy. Reluctant to transfer their technologies to RoK, companies from developed countries also demanded a stringent IPR regime to prevent the country from catching up with their technologies through reverse engineering. This, in turn, highlighted the need strengthen domestic R&D efforts. In the meantime, RoK also saw a rapid surge of wages in the labour market, influenced by the growing power of the labour movement. This put the brakes on RoK’s export-driven strategy of promoting exports through imitation of foreign technologies based on cheap labour. In a bid to overcome these challenges at home and abroad, the RoK government set a goal in its 5th NEDP (1982 – 1986) of pursuing stability and balance rather than volume-oriented economic growth—the first case of such a policy shift in the country’s development history. While initiating the industrial rationalization strategy on overly invested heavy and chemical industries, the government shifted its policy focus from the government-led direct industrial promotion to indirect support for the private sector, adhering to market principles.

Conforming to the free trade regime, government regulations on FDI and FL were eased considerably in the 1980s, as shown in Table 9: RoK’s FDI openness improved significantly, from 44 percent in the 1970s to 66 percent in 1984 and 90.6 percent in 1994. In the case of both FDI and FL, the government gradually migrated from the “positive” list, industries eligible for FDI, to the “negative” list, industries not eligible for FDI. It later dropped off the list when it joined the WTO in 1995 (Kim 1997). In addition, developed countries steadily increased their IPR pressures on the RoK government as they started to recognize the country as a potential buyer. Such pressure finally led to the signing of an IPR Treaty with the United States in 1985. Since then, patent registrations in RoK filed by MNCs continued to increase. In particular, the revision of the Patent Act of Korea in 1987 allowing process and substance patents made it impossible for the country to maintain traditional ways of producing goods by imitation and increasing companies’ demand for technology transfer through FDI and FL, especially in the pharmaceuticals and chemicals industries (Hong et al. 2010).

Under the influence of the free trade regime and the WTO, industrial policies of the RoK government shifted from the previous vertical (selective) to a horizontal (functional) approach. A prime mode of government funding had been direct financial support for selected strategic industries through bank loans. However, this was diversified to include

indirect support using various funds aimed at industrial technology development and venture startups. Numerous funds for industrial and technological support were also established directly by the government or through its participation in private-sector programmes. [21]

The RoK government also supported private companies’ technology innovation by using public procurement to create domestic markets for them. Initiated by the second Technology Promotion Meeting in June 1982, the RoK government adopted a series of innovation-friendly measures within public procurement policies. Beginning in 1982, R&D investments could be reflected in product costs, in 1983 a quality index was included as one critical selection criteria from the lowest-priced government bid system, and a three-year procurement plan involving public agencies was announced in 1984 (Min et al. 2006). Public procurement was more powerful than direct R&D subsidies as market creation drew the full support of corporate leadership in R&D activities at the time (Kim et al. 1987).

Box 1 Public procurement programme for the computer industry during 1980s

The RoK government introduced a policy of public procurement of personal computers for public schools in 1982 to promote its newly emerging computer industry. It initially purchased 5,000 units of personal computers, followed by even more in subsequent years, and introduced the Project on Computerization of the Government Administration Services in 1983 (Kim and Dahlman 1992). As part of these programmes, the government put in place technical specifications and local content requirements for the procurement. This policy encouraged local manufacturers to enter the newly promoted industry and invest in indigenous R&D for the development and commercialization of high-tech computer products. As a result, the RoK computer industry gained initial success—a growth rate of 63.3 % and 91.6 % in production and exports, respectively, between 1983 and 1988. Since 1989, however, industry growth has slowed as the country failed to compete against other developing countries such as Taiwan (Cho 1995).

Technology drive with indigenous R&D efforts in both public and private sectors

During this stage, the RoK government aimed to secure international competitiveness through technology development to survive competition with both developed and developing countries. While developed countries maintained their technological advantage over the RoK, developing countries were leveraging cheap labour as their comparative advantage. Faced with such challenges, the RoK government revealed the 5th NEDP (1982 – 1986), in which it specified fostering high-tech industries as its key mission, with a goal of advancing industrial technologies and thus improving the country’s international competitiveness through S&T development.

To coordinate technology drive policies, the monthly Export Promotion Meeting, which had served as a control tower for the government’s export drive during the technology introduction stage, was benchmarked to launch in 1982 the quarterly Technology Promotion Meeting, chaired by the president. The RoK government operated this quarterly meeting from 1982 until 1990 with the participation of more than 200 experts from the government and the private sector, including ministers and corporate CEOs (STEPI 2017).

To promote indigenous R&D in the public sector, MOST became the first ministry to launch a large-scale national R&D project, the National Specific R&D Program, in 1982. Following this initiative, the Ministry of Trade and the

21 These programmes included National Investment Fund, the Industrial Development Fund, the Korea Development Bank Technology Development Fund, the Industrial Technology Promotion Fund, the Small & Medium Industry Promotion Fund, the Science & Technology Promotion Fund, the Information & Communication Promotion Fund and the Technology Finance Fund.

Ministry of Information and Communication kicked off similar R&D projects in 1987. These R&D projects continued operations in the 1990s, leading to the launch of the Highly Advanced National (HAN) Project [22] in 1992 and the Creative Research Promotion Program in 1997. As multiple ministries initiated their own R&D projects, the National Science and Technology Council was established as an advisory body, under the direction of the president, to facilitate inter-ministerial coordination.

The RoK government also introduced various policy measures to develop the indigenous technological capabilities of private companies. The presidential decree of 1978 recommended manufacturers with sales exceeding $ 0.3 billion establish their own affiliated R&D centres (Min et al. 2006). The Technology Development Promotion Act was revised in 1982 to strengthen a system called "reserve for technical development", promote corporate R&D centres' participation in national R&D projects and provide various kinds of tax and fiscal incentives for corporate R&D activities. The revision allowed GRIs and private companies to form R&D consortia. These national R&D projects provided opportunities for private companies to, initially, secure domestic markets for import substitution and export their market-proven products to overseas markets in a later phase. Thus, companies were eager to take part in these government R&D projects as they guaranteed high returns even with high-risk nature of technology development. The RoK government determined the appropriate number of participant companies, taking into account the estimated size of domestic and international markets. For new technologies under the R&D phase in which markets were nonexistent in RoK, the government created early markets for them upon the completion of technology development. The successful developments of TDX, CDMA and DRAM are good examples of successful import substitution and export-led technology transfer of advanced foreign technologies through joint public-private R&D (Chung and Ahn 2011). Through these measures, the number of corporate R&D centres soared from 54 in 1980, exceeding 1,000 in 1992, to 7,110 in 2000; and their R&D expenditure grew from $ 70 million to $ 8 billion during the same period. Overall, corporate R&D expenditures increased nearly 40-fold, from $ 564 million during the technology introduction stage (1962 – 1981) to $ 26 billion during the technology internalization stage (1982 – 2001) (Hong 2011). In the 1990s, RoK companies also initiated outward FDIs by opening overseas R&D centres and performing M&A activities.

The transfer of informal know-how between RoK companies and their counterparties from developed countries continued during this stage, via OEM or ODM contracts (Hobday 1995b; Hobday et al. 2004). In particular, for US companies that were being marginalized in the US market against Japanese companies in the 1980s and 1990s and were looking to set up a production base in developing countries, RoK companies were viewed as good OEM or ODM partners with improved technological capabilities. For RoK companies, OEM or ODM contacts with US companies also offered stable and consistent access to the advanced US market as well as informal learning. [23]

The shift to a technology-driven strategy also changed the country's human resources needs from skilled technicians to higher-quality scientists and engineers, highlighting the importance of research-oriented universities like KAIST. The enactment of the Basic Science Promotion Act in 1989 allowed numerous universities to transform from teaching-oriented to research-oriented higher education institutions. In addition, GRIs also played a key role as major suppliers of high-calibre talent, mostly graduates of leading science and engineering graduate programmes in the RoK. Some of them moved to private companies and others launched start-ups, which in turn accelerated the spread of the country's S&T-based innovation capabilities across industries (Hong 2011). RoK's technology internalization stage is often characterized by the spread of innovation capacity, driven by the mobilization of high-calibre researchers.

22 The project was known as the G7 Project as its main goal was to advance the nation's S&T capability to the level of the G7 countries.
23 Even RoK conglomerates like Samsung and LG kept their ODM contracts in some products while transitioning to OEM until the early 2000s (Hobday et al. 2004; Park 2016).

STI-supporting indigenous R&D and the private sector's transition to a leading position

With widespread awareness of the key importance of technological capabilities for national competitiveness, STI policies that were formerly considered supplementary measures supporting industrial policies soon became a central element in the government's industrialization strategy (Kim 1997). This also led to major changes in the country's technology supply strategy. A more stringent international IPR regime made it difficult for the RoK to continue its technological learning approach based on the imitation of foreign technologies, which consequently facilitated the development of indigenous technologies. With this goal in mind, the government launched the first national R&D programme in 1982. With the participation of private companies in the national R&D programme, the gross expenditure on R&D in both the public and private sectors increased dramatically, followed by rapid growth in patent activities. GRIs and private companies actively engaged in collaborative R&D throughout the 1980s and 1990s, but their roles and importance evolved gradually. At first, GRIs played a leading role in national R&D projects by absorbing and assimilating advanced foreign technologies and transferring them to local companies. From the 1990s onward, private companies began to take a leading role using strengthened technological capabilities acquired through their corporate R&D centres, thereby gradually weakening the leading role of GRIs. Accordingly, in the 1990s, the RoK government allowed private companies to select technologies to be developed under the national R&D programme by taking a demand-oriented technology development approach.

Regarding foreign technologies, formal transfer mechanisms such as FDI and FL were frequently used, along with previous capital goods imports and OEM/ODM contracts (with more to ODM). Throughout this period, RoK industries remained heavily dependent on foreign technologies, as reflected in the technology balance of payments, which remained merely at 0.05 (Table 7). In terms of patent applications and registrations, it was only until 1992 and 1996, respectively, that the share of patents applied for and registered by RoK nationals overtook that of foreigners. In summary, active R&D along with progressive foreign technology imports during the technology internalization stage paved the way for the next and final industrial technology development stage, technology creation.

TECHNOLOGY CREATION STAGE (1998 – PRESENT)

Until its admittance as a member of the OECD in 1996, the RoK economy had achieved steady growth through continuous industry upgrading (from low-end to high-end market segments within an industry), as well as diversification to high-tech industries. Many RoK companies had by then secured a strong position in the international market in many high-tech industries, including semiconductors, displays, automobiles, shipbuilding, mobile phones, steel and petrochemicals. However, the Asian economic crisis of 1997 brought about major changes in government-industry relations, corporate governance of large companies, management-labour relations and employment patterns. The accelerated privatization of the public sector and increased contribution of private companies to industrial technology development led the government's role to gradually dwindle, blurring the distinction between industrial and STI policies. The government's STI policies had to face another shift at the beginning of the new millennium. This section reviews the country's current, ongoing stage of technology creation, which is characterized by another round of policy shift from investment-driven to innovation-driven growth following the Asian economic crisis.

Nurturing a new growth engine in response to a dwindling growth rate

A key direction of RoK industrial policy in the late 1990s was to create market-oriented environment (Lim 2008). The disciplinary mechanism that had worked so effectively in the earlier stages of the country's industrialization process through various regulatory measures, including policy financing, was no longer a valid option. It was time to explore new industrial paths instead of pursuing the catch-up strategy of simply following benchmarks set by developed countries. Faced with a slowdown in its economic growth of less than 5 percent since 2000,[24] the RoK has been in dire need of a policy shift from the existing input-based, investment-driven growth to innovation-driven growth that will capitalize on technology innovations to sustain dwindled growth rate and create new jobs. Big conglomerates with own R&D capabilities also began to take their own strategies in competing globally, relying less on the public S&T system. As result, the supportive policies of the RoK government are now mainly aimed at discovering new emerging growth engines, investing in basic science research with universities and GRIs, cultivating SMEs and start-ups, and promoting balanced regional development.

First, as a specific measure to achieve these policy objectives, the RoK government has exerted its efforts to identify and nurture new technologies and industries with high job-creation potential. In the 2000s, for example, the government investments were concentrated on the so-called "6T" fields: information technology, biotechnology, nanotechnology, space technology, environmental technology and culture technology. In 2003, the government selected the top 10 industries as next-generation growth engines. A similar process of identifying future growth engine industries has been repeated every five years, upon the inauguration of a new president who serves a five-year term. More recently, the RoK government has been making serious investments in up-to-date technologies like AI, IoT, cloud computing, big data and mobile technology that are closely related to the 4IR.

Second, the government has been pursuing a strategy of investing in basic science research in the public sector, including in universities and GRIs, where there is suboptimal R&D investment due to the market failure approach. It has also been focusing more on SMEs and venture start-ups that possess creativity and huge potential for job creation instead of large conglomerates like Samsung, Hyundai and LG, which already have sufficient technological capabilities and international market competitiveness. SMEs and venture start-ups in ICT, materials, parts and equipment industries have benefited from the strategy.

Lastly, the government has been promoting balanced regional development to address the regional imbalance caused by resource concentrations on and near the capital city. To do so, the government has actively pursued the establishment of regional innovation systems led by regional stakeholders, including regional clusters, in consideration of varying regional characteristics. Many public institutions and agencies have also been moved to various parts of the country.[25] In these systems, regional stakeholders take their own initiative in planning, identifying and supporting regional innovations.

Adoption of an innovation system approach and efforts to improve efficiencies in STI policies

Innovation has been a keyword in the RoK's S&T policy domain since 2000, when the country officially announced its plan to shift its policy focus from investment-driven growth to innovation-driven growth. By that time, the STI policy infrastructure was well established and the level of investments in STI in scale and intensity was high in the RoK. Therefore, the government was highly interested in improving efficiencies in STI policies—in terms of governance, institutions R&D investment and contents, etc. Accordingly, the concept of the National System of Innovation was incorporated into the country's S&T policy in 2002 by the then new government. Further, the concept of a

24 Kim (2021) argues that the growth rate of the RoK economy since 2000 has been good compared to other OECD countries, while the political and social mood in the RoK has struggled to adjust to lower growth rates.

25 Similar to Brasilia, in Brazil, a planned city called Sejong City was constructed in the centre of the country, where government ministries and related public organizations have been relocated. By relocating most ministries from Seoul to Sejong, the government has indicated its strong intention to balance regional development.

4. Review of technology development experiences in selected East Asian countries

Box 2 Emergence of sustainability and inclusiveness in RoK development strategies

While common global challenges like global warming, sustainability and inequality have been emerging for quite some time, the global financial crisis of 2008 gave momentum to raise awareness of these issues in the RoK. In relation to inclusive and sustainable development, the government has pursued several seminal policies, including "Green Growth" in 2008 and, more recently, a Korean New Deal in both 2020 and 2021.

In 2008, the new RoK government adopted Low-carbon & Green Growth Strategy as its new vision by incorporating the concept of environmentally sound and sustainable growth into its development path. Still, the government conceived of the concept as a means of economic revitalization, with less consideration on sustainability. In fact, the status of the Sustainable Development Act and the Climate Change Act became degraded after the Low-Carbon Green Growth Basic Act was enacted in 2009. Nevertheless, the strategy became obsolete without much accomplishment with the election of the new government in 2013.

In July 2020, the RoK also announced the first iteration of the Korean New Deal as a way to cope with the economic recession caused by the COVID-19 pandemic, by using the American New Deal as a benchmark. The plan comprises three pillars: a digital new deal, a green new deal and a safety net for employment. This strategy is aimed at ensuring a swift transition to a digital and green economy so that the country would not lose international competitiveness in the process of digital transformation and transitioning to a low-carbon society. The main difference from previous policies is its third pillar—attempting to encompass the concept of inclusiveness and sustainability by building a safety net for employment as a means to address skills mismatch and income inequality that may arise as part of a digital and green transformation. This is the first instance that the RoK government has explicitly specified inclusiveness and sustainability as an important component of its major economic policies. It also reflects the heightened interest of RoK society in such social issues as social justice and wealth inequality, which have surfaced since the 2008 global financial crisis. In July 2021, the RoK government announced a renewed version of the Korean New Deal. Reflecting on several concerns of the previous version, including weak consideration of the impact of digital transformation in jobs, the Korean New Deal 2.0 expanded the idea of the safety net and changed its name to "human new deal". It is still too early to decide whether the plan is attaining the targets, but it is pivotal in that it is the first of its kind to include the concept of inclusiveness and sustainability at national policy level (Cho et al. 2021). There are also doubts, however, on the continuity of the plan, which is scheduled to last until 2025, since there will be a new presidential election in March 2022.

Regional Innovation System was also introduced to address the issue of regional imbalance of development, which encouraged the RoK government to make massive investments in building regional innovation systems tailored to regional needs and characteristics.

In 2001, the RoK government enacted the Science and Technology Basic Law and developed the Five-Year Science and Technology Basic Plan, under which the national R&D programme was redesigned to develop core technologies that can help the country secure competitiveness in promising future industries with huge job-creation potential. In 2002, the National Technology Road Map (NTRM) was developed to systematically identify technology-based new growth engines. Most of the R&D programmes implemented during this stage, including the 21st Century Frontier R&D Program (1999), the New Growth Engine Program (2008) and the Global Frontier R&D Program (2010), have aimed at securing core, cutting-edge technologies in future industries whose markets have yet to be formed. These technologies will then help the country secure future markets and international competitiveness. In addition, the Master Plan for Basic Research Promotion (2006 – 2010) was developed to strengthen basic science research at RoK universities and GRIs. As part of the plan, the government presented an investment target of KRW2.4 trillion, or 25 percent of government R&D expenditure, by 2010. Finally, in the early 2000s, the National Research Center, the Medical Research Center and the Advanced Basic Research Lab were launched to promote basic science research and industry-university collaboration.

At this stage, the ratio of gross expenditure on R&D in GDP increased significantly, from 2.13 percent in 2000 to 3.32 percent in 2010 and 4.64 percent in 2019. With a surge in R&D investment in the mid-2000s, RoK began deliberating on how to ensure the efficiency of its national R&D system and achieve qualitative along with quantitative growth in S&T. In other words, the country is constantly reviewing whether R&D inputs are optimal, corresponding outputs and outcomes are reasonable, and the R&D project selection and evaluation system is properly functioning. It also continues to explore ways to promote the commercialization of publicly-supported R&D outcomes.

There also arose the issue of lack of coordination and cooperation due to inter-ministerial silo effects, since multiple ministries besides MOST began their own R&D projects from the late 1980s onwards.[26] In response, the National Science and Technology Council (NSTC) was established as a control tower to coordinate all the reviews, analyses, evaluations and adjustments related to the national R&D programme and implemented by multiple government ministries, including MOST. In the history of the RoK government's organizational restructuring, the Minister of Science and Technology was once promoted to the prime minister's position to better coordinate inter-ministerial R&D activities.

Another issue in policy design and implementation is due to the fact that there is a change of presidency every five years. All the main policy initiatives led by each president lose their political momentum when a new presidential administration gets into power. Examples include "innovation-led growth" between 2003 – 2008, "green growth" between 2008 – 2013, and "creative economy" between 2013 – 2017, all of which became obsolete with the inauguration of a new government. As mentioned earlier, the current government's Korean New Deal initiative may face a similar policy situation after the next presidential election, scheduled for March 2022.

SUMMARY

The RoK's industrialization began with the first NEDP in 1961, and from the beginning, the strong linkage between industrial and STI policies was evident—in, for example, a bureau of the EPB becoming MOST, the 1st TPP as a tool for the 1st NEDP, in addition to the strong high-level support of the coordinating mechanism of the monthly Export Promotion Meeting throughout the technology introduction stage. During that stage, the country's basic STI infrastructure was established and GRIs played a role as contracting intermediaries supporting the needs of industry, which was then heavily dependent on foreign technologies.

During the internalization stage, the government pushed forward a "technology drive", with heavy investments in indigenous R&D activities, such as large-scale national R&D programmes, while industrial policies transitioned from taking a sectoral to a functional approach. GRIs played the role of an innovation intermediary to the needs of industry, supplying domestic technologies for industrial upgrading. In this stage, public-private partnerships were successful for high-tech national R&D programmes.

During the creation stage, the distinction between industrial and STI policies has become blurred. The focus of government policies in this stage is to revitalize the economy by promoting new growth engine industries to tackle the perceived lower economic growth rate. The main governmental policies now support SMEs and start-ups and promote basic science research with GRIs and universities. The government is also constantly reviewing STI policies to improve its STI system in terms of governance, institutions, R&D investment and contents, etc. Policy inconsistency, originating from a change in presidential administration every five years, has become a chronic issue.

Table 10 summarizes the evolution of industrial and STI policies over the course of the industrial development of the RoK.

26 As of 2019, MOST was responsible for approximately one-third of total national R&D, while other ministries accounted for the remaining two-thirds.

Table 10 Overview of industrial and STI policies in the industrial development of the RoK

Stage	Technology introduction stage (1961 – 1980)	Technology internalization stage (1981 – 1997)	Technology creation stage (1998 – present)
Major events	• US policy change from aids to loans (late 1950s) • Military coup (1961) • Nixon Doctrine (1969) • 1st oil shock (1973)	• 2nd oil shock (1979) • Military coup (1980) • IPR agreement with the United States (1985) • Accession to the WTO (1995) • Joining OECD (1996)	• Asian economic crisis (1997) • Global financial crisis (2008)
Key policies and institutions	• 1st five-year NEDP (1961) • Establishment of EPB (1962) • Establishment of Bureau of Technology Management under the EPB (1962), later becomes MOST (1968) • Establishment of KIST (1966), six GRIs (early 1970s), KAIST (1973) and NRF (1977) • S&T Promotion Act (1967)	• Technology Development Promotion Act (revised) (1982) • IPR agreement with the United States (1985) • FDI/FL policy shifts from positive list to negative list, and to abolition • Basic Science Promotion Act (1989) • Abolition of EPB & discontinuity of NEDP (1993)	• Establishment of National Science and Technology Council (NSTC) • Adoption of national/regional innovation system (2002) • Low-Carbon, Green Growth (2008) • Creative Economy (2013) • Korean New Deal (2020) and Korean New Deal 2.0 (2021)
Demand-side policies	• Strong coordinating mechanism for export industries through monthly Export Promotion Meeting chaired by the president (1965 – 1979) • Promotion of strategic industries: light industries (1960s) and heavy and chemical industries (1970s) • Loans to selected companies with disciplinary measures	• Shift of industrial policy from sectoral to functional approach • Incremental shift to trade and investment liberalization • Public procurement for new technology markets (1982)	• Promoting new growth engine industries to tackle low growth rate: 6T industries and next-generation growth engines • Promoting low-carbon industries (mid-2000s) and 4IR industries (late 2010s)
Supply-side policies	• Foreign technology assimilation through import of capital goods and turnkey projects with limited FDI/FL • Established basic S&T infrastructure, including a ministry, GRIs and a funding agency	• Increasing use of FDI and FL • Launch of large-scale national R&D programmes, first by MOST (1982) and later by other ministries (1987) • Technology Development Promotion Act allowed for public-private partnership R&D consortia • R&D incentives provided to private companies • Strong coordinating mechanism created for domestic R&D through quarterly Technology Promotion Meeting chaired by the president (1982 – 1990) • Basic research promoted with universities and GRIs (1992–)	• Policies focus on supporting SMEs and start-up ventures • Investments in basic research with GRIs and universities • Improvement of efficiency in public S&T system • Coordinating body for STI policies: NSTC (1999–)
Role of STI policies in industrial development	• Demand-side approach prevailed with STI policies as a tool for implementing industrial and economic policies • GRIs mainly played role of a consulting intermediary for industry in foreign technology sourcing	• Demand-side approach continued but with more emphasis on STI providing required indigenous technologies to industrial upgrading and diversification • GRI-led joint R&D in collaboration with private sector as an innovation intermediary	• Demand-side approach continued but change of the main policy target group from large conglomerates to SMEs and ventures • GRIs fill the gap of sub-optimal R&Ds on basic research as an innovation intermediary
Stage transition		• Two takeoffs: both R&D inputs (investment) and R&D outputs (patent registration) increased exponentially in early and mid 1980s, respectively • Two overtakings: (1) R&D investment by private sector overtook that of public sector in 1980; (2) number of patent registrations by residents overtook that of non-residents in 1993	• Significant improvement in terms of technology balance of payments since the late 1990s • Top level R&D input & output • National R&D programme targeting high-tech and emerging industries

Source: Authors' elaboration.

4.2 People's Republic of China [27]

INTRODUCTION

Over a relatively short period of time after the Reform and Opening-Up Policy in 1978, the People's Republic of China (herein: "China") has achieved remarkable economic growth, maintaining an annual average growth rate of 9.4 percent for more than 40 years. Despite a per-capita income of $ 10,610 in 2019 (World Bank 2021), it finally became the second biggest economy in the world after the United States, surpassing the United Kingdom and France in 2005 and Japan in 2010. [28] China was initially considered the world's factory, based on its comparative advantage of cheap labour cost. However, China has recently emerged as a leading industrial powerhouse, competing against advanced countries even in some high-tech and emerging industries, based on its strong S&T capacity. It has overtaken the United States in terms of the number of journal papers in 2018; and in terms of the number of the top 1 percent of highly cited papers, China has risen to world #2 after the United States in 2013 (NISTEP 2021).

This section chronologically outlines the evolution of STI policies over the course of China's industrial development, according to the aforementioned stages: technology introduction stage (1978 – 2001), technology internalization stage (2002 – 2011) and technology creation stage (2012 – present).

TECHNOLOGY INTRODUCTION STAGE (1978 – 2001)

Between 1949 and 1978, China's industrial technology policy focused on improving agricultural and industrial productivity, while pursuing space and defense technologies under the legacy of a Soviet Union-model S&T system. In the field of nuclear and space technologies, throughout the 1960s and 1970s China managed to succeed in the indigenous development of atomic bombs (1964), hydrogen bombs (1967), intercontinental ballistic missiles and satellites (1970) through the Two Bombs and One Satellite Project (Eun 2021). During the Cultural Revolution (1966 – 1976), however, China's S&T infrastructure was heavily disrupted, and the country became completely isolated from the international community (Sun 2002). Following the introduction of the Reform and Opening-up Policy by Deng Xiaoping in 1978, China pursued a market economy system and began to participate more fully in the international community. These dramatic changes helped to spur China's rapid industrialization. This section reviews China's technology introduction stage, spanning from the introduction of the Reform and Opening-up Policy in 1978 to China's joining of WTO in 2001, when the country actively sought the introduction of advanced foreign technologies based on the Trading Market for Technology strategy.

Industrial policy and failed attempt at trading market for technology

Immediately after the Cultural Revolution, China vigorously pushed forward import substitution in light industries to tackle the shortage of commodities, vital elements to the life of the Chinese people. Through a policy called the Six

27 Unless otherwise referenced, the content in Section 4.2 People's Republic of China and 4.3 Thailand is based on Park et al. (2021), which was implemented as a component of the joint research project between UNIDO and STEPI.
28 See Korea Joongang Daily, https://www.joongang.co.kr/article/23854466#home (accessed 31 August 2021).

Priority Supports for Light Industry, the Chinese government provided the following six types of support for its light industries:
(1) raw materials and power supplies;
(2) equipment and facility renovation;
(3) infrastructure building;
(4) bank loans;
(5) introduction of foreign capital and technologies; and
(6) transportation services (Choi et al. 2020).

This served as momentum for the Chinese government to shift the focus of its industrial policy from heavy to light industries. The 6th Five-Year Plan (covering 1981 – 1985), the first of its kind developed after the introduction of the Reform and Opening-Up Policy, also specified the government's shift in focus towards light industries.

The State Council of China conducted case studies from 1985 to 1987 to analyse the industrial policies of Japan and the RoK. Based on the results of the study, the first industrial policy of the Chinese government, the Decisions on the Important Issues of Current Industrial Policies, was developed in March 1989 using the Japanese and Korean cases as benchmarks. This policy was aimed at restructuring manufacturers of luxury goods and goods experiencing shortages of raw materials and improving their outdated processing technologies, while pursuing the advancement of basic industries like agriculture, energy, transportation and raw materials. In November of 1989, an additional policy called Decision on Advanced Governance Restructuring and Reform was instituted to improve industrial policy governance over a three-year period to address the following structural issues of the Chinese economy:
(1) over-production exceeding required supplies;
(2) unbalanced development between agricultural and industrial sectors;
(3) outdated basic industries and their facilities relative to processing industries; and
(4) low efficiency in manufacturing, retail and construction sectors (Choi et al. 2020).

Then in March 1994, the State Council released the Outline of National Industrial Policy for the 1990s, which is often viewed as the Chinese government's first industrial policy incorporating market mechanisms (Choi et al. 2020). It specifies that the country abide by the principle of "establishing a socialist market economic system so as to give a basic role to the market for the allocation of resources under the macro-economic control by the State." It also emphasized the need for designating and promoting the following four sectors as the country's pillar industries:
(1) electronics and machinery;
(2) petrochemicals;
(3) automobiles; and
(4) construction.

This outline policy was then followed by subsequent policies on specific industries covering automobiles, energy, software and semiconductors.

From the early phase of the Reform and Opening-Up Policy, China actively pursued the Trading Market for Technology Policy to secure a sufficient supply of capital and technologies that it had lacked to date (Mu and Lee 2005; Yeo 2019). For foreign companies, the only way to secure access to the Chinese local market was to set up IJVs with Chinese counterparts. Through IJVs with their Chinese partners, foreign companies were provided market access and tax incentives on the condition of producing and selling goods within China. This policy was frequently adopted in the automobile, chemical and electronics industries. The Chinese government expected that Chinese companies would learn advanced technologies from foreign counterparts in the process of establishing IJVs and producing goods via IJVs, including active technology transfer. Driven by this policy, FDI increased significantly as a result.

However, technology transfer did not take place as frequently as expected (Cho 2007). Such low performance in technology transfer can be explained by factors related to foreign and Chinese local companies. First, foreign companies allowed R&D of their core technologies to be conducted only at their headquarter sites. Their technologies were already embodied in the capital goods imported to China, whereas only low value-added, simple assembly works were performed within China, giving Chinese companies little opportunity to absorb foreign technologies and improve their own technological capabilities. Satisfied with just increased IJV sales and earnings, the Chinese counterparts of IJVs did not make much effort to assimilate imported foreign technologies. Despite a wider opening of Chinese industries to foreign companies by the Chinese government in 1992, the Trading Market for Technology Policy had done little to help Chinese companies' enhance their technological capabilities (Yeo 2019). [29]

Restored STI infrastructure and some success in commercialization of S&T

China's S&T policy focus during this introductory stage was on restoring a damaged S&T ecosystem. With the inauguration of the Deng Xiaoping government, China started to bring scientists and researchers back to the research frontlines, rebuild S&T related organizations and relaunch R&D projects, while emphasizing S&T as the country's key productive force and recognizing scientists as workers. The Chinese government explicitly stated the importance of S&T on economic development in 1982 (Sun 2002). Against this backdrop, the 1978 – 1985 Outline of National Science & Technology Development policy was instituted (陈劲等 2013). It was designed to revitalize the Chinese S&T system by increasing R&D funding and restoring R&D facilities. However, the policy emphasized only basic research for GRIs in the public sector (Sun 2002). In 1983, the Leading Group for S&T was also established by the State Council to serve as a coordination body headed by the premier, with minister-level members reviewing national S&T strategies and policies and addressing inter-ministerial affairs.

With the Decision on the Reform of the S&T System in 1985, the Chinese government tried to shift the focus of public-sector R&D from basic research to commercial production by presenting the following strategic orientation of the country's S&T policy: "economic construction should rely on the development of S&T and they in return should be geared to the needs of economic construction" (张永凯 2019). The key contents of this policy included:

(1) promoting the commercialization of technology outcomes and developing technology markets;
(2) organizational restructuring of the S&T system and strengthening R&D capabilities;
(3) reforming the agricultural S&T system and pursuing specialization, commercialization and modernization of rural regions;
(4) expanding research institute autonomy and improving government organization control and management of S&T related works;
(5) emphasizing the opening-up and global expansion of S&T as a long-term policy goal for developing China's S&T; and
(6) reforming S&T human resources management system.

Subsequently, the Chinese government also gradually reduced R&D funding for GRIs in order to increase GRI participation in newly created technology markets (commercialization of R&D outputs) [30] and changed its funding system in 1986 from an assignment to a bidding system (Gu 1999). However, this reform policy failed to garner the expected results (Sun 2002). While Chinese GRIs did produce technologies that were commercially unproven, private companies did not have sufficient technological capabilities to assimilate, adapt, modify and utilize them in their production. In 1987, the Chinese government even tried to merge GRIs with state-owned enterprises, but to no avail as cultural differences, reluctance of supervising ministries and partial integration of finance with limited control proved onerous (Gu 1999).

To a certain extent, there was positive entrepreneurship from GRIs during this reform period. Start-ups originating from universities and GRIs in the public sector were successfully launched—especially in high-tech industries capitalizing on their S&T capabilities. As explained earlier, Chinese firms during this period lacked capabilities to internalize and commercialize technologies possessed by universities and GRIs. Taking advantage of this situation, professors and researchers within universities and GRIs launched start-ups on their own, generating numerous enterprises run by universities and research institutes (Lee et al. 2011; Eun et al. 2006). Among successful examples are Lenovo, Founder and Tsinghua Tongfang in the personal computer industry and Dongruan in the software industry. Eun (2021) describes this development as vertical integration of research-industry linkage (or research internalizing business activities) because universities and GRIs maintained their involvement in the operations of their businesses.

During this technology introduction stage, the Chinese government implemented a series of successive national mid- and long-term R&D programmes and commercialization projects as a way to integrate S&T into industrial development. In 1986, the Chinese government announced the National High-Tech Development Plan (herein: "863 Program"), its first mid- and long-term R&D plan in S&T. The 863 Program aimed to improve China's technological level to that of developed countries in 15 specific technologies in seven selected high-tech fields, including biotechnology, space, information and telecommunications technology, laser technology, automation, energy and new materials (王蕾 2021). In 1988, the government also developed the Torch Program to promote the commercialization and industrialization of Chinese high-tech products. S&T Service Centers were established and High-Tech Industrial Development Zones were designated in key regions throughout the country to promote the advancement and commercialization of seven core technologies: microelectronics, IT, biotechnology, new materials, mechatronics, laser technology and energy.

China's Decision on Accelerating Scientific and Technology Progress in 1995 also presented the Strategy of Revitalizing China through Science and Education, which called for progress in education as well as in S&T as a powerful engine for the country's socioeconomic growth. The strategy was specifically aimed at pursuing S&T innovation and industrialization and improving the indigenous innovation capabilities of China's S&T. Several projects were proposed, including the 211 Project and the 985 Project. The former was focused on making Chinese universities globally competitive, while the latter targeted the development of world-class Chinese universities. As student enrollment in universities increased, these policies provided educated scientists and engineers to the industrialization of China (Eun 2021). It is important to note that during this stage, S&T policy was not simply aimed at assisting technology development; it was also focused on promoting R&D required for industrial technology development. For this reason, the Law on Promoting the Transformation of Scientific and Technological Achievements was enacted in 1996. And in line with the 1995 Strategy, the Leading Group for S&T and Education was reorganized from the previous Leading Group for S&T by the State Council, with similar responsibilities and a coordination body chaired by the premier and minister-level members from S&T, Education and Finance ministries, among others.

These plans and policies enacted during China's technology introduction stage have had a positive impact, as they all encouraged and expanded R&D investments and supply of human resources for the country's industrial technology development. Despite these obvious merits, the impact of these plans and policies, especially those related to R&D, remained rather limited due to the supply-side approach of the S&T system, the fact that GRIs acted as producers and private companies as users, and the lack of private companies' innovation capacity, including their capabilities to absorb external technologies (Eun 2021).

29 One exceptional case was the telecommunication equipment industry, where Chinese companies benefited from successful technology transfer from foreign companies through IJVs. Technology diffusion also took place within the industry, driving indigenous Chinese manufacturers to emerge and dominate the market from the mid-1990s onwards (Mu and Lee 2005).

30 Government funding decreased from 64 percent in 1986 to 28 percent in 1993 in GRI budgets (Eun 2021).

TECHNOLOGY INTERNALIZATION STAGE (2002 – 2011)

The Trading Market for Technology Policy strategy, which was based on the size of the Chinese domestic market, did not bring much success in promoting technology transfer through IJVs during the technology introduction stage. Rising labour costs resulting from economic growth made it inevitable for China to shift to higher value-added industries. It was predicted that China would lose competitiveness in the technology-based international market if it insisted on continuing its heavy dependence on foreign technologies when joining the WTO was imminent. In consideration of these changes at home and abroad, from the late 1990s China began to expand its R&D investment to spur indigenous innovation.

Industrial policy to promote high-tech industries

During this stage, China's joining of the WTO incorporated the country into the global value chain, which led to intensified competition in both the local and international markets. Chinese companies were thus pressured to upgrade their technologies, promoting indigenous technologies, which spurred full-fledged domestic R&D efforts. In the meantime, the share of high-tech industries in China was quite low, relative to that of capital-intensive heavy industries like steel, cement, coal and petrochemicals. Therefore, the Chinese government began emphasizing the need to develop high-tech industries along with an overall upgrade of its existing industries, and announced the National Industrial Technology Policy twice, in 2002 and 2009. As part of this policy, corporate-led R&D centres were established, corporate R&D investments were expanded, and industry-research collaboration was soon in high demand. As result, the number of R&D centres affiliated with mid- to large-sized companies, R&D investments, and the number of patent registrations rose roughly 3 times, 2.5 times and 5 times, respectively, from 2000 to 2012 (Choi et al. 2020).

In 2002, upon the leadership change to Hu, the 16th National Congress set a New Path to Industrialization to pursue the development of high-tech industries more fully. And in 2007, China announced the 11th Five-Year Plan, which set forth a national target of raising the share of high-tech industries' value added in GDP to more than 10 percent and their share of exports to 30 percent. The plan suggested target industries to be promoted, including ICT, biotechnology, space, new materials and new energy. The government also announced a more comprehensive plan for developing high-tech industries, including the cultivation of large high-tech companies, the expansion of high-tech exports and the establishment of industry clusters.

That same year, industry-research alliances were set up by industrial sectors under the sponsorship of the government, which provided industry-specific support for steel, coal, chemicals and agricultural equipment. Through industry-university-research partnerships, efforts were made to strengthen industrial competitiveness by industry sector (OECD 2008). This occurred with the change to the policy covering relationships between universities, GRIs and industry that dated from the early 2000s. The government pushed forward this break from the earlier vertical integration linking research and industry since university-run and GRI-run enterprises occasionally brought big financial and organizational problems to universities and GRIs. Subsequently, beginning in 2004, university-run and GRI-run enterprises became more independent from the private sector and the linkage between research-industry became horizontal (Eun 2021).

As a response to the global financial crisis of 2008, the Chinese government issued the Decision on Accelerating the Development of Strategic Emerging Industries in 2010 to develop a group of technology-intensive industries as new growth engines. The emerging industries selected in the document included next-generation information technology, biotechnology, advanced equipment manufacturing, new energy, new materials and new energy vehicles. This policy was aimed at identifying emerging industries—ones that did not overlap with the country's existing core industries—that would lead China's future economic growth.

Along with these policies, the Chinese government also pushed forward intensive industrial restructuring for industries that had exhibited chronic over-supply issues since the 2000s. Beginning in December 2003, the government restricted new entrants and investments in steel, aluminum, cement and automobile industries with stricter environmental regulations. In September 2009, industrial restructuring measures were again adopted to address overlapping investment and oversupply issues in new emerging industries like wind power equipment and solar panels (Choi et al. 2020).

During this technology internalization stage, China's rapid industrialization was accompanied by a gradual dissemination of such concepts as sustainable growth and green growth, which gave birth to renewable energy industries focusing on solar and wind power. Despite its disadvantage as a latecomer, China attempted to develop renewable energy industries as an opportunity to leapfrog advanced countries as well as to resolve contemporary energy security and environmental challenges (Oh 2014). In the 2000s, the Chinese government tried to induce local and foreign companies' market participation in green industries by creating local solar and wind power markets. It also introduced some regulatory measures like local content requirements and import tariffs on intermediate goods to promote technology transfer between Chinese and foreign companies. Capitalizing on the local markets, Chinese companies acquired technological independence through indigenous development in photovoltaic industry and the takeover of foreign companies in the wind turbine industry. They emerged as new global leaders in both solar and wind power generation markets (Fu and Zhang 2011; Gandenberger and Strauch 2018).

In addition to the renewable energy industry, the state's heavy involvement in creating demand for markets was, among other factors, a major reason for China's success in its technological catch-up of high-tech industries like telecommunication equipment and high-speed rail. The state nurtured indigenous technology development by announcing TD-SCDMA as one of the national standards for 3G networks in the telecommunication equipment industry, and the Mid- and Long-term Railway Network Plan 2004 to spur the high-speed rail industry (Zhou et al. 2016). [31]

Heavy investments in STI in tandem with the reform of the S&T system

During this stage, the Chinese government began to make systematic efforts to implement S&T policy in a full-fledged manner. Under the Strategy of Revitalizing China through Science and Education, the government introduced the concept of innovation policy and pursued a reform of shifting from a GRI-centred R&D system to a firm-centred innovation system. It also carried out a reform of GRIs, including the Chinese Academy of Sciences (CAS), while promoting the government R&D programme on a large scale.

In 1999, the Chinese government issued the Decision on Strengthening Technical Innovation, Developing High Technology and Realizing Industrialization, which presented four key policy directions:
(1) strengthening technical innovation, advancing high technologies and realizing industrialization;
(2) significantly improving social productivity;
(3) building a policy environment conducive to high technologies and their industrialization; and
(4) strengthening the government's leadership and guiding capacity.

Under this policy stance, China's national R&D investment surged rapidly from 1999 (as already shown in **Figure 5**). The share of R&D investment in GDP rose from a mere 0.6 percent in 1997 to over 1 percent in 2002 and reached 1.7 percent in 2009. It is widely agreed that this policy was conducive to the systematic and stable development of S&T by implementing a "government-led and market-driven S&T system" model and introducing an open competition system in S&T development, allowing market mechanisms to function in allocating S&T resources (张永凯 2019).

31 The heavy involvement of the state in demand creation can also be seen in the Chinese civil aircraft industry during the 2010s, with policy measures of local standard-setting and public procurement (He 2015).

One of the biggest issues in China's S&T policy during the technology internalization stage was the reform of the Chinese Academy of Sciences (CAS), a core knowledge supplier to China's S&T system. In 1997, CAS presented to the government a plan to reform in its report on the "establishment of national innovation system in preparation for knowledge-based economy"; the reform initiative was officially approved by the Chinese government in 1998. Accordingly, reforms of GRIs such as CAS were carried out throughout the 2000s (Lee and No 2005; Frietsch 2020b). As part of its reform initiative, CAS presented the following specific activities to achieve its three-staged reform goals:
(1) reforming the knowledge innovation process;
(2) ensuring reasonable resource allocation;
(3) pursuing organizational restructuring;
(4) pursuing system reform and management innovation;
(5) developing and utilizing innovation teams;
(6) encouraging the opening up of and collaboration with external parties;
(7) promoting an innovation culture; and
(8) refining the innovation infrastructure (Lee and No 2005).

In fact, the CAS reform brought about major changes to China's industry-university-research collaboration system. Significant structural changes were made, moving away from the Soviet Union model of government-led, top-down S&T research to a system of creating frontier scientific knowledge led by public institutions with strengthened linkages between R&D and technology commercialization.

During this stage, the National Mid- and Long-Term Program for Science and Technology Development 2006 – 2020, which best represents the Chinese government's STI policy drive, was established. The plan emphasized sustainable economic growth as well as S&T innovations to address socioeconomic problems by designating seven priority areas:
(1) energy;
(2) water and mineral resources;
(3) environment;
(4) agriculture;
(5) manufacturing;
(6) transportation; and
(7) information and modern services.

After China joined the WTO, it started to emphasize the importance of developing high-tech industries, implementing various support policies to cultivate indigenous high-tech companies. In fact, throughout the technology internalization stage, the government consistently emphasized indigenous innovation by Chinese innovation actors, which led to an immense increase in R&D budget and intensity, number of universities and headcounts of R&D-related human resources. Meanwhile, it kept mandating the establishment of IJVs between local and foreign companies for new entrants into the Chinese domestic markets and put an emphasis on technology transfer of foreign technologies, which caused occasional conflicts of technology transfer and other unfair market practices (Andreff 2015).

TECHNOLOGY CREATION STAGE (2012 – PRESENT)

After a long period of high growth over 10 percent, China's economic growth rate dipped to a range of 7 percent in the 2000s. In 2012, the 118th National Congress of the CPC announced an innovation-led development strategy, signaling the start of an intense competition with developed countries. Once considered simply a global factory, China has emerged as a leading industrial powerhouse by promoting cutting-edge R&D efforts in future high-tech industries such as electric vehicles, space and satellites, supercomputing, semiconductors, quantum computing and communication, AI, 5G and biotechnologies, along with more robust investments in basic science.

Industrial policy for a self-sustaining and outward-oriented economy

China's industrial policy during the technology creation stage is best represented by the following key initiatives: Made in China 2025, for upgrading manufacturing industry; Internet Plus Initiative, for creating emerging industries; and Mass Entrepreneurship and Innovation Initiative, which promotes entrepreneurship and start-ups. In addition, China is attempting to emerge as a leading industrial powerhouse, with core strengths in high-tech and knowledge-intensive industries, by implementing the Belt and Road Initiative, often dubbed China's Marshall Plan, along with the New Infrastructure Construction Plan, the Chinese version of a New Deal for transforming the country into a digital superpower and overcoming the COVID-19 crisis.

The most representative policy of this current stage is Made in China 2025, a national strategy to address China's chronic oversupply issue and achieve qualitative growth. This strategy specifically aims to promote 10 key sectors and transform them into high-tech manufacturing industries through restructuring and technology innovations in traditional manufacturing industries. The 10 key sectors cover:
(1) new information technology;
(2) high-precision numerical control tools and robots;
(3) aerospace equipment;
(4) marine equipment and high-tech ships;
(5) advanced railway equipment;
(6) energy-saving and "new energy vehicles" (NEVs, which include battery electric vehicles, plug-in hybrid electric vehicles and fuel-cell electric vehicles);
(7) power equipment;
(8) agricultural machinery and equipment;
(9) new materials; and
(10) biomedicine and high-performing medical devices (Baek et al 2018).

In addition, the Internet Plus Initiative is geared towards making technological progress, improving efficiency and conducting organizational reform by converging internet technology with various social and economic sectors of China. This initiative is expected to help China's successful transition to a new socioeconomic development mode with enhanced innovation capacity and productivity of the real economy.

During this stage, the Chinese government has also pushed forward state-led, mega-size projects to create demand. One of the most well-known of these is the Belt and Road Initiative, which is designed to link China with Europe, Asia and the wider world through land and sea routes. This initiative, often dubbed the Silk Road Project of the 21st century, was first revealed at the APEC Summit Meeting held in Beijing in November 2014. According to official data released by the Chinese government, geographical areas covered by this initiative contain 4.4 billion people (63 percent of the world's population) with an aggregate GDP of $ 2.1 trillion (approximately 29 percent of global GDP). As part of the initiative, China is stepping up its efforts to construct core infrastructure, including railways, expressways, harbors, electricity and telecommunications, using the locally developed Bei Dou Navigation Satellite System.

To recover in the aftermath of the COVID-19 pandemic and progressively respond to the need for increased digital transformation, the Chinese government announced the New Infrastructure Construction Plan on 22 May 2020. Being differentiated from traditional infrastructure projects, seven key areas of projects have been selected for new infrastructure:

(1) 5G networks;
(2) data centres;
(3) AI,
(4) NEV charging stations;
(5) industrial internet;
(6) ultra-high voltage equipment; and
(7) high-speed railway.

The core of the Chinese-version New Deal programme is to build and expand 5G- and AI-related infrastructure required for the 4IR and promote the high-speed railway and electric vehicle industries, where China maintains a comparative advantage. These seven key areas of the plan are also closely related to the 10 key areas of Made in China 2025 and the 11 convergence areas of the Internet Plus Initiative (Baek, et al. 2018). Compared with previous New Deal policies—like the Western Region Development Policy and Four Trillion Yuan Policy, implemented by the Chinese government for the purpose of overcoming the Asian and global financial crises—the New Infrastructure Construction Plan of 2020 has a wider scope, with its focus placed on AI and digital transformation.

Another important policy shift in 2020 was change from the export-based growth strategy to the "dual circulation" strategy, reducing its reliance on international markets and increasing the growth of the domestic market (so-called "internal circulation").

STI policy to compete in future strategic industries

China's S&T policies that have been implemented since 2010, when the country's S&T and industrial foundation was solidified, are mostly geared towards building and upgrading its national innovation system and achieving strategic goals for emerging as an innovation superpower.

The comprehensive Opinions on Deepening the Reform of S&T System and Accelerating the National Innovation System policy was issued in 2012 for the purpose of reforming China's national S&T system and building its national innovation system. This policy aimed to build a foundation for a uniquely Chinese national innovation system by 2020 and enhance self-supporting innovation capabilities, while complying with the principles of a socialist market economy and scientific development (薛澜, 何晋秋 2016; 曹希敬, 袁志彬 2019). Later, the Outline of the National Innovation-Driven Development Strategy of 2016 presented China's long-term STI direction (曹希敬, 袁志彬 2019; 穆荣平, 陈凯华 2020). This strategy is a three-phased goal to pursue innovation-driven development. The goal of the first phase is for China to join the ranks of innovative countries by 2020 while building an indigenous national innovation system unique to China, by achieving targets of 2.5 percent of GDP share in R&D investment and 20 percent of GDP in knowledge-based service industries. The second phase focuses on China becoming a global innovation leader, with China's key industries positioned in the upstream of the global value chain and the share of R&D investment in GDP raised to 2.8 percent by 2030. The goal of the third phase is for China to emerge as a global STI superpower by 2050 (Baek et al. 2018; 陈劲 2020).

During its technology creation stage, the Chinese government has fiercely expanded its R&D investment in strategic emerging technologies such as electric vehicles, space and satellites, supercomputing, semiconductors, quantum computing and communication, AI, 5G and biotechnologies. When application research is needed for technology commercialization, private companies take the lead in forming industry-university-research consortia and running technology demonstrations, whereas the government's role is in providing R&D funding and pilot project complexes for respective technologies. This intention was very much in focus during the implementation of the New Generation Artificial Intelligence Development Plan in 2017. First, the government designated 15 innovation parks as AI Open Innovation Platforms and established AI Industry Development Alliances, members of which include high-level government officials, renowned professors and experts from the private sector (Baek et al 2020). Then, private companies like Baidu (autonomous driving), Alibaba (smart city), and Tencent (medical imaging) were tasked with playing leading roles within the industry-university-research collaborations, especially in implementing pilot projects in hopes for faster commercialization of AI. Similar policies are being applied for other digital technologies, such as 5G, block chain, etc.

In its Outline of the 14th Five-Year Plan (2021 – 2025) for National Economic and Social Development and the Long-Range Objectives through the Year 2035, announced in 2021, the Chinese government presented development goals for seven key S&T fields and eight key industries, along with specific targets for maintaining a total R&D investment growth rate of over 7 percent, expanding the share of basic research in the total R&D investment to 8 percent, and creating 12 high value-added patents per 10,000 population. Of the industries that were selected for the Made in China 2025 Strategy, aerospace is included in this list of emerging industries of the 14th FYP, which also aims to develop all other industrial sectors, except for agricultural machinery.

During this creation stage, China has clearly set forth its goal of emerging as a high-tech superpower. When it comes to S&T policy, China has presented national goals that demonstrate China's confidence in its emergence as an innovation superpower while implementing a set of policies to upgrade its indigenously formed STI ecosystem. In fact, China has already reached the world's top level in various S&T indicators, such as R&D investment and number of researchers, publications and patents (NISTEP 2021). Amid an ever-intensifying competition with the United States, the following policy measures are being emphasized:
(1) promoting technological self-reliance and basic research as an effective countermeasure to US sanctions;
(2) strengthening international cooperation with third-world countries; and
(3) pursuing the Dual Circulation Economic Strategy, a growth policy focused more on the domestic market.

SUMMARY

Our analysis of the evolutionary changes in China's industrial and S&T policies reveals the following. After the introduction of the Reform and Opening-Up Policy in 1978, the Chinese government strived for technology transfer from foreign countries through the Trading Market for Technology Strategy, which failed to develop local Chinese companies' technology absorption and assimilation capabilities. However, Chinese universities and GRIs were able to engage in active technology commercialization, leading to the establishment of a myriad of enterprises run by universities and GRIs (Lee et al. 2011; Eun 2021).

Prior to China joining the WTO, the need for indigenous R&D and technological self-reliance had been a consistent focus within China since the late 1990s and led to a significant increase in R&D activities in the country's public and private sectors. In the mid-2000s, China began to develop a private sector-led innovation ecosystem and stepped up its policies of mandating foreign companies entering the Chinese market to transfer their technologies and set up IJVs with Chinese counterparts. This led to the emergence of indigenous Chinese companies with technological capabilities suited to specific industrial sectors. Further supported by the Chinese government's increased R&D support, expanded subsidies and policies favoring local Chinese companies, Chinese companies started active technology catch-up in a full-fledged, comprehensive manner.

The 2010s saw explosive growth of indigenous Chinese companies in core industries, the emergence of big-tech Chinese companies as competitive as their global rivals in newly emerging industries (for example, the internet and platforms), and some successful cases of public technology commercialization (such as high-speed railways) that China had long been lacking. Since 2015, China has been also making intensive investments in future high technologies such as AI, quantum computing and 5G networks. In addition, mega-size global projects like the Belt and Road Initiative are being actively implemented, creating formidable market demands.

While there is intensifying competition between China and the United States for global economic hegemony, which began with the trade conflicts between the two rivals, China's industrial and S&T policies are now facing a major turn. Currently, the country is focused on inward-looking policies with self-sustaining supply chains in key strategic industries and domestic market-led economic growth. In areas where China lacks technological capabilities, the government is now calling for strengthening the role of Chinese innovation actors and making all-out efforts to accelerate technological self-reliance.

Table 11 summarizes the evolution of industrial and STI policies over the course of the industrial development of China.

4.3 Thailand

INTRODUCTION

Like the RoK and China, Thailand has also experienced changes in its industrial structure over the past 60 years, transitioning from an agriculture-based to an export-led manufacturing economy (**Table 12**). In 1951, the agricultural sector accounted for 44 percent of Thailand's total GDP, but the share dropped to 8.6 percent in 2020 (World Bank). During the same period, the share of the manufacturing sector in the country's total GDP grew from 13 percent to 27.5 percent, allowing Thailand to position itself as a manufacturing-based economy focused on the automotive and electronics industries (NESTA 2020). In the meantime, the services sector (which includes the tourism industry) is responsible for about half of the country's GDP and represents 40 percent of the country's employment. When it comes to the industrial sector, electronics and automotive manufacturers account for 39 percent of the country's GDP. While the agricultural sector accounts for only 10 percent of Thailand's total GDP, it is still responsible for 35 percent of the country's employment, which testifies to a vital overall role the agricultural sector continues to play in the Thai economy (Intarakumnerd 2019; UNCTAD 2015).

Table 12 Share (%) of total Thai GDP, by major production sector, 1961 – 2020

Sector	1961 – 1970	1971 – 1980	1981 – 1990	1991 – 2000	2001 – 2010	2011 – 2014	2020
Agriculture	31.1	25.4	16.8	10.0	10.6	12.3	8.6
Industry	22.8 (14.2)	27.9 (19.0)	32.8 (23.3)	40.2 (29.5)	43.7 (34.4)	42.8 (34.1)	33.1 (25.2)
(Manufacturing)	46.0	46.7	50.3	49.8	45.7	44.9	58.4

Source: World Bank databank, with data extracted from ADB (2015).
Note: GDP … gross domestic product.

Table 11 Overview of industrial and STI policies in the industrial development of China

Stage	Technology introduction stage (1978 – 2001)	Technology internalization stage (2002 – 2011)	Technology creation stage (2012 – present)
Major events	• Cultural Revolution (1966 – 1976) • Reform and Opening-up Policy (1978) • Establishment of Sino-US diplomatic relations (1979) • Deng's Southern Tour (1992) • Leadership change to Jiang (1992)	• Asian economic crisis (1997) • Return of Hong Kong (1997) and Macao (1999) to China • Accession to the WTO (2001) • Leadership change to Hu (2002) • Global financial crisis (2008)	• Leadership change to Xi (2012) • Sino-US trade dispute (since 2018)
Key policies and institutions	• 6th FYP (1981 – 1985): 1st integration of S&T planning • Shenzhen Special Economic Zone (1980) • Decision on the Reform of the S&T System (1985) • Spark (1985), 863 (1986), Torch (1988) and 985 (1998) R&D programmes • Strategy of Revitalizing China through Science and Education (1995)	• Western Region Development Policy (2000 – 2010) • National Industrial Technology Policy (2002 and 2009) • National Mid- and Long-Term Program for S&T Development 2006 – 2020 (2006)	• Belt and Road Initiative (2014) • Made in China 2025 Strategy (2015) • Internet + (2015) • Outline of the National Innovation-driven Development Strategy (2016) • New Infrastructure Construction Plan (2020) • Dual Circulation Strategy (2020)
Demand-side policies	• Industry promotion begun based on FDI since 1978 and its expansion after Deng's Southern Tour (1992) • Priority on consumer goods industry (1980s) • Promotion of pillar industries (1994): 1st industrial policy in China	• Promotion of renewable (solar and wind) energy (2000s) • Demand creation in high-tech industries (telecommunication, high-speed railway) • Promotion of strategic emerging industries (2010–)	• Promotion of NEV and battery industries (2010s) • Demand creation in domestic markets with New Infrastructure Construction Plan (2020) and Dual Circulation Strategy (2020)
Supply-side policies	• Restoration of S&T infrastructure (1977 – 1980) • Push to commercialization of R&D outputs of GRIs • Relied on trading market for technology based on FDI for sourcing foreign technologies • Establishment of Leading Group for S&T (1983)	• Continued IJV arrangement for FDI for sourcing foreign advanced technologies • Reform of GRIs to stimulate industrial technology development • Strong university-GRI-industry collaborations for high-tech industries	• Strong university-GRI-industry collaborations continued with private companies leading national R&D programmes in new digital technology sectors
Role of STI policies in industrial development	• Supply-side approach: GRIs as technology producers and industry as users • Inherited a Soviet model S&T system, attempted to link GRIs' outputs in public sector into commercialization • Success of spin-off institute and university-run enterprises in high-tech industries • Import of foreign technologies mainly through IJV arrangements based on FDI	• Demand-side approach with the adoption of IS concept (2002) • Strong commitment to indigenous R&D efforts with GRIs and universities • Continuing technology transfer through IJV arrangements	• Continued demand-side approach with market creating policies • Strong university-GRI-industry collaboration with private companies leading national R&D programmes in new digital technology sectors
Stage transition		• Two takeoffs: both R&D inputs (investment) and R&D outputs (patent registration) increased exponentially in early and mid 2000s, respectively • Two overtakings: (1) R&D investment by private sector overtook that of public sector in 1999; (2) number of patent registrations by residents overtook that of by non-residents in 2000	• World's second-largest R&D inputs and outputs (journal papers) after the United States • Strong S&T capacity in terms of academic performance • Competing in high-tech and new emerging industries based on world class S&T system

Source: Authors' elaboration.

Thailand is the world's largest exporter of primary or primary-based products, such as rice, rubber, sugar, cassava, shrimp and canned pineapple. In addition, the country is a major automotive manufacturer and exporter and it remains an important electronic parts exporter—including the second-largest exporter of hard disk drives. As such, the share of exports in Thailand's GDP reached 71.4 percent in 2008 and remained in the range of over 60 percent until 2019, confirming the country's status as an export-oriented economy. Over the years, the country's export mix changed, along with transformations in its industrial structure. While Thailand's export of primary goods such as raw materials has declined, exports of intermediary goods such as semi-finished products have increased, reflecting the significant structural changes that are underway (Kim 2019).

Through the afore-mentioned industrialization process, Thailand achieved rapid growth from the mid-1980s to mid-1990s and finally emerged as part of the second wave of the NIEs in Asia. However, after suffering a major blow from the 1997 Asian economic crisis, Thailand seems to have fallen into the so-called "middle-income trap", with its current per capita GDP remaining at an upper-middle-income level of $ 7,800.[32] In fact, taking advantage of FDI, Thailand was in a better position than other NIEs in terms of job creation, capital formation and product diversification. However, unlike neighboring countries such as Malaysia and Singapore, the country has failed to use such advantages in advancing its endogenous industries and strengthening STI capacities (Lauridsen 2004; Intarakumnerd 2019).

This section organizes the industrial development process of Thailand into three stages:
(1) ISI period (1961 – 1980);
(2) EOI period (1981 – 1996); and
(3) economic recovery and moderate growth period (1997 – present).

The first period started off with the development of the National Economic and Social Development Plan (herein: "NESDP") in 1961. During the second period, which ended the year before the outbreak of the Asian economic crisis in 1997, Thailand achieved rapid economic growth propelled by expanded foreign direct investment. Currently, Thailand is in the third period of its development path, striving to recover from the economic crisis and reboot its economy.

IMPORT SUBSTITUTION INDUSTRIALIZATION (ISI) PERIOD (1961-1980)

Following the introduction of the NESDP in 1961, the Thai government strived to develop local industries capable of producing import substitutes, while pursuing the diversification of its agricultural products. During this period, the Thai government mainly established institutions and practices to attract FDI. It also signed the Treaty of Amity and Economic Relations with the United States, which has led to a significant increase in investment from the United States as the treaty allowed US-based companies to enjoy similar privileges as local Thai firms. Overall, Thailand achieved significant economic growth during this period, and it was able to maintain this ISI strategy until the outbreak of the global recession that was triggered by the 1979 oil crisis.

32 World Bank, http://data.worldbank.org (accessed 16 June 2021).

Institution-building for import substitution policy

Since 1961, Thailand has developed and implemented NESDPs every five years. In the first NESDP (1962 – 1966), the Thai government concentrated its efforts on building foundational economic infrastructure such as transportation, telecommunication, agricultural water and power plants. More specifically, the government focused on building and expanding infrastructure such as the hydraulic facilities of the Mekong River and Nan River basins, highways and hydroelectric power plants. As part of the second NESDP (1967 – 1971), the Thai government poured investment into developing rural agricultural regions. During this period, the second half of the 1960s, the country's overall economic infrastructure improved, leading to an increase in power generation, and producing an annual average growth estimated at an impressive 7.5 percent (Bae and Han 1991). The Thai government also pursued the diversification of agricultural products by building necessary infrastructure such as roads, dams and reservoirs. As result, Thailand was able to maintain a formidable annual GDP growth rate of 8 percent throughout the 1960s, driven by exports of primary goods and agricultural products. In fact, rice, lumber, tin, and rubber accounted for over 80 percent of the country's entire exports in the 1960s.

In 1966, the Thai government established the Board of Investment (BOI) to control and manage foreign companies' access to and investment in the Thai market, focusing on developing import substituting industries. This ISI-oriented policy stance was best observed in its customs policy. For products from capital-intensive industries such as textiles, automobiles and pharmaceuticals, the Thai government maintained high tariffs—levying tariffs of over 90 percent on some select products like automobiles, while lowering tariffs on capital and intermediate goods. The government gradually expanded the scope of import substitution from consumer goods to capital and intermediate goods (World Bank 1993). Simultaneously, the Thai government maintained strong economic and military ties with the United States during this period. In 1996, the two governments concluded the US-Thai Treaty of Amity and Economic Relations, which granted US investors the same treatment and rights as local Thai companies, except for certain protected industries (OECD 2021). The treaty significantly contributed to the FDI flow from the United States in this early stage of Thai economic development (World Bank 1993).

With the enactment of the Investment Promotion Act in 1977, the Thai government laid a legal foundation for promoting FDI by removing potential obstacles that could jeopardize the security of investments and providing tax benefits and extra incentives for designated Special Investment Promotion Regions. In principle, foreign investment was strictly regulated across the agricultural, industrial and service sectors. However, the Alien Business Law allowed foreign investors to access Thai markets in such sectors as textiles and automobiles, which needed foreign investment for their growth, while protecting local industries where Thai firms possessed domestic production capacity. Overall, the Thai government's import substitution policy during this period can be considered successful. However, in the late 1970s, which coincided with the period of the fourth NESDP, the country's annual GDP growth rate fell to about 7.2 percent due to the second oil shock of 1979 and subsequent global depression and inflation. GDP per capita growth rate stagnated at 3.3 percent, sending the country into an economic crisis (Bae and Han 1991).

Limited interest in STI policy

During this period, the Thai government's interest in science, technology and innovation remained limited. In the 1960s and 1970s, only a few S&T-related institutes and practices were established. After the establishment of the National Research Council of Thailand in 1956, which was designed to advise the government on S&T issues and fund university research, the Thai government also founded the Thailand Institute of Scientific and Technological Research (TISTR), a government-funded research institute. Then in 1975, the Technology and Environmental Planning Division was created, under the National Economic and Social Development Board (NESDB), as a government body responsible for technology policy planning within the NESDP. Apart from these new institutional establishments, however, the level of interest in STI policies as key components of the country's ISI strategy remained limited throughout the period.

EXPORT-ORIENTED INDUSTRIALIZATION (EOI) PERIOD (1981 – 1996)

In the wake of global economic stagnation, deteriorating terms of trade and expanded budget deficits caused by the second oil shock, Thailand faced additional economic challenges in the early 1980s resulting from the fall in the price of raw materials (such as agricultural products), rising interest rates and the appreciated Thai baht, which was pegged to the United States dollar. These challenges forced the Thai government to reconsider its ISI-centred development course and shift to an EOI strategy advised by the UNDP and International Bank for Reconstruction and Development (IBRD) in the early 1980s. Accordingly, the Thai government gradually depreciated the baht. And from 1985, the Thai economy began to recover, following the fall in oil prices and interest rates, price increases of raw materials and the overall economic recovery of developed countries. Especially after the Plaza Accord was concluded, Thailand enjoyed an economic boom, propelled by FDI from Japan and NIEs in East Asia.

Transition from import substitution to export promotion

Thailand was dealt a major economic blow from the second oil shock of 1979, which led to countries around the world rushing to institute protectionist trade policies. There was also a price drop in agricultural products, Thailand's main export items. Around that time, the annual growth rate of Thailand's agricultural sector remained at just 2.1 percent and that of its manufacturing sector stood at only 5.5 percent, affected by sluggish exports, which then aggravated its trade deficit. As result, the country's annual growth rate staggered at around 4.4 percent and the government budget deficit rose to $ 2.2 billion (Bae and Han 1991). All of these factors caused a slowdown in the Thai economy. Coupled with the Thai government receiving consulting assistance from UNDP and IBRD in the early 1980s, this resulted in the BOI altering the country's development course from an ISI strategy to a EOI-based strategy. In a bid to boost exports, the Thai government eased export price regulations by depreciating the baht and allowing duty exemptions for imported machinery and raw materials used for producing export goods. This put into effect the already-enacted export support scheme of the Investment Promotion Act of 1977, with the Bank of Thailand offering special credit facilities to exporting companies (OECD 2021).

Thailand soon emerged as an attractive country for export-oriented FDI, following successive deprecations of the baht and government-led export-promoting policies. The depreciation of the US dollar relative to the Japanese yen and the German deutschemark, in accordance with the 1985 Plaza Accord, led to the further depreciation of the Thai currency. In addition, the BOI relaxed various regulations on export-oriented foreign companies in 1983. Those companies received an array of managerial benefits from the Thai government, including tariff exemptions, the ability to own land in Thailand and the import of foreign technicians, managers and equipment from abroad. The Thai government offered these export-oriented foreign companies full exemption of duties on their imported machinery, equipment and raw materials used for production, and also provided full reimbursement of all export-related taxes (World Bank 1993). As a result, Thailand received a major influx of FDI not only from Japan, which had to bear the blunt of the Plaza Accord, but also from other NIEs like Taiwan and Singapore, which had lost comparative advantage as low-cost manufacturers. During this period, the Thai government implemented its sixth NESDP (1987 – 1991) with the aim of promoting economic growth and workforce development and providing labour with a comparative advantage for export industries (OECD 2021).

This policy shift to an EOI strategy enabled the country's manufacturing sector to achieve rapid export growth in the mid and late 1980s, which then allowed the country to maintain a GDP growth rate at over 8.0 percent (Bae and Han 1991). In particular, the export of light industry products such as garments and leather goods increased significantly, while labour-intensive industries (for example, electronic assemblers and footwear manufacturers) and technology-intensive industries (such as computer accessories and automobile components manufacturers) gradually expanded their share of exports (OECD 2021). In sum, Thailand's rapid economic rise during the 1980s was fueled by a surge both in FDI and FDI-based exports, which enabled the country to succeed in attracting new industries and expanding the exports of its manufacturers.

Linear model of STI policies and failed attempts to promote local supplier SMEs

With the establishment of the Ministry of Science, Technology and Energy (MOSTE) in 1979, the Thai government started to consider S&T policies as economic drivers and included them as a separate component of its fifth NESDP (1982 – 1986). Key S&T-related provisions of the 5th NESDP included collection of data on technology development, promotion of technology transfer from abroad, strengthening of S&T and R&D capacity of Thai scientists and engineers, and development of S&T human resources (Intarakumnerd et al. 2002; Bae and Han 1991). Subsequently, the Science and Technology Development Board (STDB) and three technology-specific GRIs were established to build a domestic technology supply system. The GRIs in key technology sectors include the National Center for Genetic Engineering and Biotechnology (BIOTEC), established in 1983, the National Center for Metals and Materials Technology (MTEC) and the National Electronics and Computer Technology Center (NECTEC), set up in 1986 as a funding agency to universities in tandem with research functions in each technology area. As part of the enactment of the Science and Technology Development Act in 1991, the STDB and these GRIs were merged into the newly founded National Science and Technology Development Agency (NSTDA) in 1993. But their responsibilities did not change significantly and remained concentrated in four core areas: R&D, human resource development, technology transfer and S&T infrastructure development, emphasizing their role as technology providers and that of private companies as technology users (Plaeksakul 2010). In an effort to nurture human resources, Thailand also signed the Science and Technology for Development Project (STDP) with the United States, which helped the country conduct R&D activities and receive technological counseling and training from the United States in the strategic industries of biotechnology, materials and applied electronics over a seven-year period, from 1985 to 1992 (Bae and Han 1991). During this period, therefore, Thai government focused mainly on establishing R&D capacity and nurturing human resources in key technology sectors.

In the 7th NESDP (1992-1996), the Thai government for the first time set the target of GERD (gross domestic R&D expenditures) as a share of GDP to 0.75 percent,[33] with several innovation policy measures, such as promoting private-sector R&D through tax incentives. Nevertheless, these new measures were implemented separately and isolated from the country's economic policies—including its industrial policy, investment policy and educational policies (Plaeksakul, 2010).

One change in Thai government during 1990s was its attempt to promote Thai supplier SMEs. Before the introduction of the value-added tax in 1992, the existing sales tax system disadvantaged intermediary goods manufacturers vis-à-vis the final goods manufacturers. Therefore, it was difficult to promote local firms producing intermediate goods. And since the early 1990s, worries began to grow over the country's heavy dependence on cheap labour and inward FDI, both of which might be unsustainable and hinder the country's long-term competitiveness. Though

33 This target was realized in 2016.

FDI-led export and economic growth continued, the domestic value added for high-tech export goods remained low. Local sourcing within the country increased in terms of quantity, but it was also dominated by foreign suppliers with local presence. As result, most of the added value along the value chain fell into the hands of foreign companies, while local suppliers remained comparatively marginalized. Such worries led the Thai government to come up with supportive policies for building linkages of local parts and components suppliers and their MNC end-product manufacturers (Lauridsen 2004).

Against this backdrop, the BOI and MOI, separately, began in the early 1990s to implement policies for upgrading the technological capabilities of local SMEs. The BOI established the BOI Unit for Industrial Linkage Development (BUILD) in 1991 to help local SME suppliers through information provisions and matchmaking in the field of electronics, automotive components, metals and machinery. In 1994, the BOI also pushed forward the National Supplier Development Programme (NSDP). Yet, a lack of cooperation with other ministries, including the Ministry of Industry (MOI), thwarted such attempts. The MOI instituted its own SME supplier development policy by initiating the 1995 Master Plan for the Development of Supporting Industries in Thailand. It also jointly established a plan to improve local suppliers of automobile and electronics industries with the Japan International Cooperation Agency (JICA) and the Ministry of International Trade and Industry of Japan. However, a lack of coordination with other MOI departments as well as the BOI hindered the budget allocation process. And the increased market presence of Japanese SME suppliers through FDI and the abolition of the local content requirements (LCRs) between 1995 and 1997 made local Thai firms lose even further ground. The outbreak of the 1997 Asian economic crisis also led to the plan becoming deprioritized.

To summarize, while the economic policy of the Thai government successfully transitioned from ISI to EOI in the early 1980s and resulted in rapid economic growth, its STI policies was isolated from the government's economic policy during this period, focusing on increasing R&D capacity and developing human resources based on a linear innovation model. When the Thai government realized the urgency to promote local technological capabilities for upgrading to high value-added activities, it implemented several policies to promote the Thai local suppliers in parts and components industries in collaboration with foreign MNCs. Both the BOI and MOI showed interest in supporting local suppliers, but such early efforts failed to garner tangible success due to a lack of inter-ministerial coordination and cooperation.

ECONOMIC RECOVERY AND MODERATE GROWTH (1997 – PRESENT)

Thailand successfully attracted FDI and achieved unprecedented economic growth between 1985 and 1996. However, the country suffered a major shock from the Asian economic crisis in 1997, which bluntly exposed the weaknesses of its industrial structure. It was forced to abandon earlier control of trade and investment measures, such as by abolishing LCR requirements and the fixed exchange rate system in 1997. Since then, however, Thailand has showed its commitment to sustainable and inclusive growth based on technology upgrading and strengthened innovation (Intarakumnerd 2019; UNCTAD 2015). Despite such ardent efforts to revive its economy, a variety of factors such as political instability, global financial crises and the 2011 floods have continued to hamper Thailand's economic growth. The country is not witnessing the economic dynamism it once enjoyed prior to the Asian economic crisis of 1997.

More strategic approach to industrial development with the adoption of innovation

The experience of the 1997 Asian economic crisis led Thailand to recognize the structural weakness in its industrial competitiveness as well as the importance of domestic industrial technological capabilities, especially those of SMEs (Intarakumnerd 2017). After major industries started to falter near the end of 1998, political logic dictated

strong support for a policy direction to promote local SMEs. By 2000, a series of comprehensive SME-supporting policies and institutions, led mainly by the MOI, had already been put into place—such as the SME Promotion Act, SME promotion fund, SME Master Plan (1999 – 2004), SME Promotion Office and Institute of SME Development. Unfortunately, these policies were not successful due to a lack of policy consistency and coordination with inter-ministerial rivalries and weak public-private linkages, which led to a lack of participation of local SMEs (Lauridsen 2004).

In 2001, the Thaksin government—inaugurated with the backdrop of strong public support—aggressively pushed ahead with its industrial policies for innovation-led growth (Intarakumnerd and Chaminade 2007). The administration actively incorporated the concept of innovation system and industrial cluster into the ninth NESDP (2002 – 2006) and subsequently designated five strategic industrial sectors and implemented cluster policies based on geographical proximity. The five designated sectors included automotive, food, tourism, fashion and software industries, with long-term visions set forth for respective sectors. This policy approach is considered widely different from previous S&T-based linear models (NESTA 2020).

During the 2000s, successful efforts for building backward linkages and upgrading the competitiveness of supplier industries were made in several of Thailand's leading industries, notably, the automotive industry and the hard disk drive (HDD) industry (Intarakumnerd 2017; UNCTAD 2015). In both, the collaboration between industry, universities and MNCs intensified. There are three important factors that have contributed to successful knowledge spillover and technological upgrading in these sectors. First, sector-specific agencies such as the Hard Disk Drive Institute (HDDI)[34] and the TAI (Thailand Automotive Institute) played a critical role as innovation intermediaries in promoting collaboration among industry participants. They provided local firms with implementation of joint projects, provision of financing, physical infrastructure and consulting services to support the needs of a specific sector. Second, MNCs were heavily involved in both industries. For example, the Automotive Human Resource Development Programme (AHRDP), conducted in 2006 – 2011, was a joint Thai-Japanese project involving Toyota, Honda, Nissan and Denso.[35] There was a similar training programme in the HDD industry, in which Thai engineers and researchers, in collaboration with Western Digital, were dispatched to the United States for up to 1.5 years. Research centres specializing in the HDD industry were established in three of Thailand's leading universities with the financial support of HDDI.[36] Further, MNCs such as Western Digital and Seagate in the HDD industry, and Toyota, Honda, Nissan and Isuzu in the automotive industry set up local R&D and technical centres in Thailand, although their research activities focused mainly on process innovation, product testing and technical training. Third, all the projects were jointly designed, approved and funded by both Thai agencies and MNCs and, therefore, garnered mutual benefits. This exemplifies the improved technological upgrading of Thai local companies in some sectors.

Such strategies continued even after the fall of the Thaksin administration following a military coup. Comprehensive efforts to transform the country into an innovation-based economy through strengthened R&D capacity began in the 2010s. During this period, Thailand, in addition to NESDP, announced the Thailand 20-Year National Strategy Framework, 2017 – 2036 as its long-term development strategy and set forth "sustainable development towards a high-income country" as its basic direction for pursuing national development over the coming two decades. The Thai government also set out 10 development strategies to achieve this objective. Of those specific strategies, the eighth strategy of "advancing science, technology, research and innovation" and the ninth strategy of "developing regions, cities and economic zones" are especially relevant to both the S&T and industrial sectors. Since the 9th NESDP (April 2021), the Thai government has continued to uphold "sufficiency economy", "sustainable development" and "human-centered development" as its three key policy objectives.

34 It was organized as an industry consortium in the late 1990s and officially renamed as HDDI in 2005

35 Federation of Thai Industries, Japan International Cooperation Agency (JICA), Japan External Trade Organization (JETRO) and Japanese Chamber of Commerce (JCC) were also important participants.

36 Konkaen University, King Mongkut's Institute of Technology Ladkrabang and King Mongkut's University of Technology Thonburi.

In 2015, Thai government announced two important demand-creation policies: Thailand 4.0 and the Eastern Economic Corridor (EEC). With Germany's Industry 4.0 as a model, Thailand 4.0 follows the global trend of digital transformation, while the EEC was designed as a space for practically implementing the planned policies and strategies. Thailand 4.0 presents two key strategies:

(1) creating high value added through smart technologies and digital transformation by applying ICT technologies to industrial sectors where comparative advantage has already been achieved; and

(2) designating and promoting new industrial sectors as future growth engines.

In accordance with this scheme, the Thai government has designated 10 industrial sectors—including the automotive, electronics, tourism, biotechnology and food industries—where Thailand remains relatively competitive. The remaining five sectors include automation/robotics, aerospace, biofuel/biochemistry, digital and medical/healthcare industries. All 10 targeted sectors will be promoted by the Thai government as the country's future growth engines for the next 20 years (NESTA 2020). In addition, the government views the EEC as its optimal strategic foothold connecting the ASEAN, Korean, Japanese and Chinese markets (Kim 2019) by investing $ 43 billion into three regions—Rayong, Chonburi and Chachoengsao—through FDI, thereby promoting 10 industrial sectors.

Demand-driven approach to STI policy

Since the 2000s, the shift of Thailand's STI policy focus, from a supply-side approach to a demand-side approach, has been clear. STI policies "formally" adopted the concept of a national innovation system and industrial clusters, stressing partnerships and linkages among innovation actors, including universities, GRIs and private companies—which is distinct from previous STI policies (Chaminade et al. 2012). The following STI polices have been subsequently implemented at the national level: National Science and Technology Strategic Plan 2004 – 2013, National R&D Strategy and Policy 2008 – 2010, National Science and Technology Plan 2012 – 2021, and 20-Year Long Term Strategy for Research Innovation. Demand-side elements are more pronounced in these policies.

The National Science and Technology Policy Committee (NSTC) was put in charge of the execution and coordination of the National Science Technology Strategic Plan 2004 – 2013. The crux of the plan involves reinforcing the country's national innovation system and implementing industrial cluster policies to strategically promote four major technologies—information and telecommunications (IT), materials technology, biotechnology and nanotechnology. Four GRIs under the auspices of the NSTDA are responsible for these activities. Subsequently, national strategies for each sector were developed: IT2000, National Strategy for Materials Sciences, Biotechnology Policy Framework and Nanotechnology Strategic Plan. Another strategy pursued by the Thai government to strengthen its research capacity was the National Research Policy and ·Strategy 2008-2010. Here, the National Research Council of Thailand (NRCT) aimed to promote comprehensive investment in research capacity-building by including natural and social sciences within the scope of this mid- and long-term research strategy. The expected outcomes of the plan included expanded R&D budget, increase in R&D investment ratio of the private sector to be on par with that of the public sector, and the development of research personnel. The National STI Policy and Plan 2012 – 2021 also targeted the increase of R&D expenditure as percentage of GDP from 0.24 in 2012 to 1.00 in 2016 and 2.00 in 2021, with private funding overtaking public funding, by a ratio of 70:30 by 2021 (UNCTAD 2015).

In 2019, the Thai government engaged in a structural revamping of its national STI system. The National Science Technology and Innovation Policy Office (STI Office) was first established in 2008 and then restructured into the Ministry of Higher Education, Science, Research and Innovation (MHESI) in May 2019. The new ministry was inaugurated by merging the Ministry of Science and Technology and the Office of the Higher Education Commission, the National Research Council and the Thailand Research Fund. In addition, the role of the STI Office was expanded to encompass not only STI policies but also higher education, which led to the birth of the Office of National Higher Education Science Research and Innovation Policy (NXPO). The Thailand Science Research and Innovation Fund was also established in 2019. Such structural changes are designed to promote cooperation and coordination between government ministries and their affiliate institutions (UNESCO 2021). However, it remains to be seen whether this restructuring brings better coordination in Thai STI governance.

There has also been a policy shift toward a demand-side approach regarding investment policies. The BOI adopted several new tax incentive schemes during this period. The Skill, Technology, and Innovation Program (2006) promotes investment in innovation activities, including investment in training, R&D and university-industry collaboration in selected industries: fashion, automotive and ICT. Requirements include R&D or designing activities; at least 1 – 2 percent of their sales should be scientists or engineers, with at least a bachelor's degree for at least 5 percent of their staff; at least 1 percent of total payroll spent on staff training; and least one percent of total payroll spent on training employees of local suppliers (UNCTAD 2015). In 2015, the BOI also adopted merit-based incentives for investment concerning Thai industry's competitiveness enhancement, based on the Seven-Year Investment Promotion Strategy (2015 – 2021). Finally, with the amendment of the Investment Promotion Act (2017), it included technology-based incentives to promote investment in targeted technologies: biotechnology, nanotechnology, advanced materials and digital technologies (BOI 2019).

Despite this policy shift from supply-side to demand-side at the design level, studies on the national innovation system of Thailand conclude that a linear innovation model is more in use at the implementation level (Intarakumnerd 2019; UNCTAD 2015). Since the early 2010s, input-side R&D indicators do show some improvement. Moderate take-off and overtaking in R&D expenditure, as well as its intensity, have been observed, as shown in Figure 7. However, further observations should be followed in order to confirm whether Thailand is on the track of technology internalization path that both the RoK and China have undertaken. Two issues deserve to be examined: first, whether the R&D investment of Thailand continues or not and is driven by private sector, and second, whether the earlier increase in R&D investment is transformed into R&D outputs—in particular, commercial outputs like patents since this recent increase was driven by the private sector.

SUMMARY

Thailand's STI policy experienced little change from the 1960s to the 1990s. Whether it was ISI or EOI, the policy focus was FDI-based industry promotion using imported foreign technologies. Economic, trade and investment policies were dominant while STI policies were neglected. Between the 1980s and 1990s, the country established the organizational structure of its S&T system by empowering key ministries, GRIs and other intermediary agencies. However, the scope of the S&T system was narrowly defined, focusing on the supply-side approach of academic research, while little emphasis was placed on innovation and industry, thus neglecting the demand side. In addition, early efforts of building backward linkages during the 1990s did not bring much success. After the Asian economic crisis, the Thai government came to realize the importance of STI policies in strengthening national competitiveness for industrial technology development (Intarakumnerd and Chaminade 2007). Since then, STI policies in Thailand began to encompass the demand-side approach—focusing on building an innovation system and linkages among innovation actors, as well as subsequent industrial and STI policies. Nevertheless, key S&T indicators do not seem to show that Thailand is successfully maneuvering into a technology internalization stage based on indigenous innovation efforts, as was the case of the RoK and China.

Table 13 summarizes the evolution of industrial and STI policies over the course of the industrial development of Thailand.

Table 13 Overview of industrial and STI policies in the industrial development of Thailand

Stage	Technology introduction stage (1961 – 1996)		Technology internalization stage (1997 – present)
	Import substitution industrialization (ISI) period (1961 – 1980)	Export-oriented industrialization (EOI) period (1981 – 1996)	Economic recovery and moderate growth period (1997 – present)
Major events	• US-Thai Treaty of Amity (1966) • 1st oil shock (1973)	• 2nd oil shock (1979) • Baht devaluation (1985) • Plaza Accord (1985) • Accession to the WTO (1995)	• Asian economic crisis (1997) • Global financial crisis (2008) • Big floods (2011) • Military coupe (2006 and 2014)
Key policies and institutions	• 1st NESDP • Establishment of BOI (1966) • Alien Business Law (1972) • Establishment of MOSTE (1979)	• Enactment of the Investment Promotion Act (1977) • Transition from ISI to EOI (early 1980s) • Depreciation of baht (1984) • 7th NESDP (1991) includes GERD/GDP targets • STDB and 3 sector-specific GRIs founded in 1980s and later merged to NSTDA in 1993	• Elimination of LCRs (1997) and fixed exchange-rate system (1997) • Foreign Business Act (1999) • Package of SME supporting policies (1998 – 2000) • National Innovation Agency (2003) • S&T Strategic Plan for 2004 – 2013 • Investment Promotion Strategy (2015 – 2021) • Thailand 4.0 and EEC (2016)
Demand-side policies	• Promotion of FDI in import-substituting local industries • Diversification of agricultural products • Promotion of local industries such as textiles, automobiles, pharmaceuticals	• Promotion of FDI in export-oriented industries	• Promotion of FDI in strategic industries • Promotion of 10 strategic industries through Thailand 4.0 and EEC
Supply-side policies	• Sourcing foreign advanced technologies using FDI	• Policy efforts for backward linkages in automotive and electronics by BOI and MOI (SME promotion) (1990s) • Promoting industrial technology development with establishment of GRIs and funding agency	• Investment policies aimed at attracting technologies, improving local competitiveness through Skill, Technology and Innovation scheme (2006) • Activity/merit-based (2015) and technology-based incentives (2017) by BOI
Role of STI policies in industrial development	• Dominance of industrial, trade and investment policies, with limited interest in STI policies	• Dominance of industrial, trade and investment policies continues • Interest in STI policies but supply-side approach focusing on academic research with a linear model of innovation, isolated from industry	• Recognized importance of STI policies as a tool to tackle structural weaknesses • Demand-side approach adopted (innovation and linkage to industry) at the policy design level to promote industrial technology development • STI policies still fragmented and inefficient, with weak inter-ministerial coordination system at the implementation level
Stage transition	• No takeoff nor overtaking observed in both R&D inputs and outputs		• Takeoff and overtaking observed in R&D expenditure and its intensity in the early 2010s • Whether there are subsequent takeoff and overtaking in R&D outputs should be confirmed in near term

Source: Authors' elaboration.

4.4 Conclusions and policy implications

Mechanisms of late industrialization by East Asian countries differ from the model of Western advanced countries. Unlike the Western approach to industrial policies, characterized mainly by a transition from a more laissez-faire to a more interventionist approach over time, East Asian countries demonstrate nearly the reverse, starting from more sector-specific industrial policies, as exemplified by RoK (SaKong and Koh 2010). Similarly, RoK and other East Asian countries did not follow the progression from science through technology to innovation policy, which was widely accepted as conventional path by Western countries (Lundvall and Borras 2005). Rather, they implemented pseudo-innovation policies, or a sector-specific technology development strategy combined with financial support for a market introduction of developed products, early in their development path, then promoting basic science towards the more advanced and recent stages of development. Regarding an innovation process to underpin economic development, the RoK shows a "reverse innovation" path (Kim 1999), beginning with process innovation and later struggling toward product innovation (Hobday et al. 2004). This observation subverts the dominant views on the innovation process from Western contexts, as Abernathy and Utterback (1978) have claimed.

In retrospect, we now understand that industrialization of Germany and the United States in the 19th century occurred based on new technologies and products, while "late" industrialization of East Asian countries occurred based on "learning of borrowed technologies" in the 20th century (Amsden 1991, p. 283). It is now well known that more industry-specific industrial policies (such as SEMATECH for the semiconductor industry in the early 1980s in the United States) were partly introduced in the United States in response to the emergence of East Asian economies. In general, East Asian pathways of industrial development enriched and redirected discussions on the roles of states in economic development, as shown in the subsequent debates on "East Asian Miracle," followed by the World Bank report, *The East Asian Miracle: Economic Growth and Public Policy* (1993). Similarly, when it comes to STI policy, scholars have discovered the proactive roles of the government in the accumulation of technological capability in East Asian countries in a retrospective way, since National Innovation Systems were conceptualized (Freeman 1995; Godin 2009). And more recently, Cherif and Hasanov (2019) have argued that STI policies lie at the heart of the success of the "Asian Miracles", emphasizing the role of industrial policy.

In this regard, this report provides empirical evidence based on case studies of three East Asian economies: Republic of Korea, People's Republic of China and Thailand. Through the lens of technology development stages, each country's industrial development was carefully analysed, focusing on linkages between demand-side and supply-side policies. Main findings from each country case follow below.

FINDINGS FROM THE ROK

With full recognition of the importance of technology to industrial development, STI has been a large part of industrial development strategies since the initial stage of RoK's industrialization. Two reasons behind this were the urgent need for defense capabilities against North Korea and the United States' refusal to aid the RoK's ISI projects. Under these circumstances, STI has been tightly incorporated in demand-side and supply-side policies throughout the RoK's industrialization process, playing a vital role in continuous industrial upgrading/diversification/deepening.

Technology introduction stage:
Demand-side approach prevailed, with STI policies considered a key tool for implementing industrial and economic policies. Without inheriting any infrastructure, the RoKs first action was to newly build STI-related institutions, including ministries, laws, national plans, GRIs funding agencies Newly established GRIs served the private sector as a contracting intermediary for sourcing foreign technologies.

Technology internalization stage:
Demand-side approach continued but with more emphasis on STI policies, providing required indigenous technologies to industrial upgrading. GRIs led national R&D programmes in collaboration with the private sector as an innovation intermediary, while the government created markets for technologies. From this stage, STI policies began to forge their own independent pathways.

Technology creation stage:
Demand-side approach continued but the main policy target changed from large conglomerates to SMEs and ventures, where market failure is pronounced. GRIs and universities fill the gap of suboptimal R&Ds in basic research.

FINDINGS FROM CHINA

Despite the legacy of a Soviet model of an R&D system, China swiftly restored its STI system from disruption during the Cultural Revolution when it adopted the Reform and Opening-up Policy. While heavily dependent on trading market for technology for sourcing foreign advanced technologies, China began to nurture indigenous innovation capabilities using a demand-side approach since the early 2000s. From the early 2010s, China positioned itself as an innovation powerhouse, based on a strong S&T system, competing at the world frontier in new emerging industries.

Technology introduction stage:
China mainly implemented a supply-side approach of GRIs as producers and private companies as users of innovation, directing R&D outputs of their GRIs to production and commercialization, with little success. Despite the recognition of the importance of STI, STI policies were not well aligned with the needs of industry. Rather, the Chinese government was heavily dependent on trading market for technology in order to absorb foreign advanced technologies. This approach also had little success between 1980s – 1990s.

Technology internalization stage:
Demand-side approach with the innovation system concept was adopted with the reform of the Chinese STI system, with GRIs and universities shifting from vertical to horizontal linkages with industry. STI policies began to be aligned with industrial development strategies, stressing indigenous innovation capabilities, but also in tandem with continuous technology transfer efforts through IJV arrangements based on FDI.

Technology creation stage:
China aims to compete in high-tech and new emerging industries based on its world class S&T system. There is strong university-GRI-industry collaboration, with private companies leading national R&D programmes in new digital sectors.

FINDINGS FROM THAILAND

In general, STI policies in Thailand have not been associated with industrial development strategies in the course of the country's industrialization process. Despite the country's rapid economic growth following the swift transition from ISI to EOI until 1996, development was mainly investment-led—exemplified by increases in FDI—not innovation-led. Without indigenous technological capabilities, the investment-led strategy had its limits, trapping Thailand in a middle-income trap. With the help of MNC counterparts, several intermittent attempts were made to strengthen backward linkages in some strategic industries, such as automotive and electronics, during the 1990s and 2000s. Innovation intermediaries in those industries played a positive role; but in general, they possessed low levels of technological learning, training of technicians and engineers, production process innovation, product innovation related to localization, etc. Since the early 2010s, R&D inputs in Thailand began to take off, and they are currently led mainly by the private sector. However, whether R&D outputs will follow—signaling a technology internalization stage—remains to be confirmed.

Technology introduction stage:
Government was dominated by industrial, trade and investment policies, with limited interest in STI policies until 1980. From the 1980s, the government showed interest in STI policies, but this was mainly a supply-side approach, led by universities and GRIs that were isolated from industries.

Technology internalization stage:
After the Asian economic crisis, the Thai government began to recognize the importance of STI as a tool to tackle its structural weaknesses, stressing a demand-side approach at the policy design level. However, policy at the implementation level has been fragmented and inefficient, leaving most innovation activities led by MNCs.

POLICY IMPLICATIONS

Based on these three country case studies, we make the following policy implications—in terms of STI policy design and implementation—that are relevant for other developing countries in their pursuit of industrial development.

- **Key STI indicators are useful in diagnosing the stages of technology development.**
  STI indicators of R&D inputs and outputs were useful for understanding different technology development stages of a developing country. However, policymakers should not assume that increasing R&D inputs (supply-side approach) will automatically upgrade a country's technological development. They should not be interpreted as a sufficient condition for a developing country's stage transition.

- **STI policies should be demand-driven.**
  STI policies should be closely aligned with demand-side industrial policies as they are complementary to each other. Accordingly, the content of STI policies should evolve over the course of a country's industrial development as each stage requires different needs of industry.

- **Investment-led growth has its limits.**
  The Thai case illustrates the limitations of investment-led growth strategy to sustain a country's industrial development. Thailand became successful in reaching upper-middle income status propelled mainly by FDIs. However, it has failed to sustain economic growth without indigenous technology development efforts.

- **Utilization of foreign technologies never diminishes.**
  The relative importance of sourcing and learning foreign technologies decreases over the course of industrial development. Although indigenous technology development efforts should be at the center of STI policies from the technology internalization stage, utilization of foreign technologies remains one of the most important mechanisms to source technologies.

- **A coordinating mechanism of STI policies with the support of high-level leadership is critical.**
  It is important to have a coordinating mechanism as STI requires inter-ministerial collaboration and is generally not considered a priority in budgeting. Both the RoK and China had the full support of high-level leadership, while Thailand does have a policy coordinating body but without the prime minister's support.

- **Creating markets facilitates industrial upgrading.**
  Government interventions in creating markets, including public procurement and standard setting policies, can facilitate industrial catch-up and leapfrogging. They can reduce technology and market uncertainties of domestic R&Ds and, therefore, can be more useful from the technology internalization stage onward.

The main policy conclusion from our findings on three East Asian countries in implementing successful STI policies is summarized by three key principles:
(1) demand-driven approach throughout the process of industrial development;
(2) strong commitment to indigenous innovation efforts beginning with the technology internalization stage; and
(3) government's ability to reflect on and adapt to changing environments.

The main driver of these principles is the increasing need for active government involvement in a country's industrial development, although not to the level of "developmental state" (Amsden 1989; Lall 1992; Chang 1994). Considering the contemporary challenges discussed in this report—namely, digital transformation, climate change and inequality—as well as the conventional challenge of industrial development, it is imperative for developing countries to play a more active role in addressing the "twin challenges" of inclusive and sustainable industrial development.

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