Charting India's Path in the Global Technology Landscape
A Comparative Policy Study

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Self-Declaration

This is to certify that the thesis submitted by me titled “Charting India’s Path in the Global Technology Landscape: A Comparative Policy Study” is my original work and has not previously formed the basis for the award of any Degree, Diploma, Associateship or Fellowship to this or any other University.

Pranitha Pullamaraju

Certificate of the Supervisor

This is to certify that the thesis titled "Charting India's Path in the Global Technology Landscape: A Comparative Policy Study" is original work undertaken by Pranitha Pullamaraju under my supervision and guidance as part of his/her Master degree in this Institute. The thesis may be sent for evaluation.

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List of Abbreviations

Abbreviation	Expansion
AI	Artificial Intelligence
AICTE	All India Council for Technical Education
AIIMS	All India Institute of Medical Sciences
AISHE	All India Survey on Higher Education
ARPA-E	Energy Department's Advanced Research Projects Agency-Energy
BYD	Build Your Dream
CHIPS	Creating Helpful Incentives to Produce Semiconductors
CII	Confederation of Indian Industry
CMC	Central Military Commission (China)
COMPETES	America Creating Opportunities to Meaningfully Promote Excellence in Technology, Education, and Science Act of 2007
CPC	Communist Party of China
CRS	Congressional Research Service
CSIR	Council of Scientific & Industrial Research
CTIER	The Centre for Technology, Innovation and Economic Research
DAE	Department of Atomic Energy
DBT	Department of Biotechnology
DOS	Department of Space
DRDO	Defence Research and Development Organisation
DSIR	Department of Scientific and Industrial Research
DST	Department of Science and Technology
EPA	Environmental Protection Agency
FDI	Foreign Direct Investment
FICCI	Federation of Indian Chambers of Commerce & Industry
FTE	Full-Time Equivalent
FY	Financial Year
FYP	Five Year Plan

GDP	Gross domestic product
GERD	Gross Domestic Expenditures on Research and Development
GII	Global Innovation Index
GNI	Gross National Income
HCL	Hindustan Computers Limited
ICAR	Indian Council of Agricultural Research
ICMR	Indian Council of Medical Research
ICSSR	Indian Council of Social Science Research
ICT	Information and Communications Technology
IIM	Indian Institutes of Management
IIT	Indian Institute Of Technology
IITP	Institute for Information & communication Technology Planning & evaluation
IMF	International Monetary Fund
IoT	Internet of Things
IP	Intellectual Property
ISI	Institute for Scientific Information
IT	Information Technology
KIAT	Korea Institute of Advancement of Technology
MIST	Ministry of Science and ICT (Korea)
ML	Machine Learning
MoE	Ministry of Education
MOST	Ministry of Science and Technology (China)
MSME	Micro, Small & Medium Enterprises
NASA	National Aeronautics and Space Administration
NIPA	National IT Industry Promotion Agency
NIS	National Innovation System
NIT	National Institute of Technology
NITI	National Institution for Transforming India
NRC	National Research Council

NSF	National Science Foundation
OECD	Organization for Economic Cooperation and Development
OPSA	Office of Principal Scientific Adviser
OSTP	Office of Science and Technology Policy
PACST	Presidential Council on Science and Technology (Korea)
PM	Prime Minister
PM-STIAC	Prime Minister’s Science, Technology and Innovation Advisory Council
PPP	Purchasing Power Parity
QS	Quacquarelli Symonds
R&D	Research and Development
S&T	Science and Technology
SME	Small and Medium Enterprises
STI	Science, Technology and Innovation
UGC	University Grants Commission
UNCTAD	United Nations Conference on Trade and Development
UNESCO	United Nations Educational, Scientific and Cultural Organization
USA	United States of America
USD	United States Dollar
WIPO	World Intellectual Property Organisation

Abstract

Over the past few decades, the dynamics of global power competition has witnessed a shift from traditional industrial resources to control over information, marking the onset of the fourth Industrial Revolution. Science and Technology have emerged as tools of economic power that have the potential to influence the geopolitical dynamics of the 21st century. Technological advancements and policy changes having the potential to create economic power asymmetries in the future. This changing technology landscape has resulted in an aggressive competition among governments and corporations to establish their leadership. As advancements have led to countries re-formulating strategies and policies, there is emphasis on the need for a comparative lens to understand where India stands and to determine its future trajectory. Within this ever-evolving realm, this project charts India's position in the global technological landscape. It conducts a comprehensive analysis of key science and technology indicators and major science, technology and innovation policies of India, China, South Korea, and the United States. The project employs input and output indicators such as investments in Research & Development, number of researchers, patent grants and total publications, and performs a comparative analysis of the technology landscape of the four countries. This exploratory study aims to contribute to a comprehensive understanding of India's technological stature and provides recommendations to India grounded on the analysis of best practices by countries.

Chapter 1: Introduction

1.1. Introduction

Growth and innovation in Science and Technology (S&T) is an integral component that ensures long-term growth and dynamism of nations (Mormina 2018). S&T advancements are precursors to significant transformations within societies and economies. These changes are driven by policy decisions, digital transformation, and demographic shifts. Globally, state behaviour is influenced by an aspiration to secure emerging technologies- a trend aptly termed 'techno-nationalism'- likely to intensify and shape industrial policy choices (Ray and Deo 2020). Such a trend is evident in the behaviour of countries within this changing landscape.

The global technological landscape is at a critical juncture, with emerging technologies like Artificial Intelligence (AI), Machine Learning (ML) and 5G, among others marking the advent of the fourth Industrial Revolution (UNCTAD, 2022). Successive Industrial Revolution have instigated exponential human progress. This shift as well promises a paradigm change in technological, manufacturing, and various other sectors, with enhanced value creation through higher productivity and efficiency across the value chain.

Amidst this changing landscape, policymaking assumes a critical role. Policymaking, defined as the process of guiding the course of action for governments and businesses (OECD 2006), encompasses numerous advantages. It not merely facilitates macro-level decision-making but also explains imperatives for change, directs focus on important issues, guides actions, manages risks, strengthens relationships, and helps build capacity (Salami and Soltanzadeh 2012). Knowledge and innovation systems are important in knowledge diffusion and provide valuable insights towards evidence-based policymaking. The governance structure of a country is pivotal in creating a responsible Science, Technology, and Innovation (STI) ecosystem. Policies and government regulations thus have the potential to either promote or hinder innovation (Patanakul and Pinto 2014), particularly in the era of the digital transformation and the Fourth Industrial Revolution.

India has laid down five S&T policies since 1958, the most recent development being the draft Science, Technology, and Innovation Policy document (2020). Despite creating robust infrastructure and making strides in certain domains, India's innovation and industrial sectors have yet to achieve the desired outcomes, partly due to challenges within the STI ecosystem and the manufacturing sector (Nath et al 2023). While India has attained the status of an emerging economy, it is yet to match the R&D investment intensities of other Asian and global economies, as could be derived from India's 12th Five-Year Plan and data from the Organisation for Economic Cooperation and Development (OECD). The patent count in India is only a fraction of that in other countries, and a similar trend can be observed in the number of Full-Time Equivalent (FTE) researchers as well. This suggests the need for the country to identify areas of improvement through global comparison and benchmarking.

Against this backdrop, the project analyses India's STI landscape and conducts a comparative STI policy study of India vis-a-vis China, the Republic of Korea (henceforth referred to as South Korea), and the United States. These countries have been chosen for their significant impact on the global technological landscape with distinct STI policy approaches that serve as the foundation for their innovation systems. Technology-related analyses traditionally focus on inputs like research expenditure and outputs like patents (OECD 1997). Following the same, the project investigates key innovation indicators such as R&D expenditures by countries as a percentage of GDP, patent grants, FTE researchers per million and the number of publications. It also analyses the Knowledge and Innovation ecosystems, S&T Governance Structures of countries, and major STI policies and conducts a comparative study of the four countries based on these indicators.

1.2. Background

The history of successive Industrial Revolutions charts the evolution of the competitive advantage of great powers, signifying paradigm shifts in the foundations of wealth and industrial technology (Anders 2017). Steam was the driving force of the first Industrial Revolution; electricity was the prime mover behind the second, and automation and machinery characterised the third. Technological developments have given rise to successive Industrial Revolutions, and those nations that have benefitted from industrialisation have established their supremacy over other nations, creating a hierarchical structure (Malik 2012). The fourth Industrial Revolution heralded at the World Economic Forum in 2015 is distinct in its foundation on cyber-physical systems (Jazdi 2014). The 21st century is marked by an integration of Information Technology into global value chains with a potential to transform practices of businesses and bring structural changes in societies (Porter and Heppelmann 2014; Drath and Horch 2014). Amid this, a thorough understanding of the technological landscape and scientific progress of individual countries is necessary to understand India's standing within this era.

Innovation has emerged as an important driver of social development and a tool for countries to enhance their global competitiveness (Wang et al. 2020). This has led to countries focusing on increasing technological inputs, a concept that could be traced to the National Innovation System (NIS) approach. The NIS emerged in the 1980s and is a system of interconnected entities that contributes to the advancement and spread of new technologies and government policies that impact the innovation process (Metcalfe 1995). The NIS drives the development and commercialisation of strategic technologies by facilitating and interacting with public sector institutions, firms, and the market, with the private sector being a critical player.

An assessment of technological capabilities of countries requires specific indicators. R&D investments are frequently used as a benchmark to assess the technological strength and overall competitiveness of a country (Wang et al. 2020). Patents help safeguard corporate and research inventions and reflect broader trends in innovation processes, economic landscape, and regulations (OECD 2004). Though advancements in S&T have the capability of shaping societies, such advancements have been uneven. This has led to an expanding technological and economic divide, which is further exacerbated by the Fourth Industrial Revolution (Mallik 2016). In this backdrop, examining the policies and strategies of key players in the technological landscape is important in identifying best practices and opportunities that could aid technological developments in India.

The rationale for selecting China, Korea, and the United States for comparative analysis with India is grounded in deliberate consideration. China's Medium- and Long-term S&T policy initiatives began in 2006, and the country aimed at becoming an innovation-oriented society by 2020 and a leader in S&T by 2050 (Agarwala and Chaudhary 2019). This highlights China's ambition for technology-led industrialisation. Korea's investments in R&D and its advantageous position in emerging technologies like semiconductors and 6G is a reflection of its strides in achieving economic parity with other developed countries. This achievement can also be attributed to Korea's governance structure and the conducive ecosystem that allowed for the integration of new technologies from abroad (OECD 2023). The United States has historically been at the forefront of innovation. The country has always acknowledged S&T as the foundation of its economy and the key role S&T plays as a driver of international development. Drawing from these countries' experiences, the project aims to highlight best practices and their strategies that have led to their growth. Integrating contemporary developments into this analysis is deemed to be important, since it represents the current frontier, in which countries should formulate policies and navigate their strategies to remain competitive. Based on this background, the project conducts a comparative analysis of the technology landscapes of the four countries with a focus on technology inputs and outputs and STI policies.

1.3. Literature Review

India's STI policies have significantly shaped its innovation landscape, with the industrial policy statements providing a guiding framework for manufacturing enterprises. Dhar and Saha (2015) examine India's technological capabilities, offering insights into the evolution of India's STI policies. Their work draws on comparisons with countries such as China, Brazil, and South Korea based on GDP growth, R&D intensity, and patent filing. However, the limitation of data availability to 2011 presents a constraint to the analysis. Furthermore, while their paper discusses comparative R&D intensity and technology exports, it does not examine STI policies leading to these outcomes.

The geographic focus of R&D has shifted, with China and India emerging as the new epicentres, potentially reshaping their global scientific and technological stature (Malik 2012). China asserts it could outcompete the United States in R&D investments, citing its institutional and policy robustness, manufacturing capabilities and global supply chain position (Doshi 2020). An assertion like this impacts the competitive dynamics and highlights the importance of recognising China's growing prominence. Meanwhile, India's NITI Aayog's (2022) report on Research and Development highlights the discordance between India's R&D expenditure and its development agenda, particularly noting the underwhelming private sector contribution. This is certainly an area that could be further explored. Government's role in technology development, especially in emerging economies, is explored by Mani (2004). His examination of fiscal and non-fiscal policy instruments presents a valuable context to the challenges highlighted in the

NITI Aayog report. In his book "The Struggle and the Promise: Restoring India's Potential", Naushad Forbes (2022) explores the transformative potential of R&D in India, emphasising the critical role of innovation within firms. He compares R&D expenditure across newly industrialised nations and highlights how India is an outlier. He focuses on a sectoral breakdown of R&D and reveals how India has no firms in top R&D sectors globally. However, he does not examine the regulatory and incentive frameworks, fiscal and non-fiscal instruments shaping R&D investments and industrial contributions to research. It is crucial to understand the efficacy of these instruments in fostering innovation to address the gaps that have been highlighted.

The role of patents as indicators of technological advancement has been studied extensively. Patents serve as the primary carrier and crystallisation of technology innovation, with over 90% of inventions and creations covered within this domain and around 80% of technical information accessible through patent documentation (Wang and Huang 2023). Such a repository of information provides a comprehensive analysis and predicts technology trends. Wang and Huang's analysis emphasises the prominence of patents as a measure of a country's technological prowess and its level of innovation. Bhaumik et al. (2009) analysed the grants of patents in China and India from 1992 to 2007 as a recorded output of the technology development process. Their findings indicate a notable advancement in patent grants within the two countries. However, their analysis reveals that China had overtaken India in ICT, particularly with regard to the internationalisation of patent development. Given the temporal context of the paper, it becomes necessary to complement the findings of this study with recent data to validate this assertion. Arora and Sanyal (2022) highlight a substantial improvement in patent applications in India in the recent past, with a surge from 9847 patent applications in 2016-17 to 30,074 in 2021-22. Nonetheless, when placed in a comparative international context, India falls behind, relative to its global counterparts, by filing merely 4% of China's patents and 9.5% of that of the US. Their paper indicates that this could be attributed to factors such as understaffing, procedural inefficiencies, and the lack of a fixed timeline for patent approvals in the patent office in India.

Recognising supply chain vulnerability and geo-political uncertainties concerning China's rise has led to a policy focus on "technology sovereignty" (Edler et al. 2021). This term indicates the ability of a political entity to navigate the global technological landscape strategically and independently. Within existing policy literature (March and Schieferdecker

2021), three categories of policy interventions emerge, namely protection, promotion, and projection. They are aimed at enhancing technological sovereignty and strategic autonomy. Policymakers are challenged to balance and find the right equilibrium among these interventions to suit the country.

Knowledge and innovation systems and governance structures are equally important drivers of innovation within a country. Jeffrey Ding's (2021) work explores the strategic implications of General Purpose Technologies like AI in the broader context of technological advancement and global power dynamics. The study emphasises that a nation's success in technology adoption goes beyond mere technological capability and is conditioned by the nature of its domestic policy, socio-economic organisations, and the ability of institutions to foster the spread of new technologies. Fan (2018) delves into the innovation dynamics of India and China against the backdrop of their economic transitions. The study analyses the impact of innovation on economic development using decomposition analysis, revealing the influential role of policy reforms. However, the temporal scope of the analysis is limited, concluding in 2013, necessitating an updated examination to capture the innovation landscape. Chinchure (2022) suggests that India's strength in terms of its economic, technological, and industrial standing positions it favourably to lead Industry 4.0. Yet, the lack of reference to robust research diminishes its scholarly foundation. A more comprehensive integration of academic literature and government policy documents would enhance its academic credibility.

While the discourse on innovation and STI policies is robust, a notable gap remains in a comparative analysis. This project addresses this gap and contributes to the existing body of knowledge by conducting a comparative study of the technology landscapes of the four countries and providing recommendations for India.

1.4. Scope and limitations of the project

The project executes a comparative analysis of the STI policies of four countries: India, China, South Korea, and the USA. The aim of the project is twofold. First, a thematic analysis of significant S&T policies focuses on salient themes that emerge consistently across countries. It is to be noted that climate and health-tech policies have been deliberately excluded since this project aims to focus on major STI policies along with a specific set of technologies aligning with Industry 4.0. Second, an analysis of the R&D and patent ecosystem of the four countries has been conducted. The overall methodology hinges on benchmarking, wherein India's STI policies have been evaluated vis-à-vis the three countries based on selected parameters. Within the ambit of R&D, a key input indicator, the study looks at the percentage of GDP that countries allocate to research activities in each country. The project also looks at the total FTE researchers per million. On the output front, the scope is confined to analysing the number of publications and patent data.

There are some limitations to this project. First, the analysis is based on descriptive statistics, and regression or correlation analysis has not been employed. Exploring association and causality to understand relations among S&T indicators better would necessitate a thorough understanding of econometrics, a justification that the author may not provide. Second, it is to be noted that the comparative analysis of select indicators has been confined to a fixed timeline of 2018 to 2022, and 2023 subject to data availability to facilitate better comparison. Future studies could look at a longer time frame to uncover further trends and patterns. Thirdly, the project only looks at select innovation indicators related to S&T, whereas numerous other indicators could be incorporated in future research. The project also reviews best practices in R&D and patents across countries, drawing recommendations for India to enhance its STI framework. Lastly, this project is strictly confined to the reliance on secondary data, given the short time frame within which the project was to be pursued. As such, primary data from expert interviews or other sources has not been included. However, it is acknowledged that incorporating primary insights could enrich the findings of the study and is recommended for future research endeavours.

1.5. Research Methodology

This exploratory study is centred on evaluating the role of STI indicators and policies in shaping technological advancements in four countries. Adopting a comparative analysis approach, the study examines major STI policies of China, India, South Korea, and the United States.

1. **Analysis of input and output indicators**: The comparative framework has incorporated indicators such as GDP Growth, GERD, total FTE researchers per million, the number of publications by individual countries and the patent count of countries.

- The data for GDP Growth Rate has been sourced from the International Monetary Fund.

- Data for R&D expenditure by different countries has been sourced from the OECD (for China, South Korea and the United States) and the Research and Development Statistics at a Glance (India). This section would employ a mixed methodology, with data points used to compare the R&D expenditure of countries as a percentage of GDP and a qualitative assessment based on secondary literature.
- A comparative analysis of patent data has been conducted using data from the World Intellectual Property Organisation's (WIPO) Intellectual Property Statistics. The methodology followed was "Reporting type: Total count by filing office" and "Indicator: 1-Total patent applications / grants (direct and PCT national phase entries)". This section also employs a mixed methodology with data points used to compare patent applications and grants, followed by a qualitative assessment based on secondary literature.
- The total number of FTE researchers per million was sourced from the UNESCO Institute of Statistics database.
- For publications, Clarivate InCites database was used, with the schema: Web of Science.

2. **Knowledge and Innovation Ecosystems and Governance Structures**: For ideating the structures, a thorough research of key government documents and research papers of the particular country was undertaken.
3. **Comparison of major STI Policies**: The analysis reviews each country's official STI policy documents, along with sector-specific policies that align with Industry 4.0, to get an insight into their major policies and strategies. In India, the Department of Science and Technology (DST) is the principal agency responsible for formulating and implementing the STI Policy, with the Science Technology Innovation Policy 2013 being India's major STI policy document. China's STI policy is articulated by the State Council and the Ministry of Science and Technology, and the National Medium and Long-Term Plan (2006-2020) provides a foundational understanding of the country's STI direction. Though the United States does not have an official STI policy, the National Security Strategy highlights how it aims to build on its strengths by implementing a modern industrial and innovation strategy. The Ministry of Science and ICT oversees South Korea's STI policy formulation, and the country's Basic plans for S&T and a Future Strategy for 2045 provide an overview of its S&T aims. Besides, sector-specific policies (excluding health and climate technologies) and their approach towards these technologies has been compared. The three sectors (AI, Semiconductors and

Quantum) were chosen considering their overall strategic importance and alignment to the fourth Industrial Revolution.

The outcomes of the comparative analysis have led to policy recommendations to augment India’s future STI strategies.

Chapter 2: Discussion

Science and Technology capabilities are essential for a country's progress on various fronts. Such capabilities can be ascertained through important indicators. S&T indicators aid in capturing the various facets of the science ecosystem within a country. These indicators have the potential to elucidate the S&T system and facilitate a deeper understanding of the policies and initiatives implemented by countries. Financial and manpower indicators serve as input metrics within the domain of S&T (Bhattacharya, n.d.). GERD is a financial input indicator that reflects the R&D investments of countries. To show the involvement of persons in R&D, an indicator like the FTE researchers per million is used. Bibliometrics measures the output of S&T activity and uses the publication count and patent count as performance indicators (Bhattacharya, n.d.). Following this approach, this chapter delves into country profiles, and provides an overview of the four countries, considering their GDP growth and GII Ranking. A five-year analysis of GERD and FTE Researchers of individual countries will be undertaken within input indicators. An assessment of the output indications encompassing the number of publications and patents within the same timeframe would be performed. The chapter will extend its focus on assessing the knowledge and innovation ecosystem and agencies responsible for STI governance to provide a holistic understanding of the country's landscapes.

2.1. India

2.1.1. Overview

India is one of the fastest-growing global economies. India's GDP increased from USD 2.84 trillion in 2019 to USD 3.73 trillion in 2023. FY 2020-21 saw a contraction of 5.8% in GDP that could be attributed to the economic challenges the country had to face during the pandemic. In the subsequent FY, India witnessed a GDP growth of 9.1%, primarily due to a low base effect from the previous year. Despite this, the GDP growth rate in FY 2022-23 remained robust at 7.2%. This growth was underpinned by robust domestic demand, fueled by substantial investments in infrastructure and optimistic private consumption. India ranked 40th in the Global Innovation Index (GII) Rankings 2022 and 2023. It had a better performance in innovation outputs than innovation inputs in 2023.

India's FDI inflows have surpassed pre-pandemic levels and have been driven by structural reforms and improvements in the business environment, making India a premier destination for FDI. The government's investment-friendly policy, including allowing up to 100% FDI through automatic routes in most sectors, has helped boost investor confidence (Economic Survey 2022-23). Government initiatives have thus played a crucial role in nurturing innovation by establishing the necessary infrastructure alongside ensuring a secure environment.

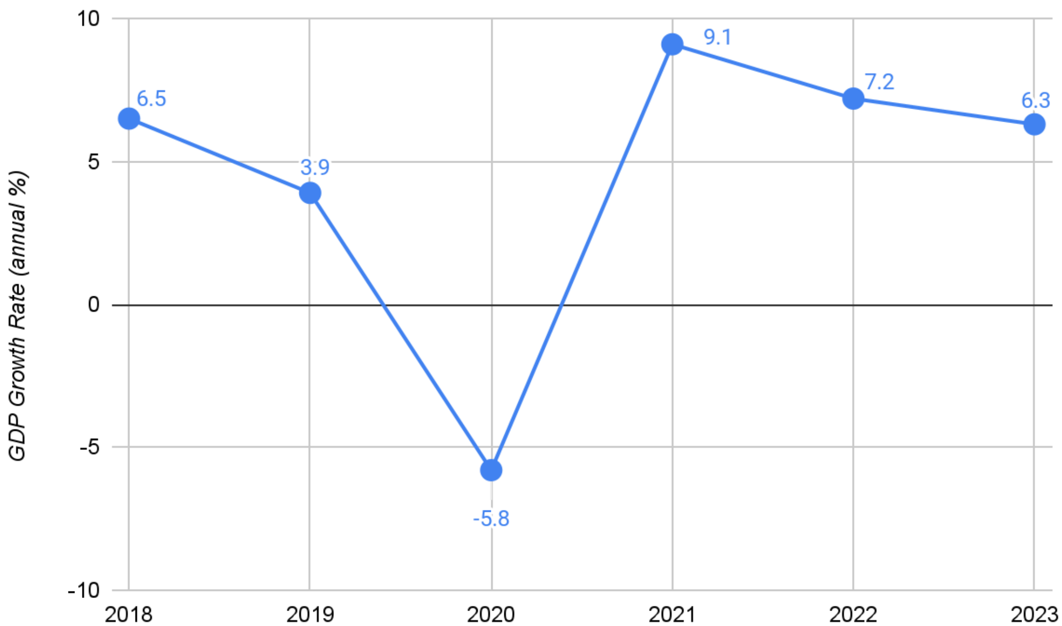

Figure 1: GDP Growth Rate (India)

Source: International Monetary Fund

2.1.2. India's Science and Technology Ecosystem

2.1.2.1. Background

India is among the few countries that had a well-established scientific community and a robust S&T ecosystem since the 1900s, even before it attained independence. During the 1940s, eminent Nobel laureate AV Hill visited India, and his seminal report, Scientific Research in India (1944), garnered support from the intellectual community during the Nehruvian era. This report served as a blueprint for organising India's S&T system and its institutional development after independence (Krishna 2021). This period also witnessed the establishment of foundational institutions like the Council for Scientific Research (1942), Tata Institute of Fundamental

Research (1945) and Saha Institute of Nuclear Physics (1949), among other research establishments that laid the foundation for India's scientific prowess.

India's approach to S&T policy can be categorised into three phases: the infrastructure phase (1947-1960), the assessment and reorientation phase (1970-1980), and the accountability phase (1980 and beyond) (Sandhya 2018). Nehru's visionary approach to development through S&T was linked to the expansion of education, skills and human capital, particularly within the higher education system. The foundation for establishing specialised engineering institutions was laid in 1945 with the institution of the Sarkar Committee. Throughout the 1950s and 1960s, efforts were made to create basic S&T infrastructure, which included expanding the number of universities to meet the growing demand for skilled professionals. During the same period, major mission-oriented science agencies in atomic energy, social sciences and medical sciences emerged and expanded (Krishna 2021). It is noteworthy that there were no policy statements concerning S&T that were passed during the Nehruvian era apart from the 1958 Scientific Policy Resolution. The third Five Year Plan focused on promoting agriculture, atomic energy, and engineering research. For the first time, the plan sought the commercial utilisation of research outcomes. The Indian Patents Act of 1970, later amended for compliance with TRIPS, and the Technology Policy Statement of 1983 emphasised technological self-reliance and a strategic approach to technological imports and FDI.

During the 1980s, India observed a diminishing impact of S&T on national competitiveness, prompting a revaluation of its policy direction (Dhar and Saha 2014). The 1991 economic reform was instrumental in bringing the industry and market-based S&T policy culture to the forefront of India's trade policy regime, and this also bought private industry players. The government's active role in fostering public-private partnerships marked a strategic effort to incentivise private industry towards R&D, sharing costs and rewards, thereby driving innovation and technological advancement (Sandhya 2018).

The boom in the biotechnology sector and the pharmaceutical industry during the 1990s is evident through increased budgetary allocations and an increase in the number of research groups and laboratories. Information and Communication Technology software emerged during the same time period. Apart from these sectors, it was the aerospace sector that placed India on the global map, and this sector also witnessed some of the most important developments, including the development of the PSLV during the 1990s. The Eighth FYP integrated S&T

policymaking with broader economic policy, favouring industrial R&D, technology identification and development. Subsequent FYPs emphasised promoting basic research, collaboration between public institutions and private industry, and developing priority sectors.

The Science and Technology Policy 2003 highlighted the need for higher investments in R&D and the incorporation of social and economic sectors with the national system. The decade from 2010 to 2020 was termed as the 'Decade of Innovation' by the then Prime Minister Manmohan Singh, culminating in the STI Policy of 2013. This policy acknowledged the previously under-emphasised role of innovation, highlighting it as a driver of development across critical R&D areas. It emphasised the prioritisation of sectors, with a specific focus on MSMEs. Government initiatives to increase GERD and private sector investments led to India occupying its spot in the list of the top 50 countries at the 48th position in the GII 2020.

2.1.2.2. Indicators

i. GERD as a percentage of GDP:

The GERD in India has seen a two-fold rise from Rs 60,196.75 crore (USD 8.43 billion with a conversion rate of 1 INR=0.014 USD) in 2010-11 to Rs 127,380.96 crore (USD 17.84 billion) in 2020-21. However, India's GERD is much lower than other countries, and has been around 0.6% to 0.7% for nearly the past decade. In India, public expenditure has been the major contributor to R&D. This trend is in sharp contrast with other developing and developed countries, where the private sector is an equally important contributor to R&D (DST 2023).

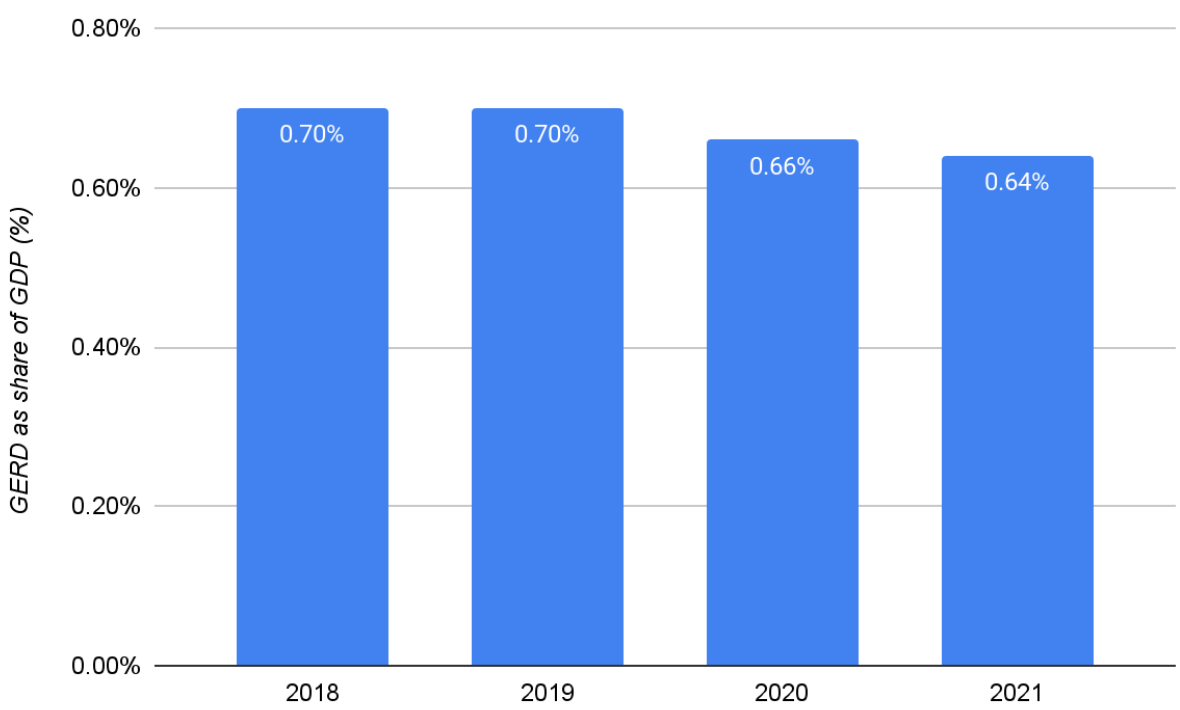

Figure 2: GERD as a share of GDP (%) (India)

Source: R&D Statistics at a Glance (2021-22 and 2022-23), DST

ii. Total FTE Researchers per million

Data from the UNESCO Institute of Statistics reveals that India had nearly 251 researchers and 260.4 researchers per million in 2018 and 2020, respectively. While India has nearly 40,000 higher education institutions (AISHE 2019), merely 1% of these institutions are engaged in active research. This number could be attributed to limited government investments in R&D, and this shortage of researchers could pose a significant challenge for India going forward.

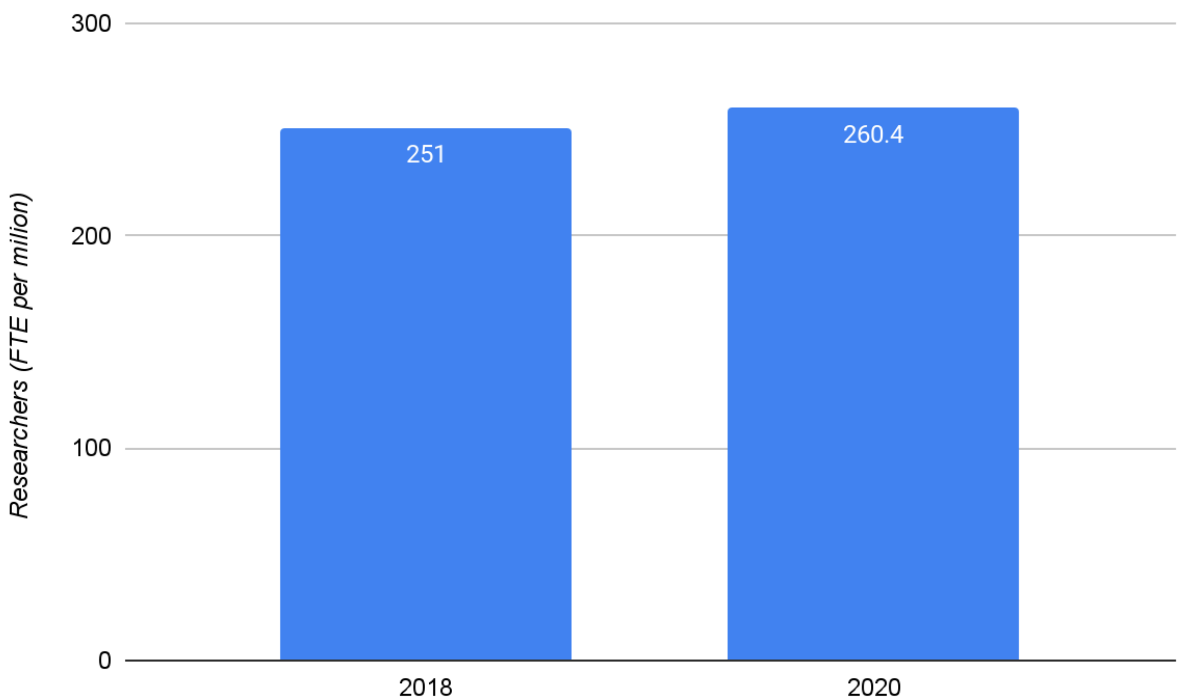

Figure 3: FTE Researchers per million (India)

Source: UNESCO Institute for Statistics

*Data for 2019, 2021 and 2022 is not available

iii. Publications

According to the Clarivate Incites database, India witnessed a significant rise in the number of overall publications, with a 40% increase from 142,853 publications in 2018 to 200,475 publications in 2022. Across five years, the top three areas of publications include Materials Science, Engineering (Electrical and Electronics), followed by Telecommunications.

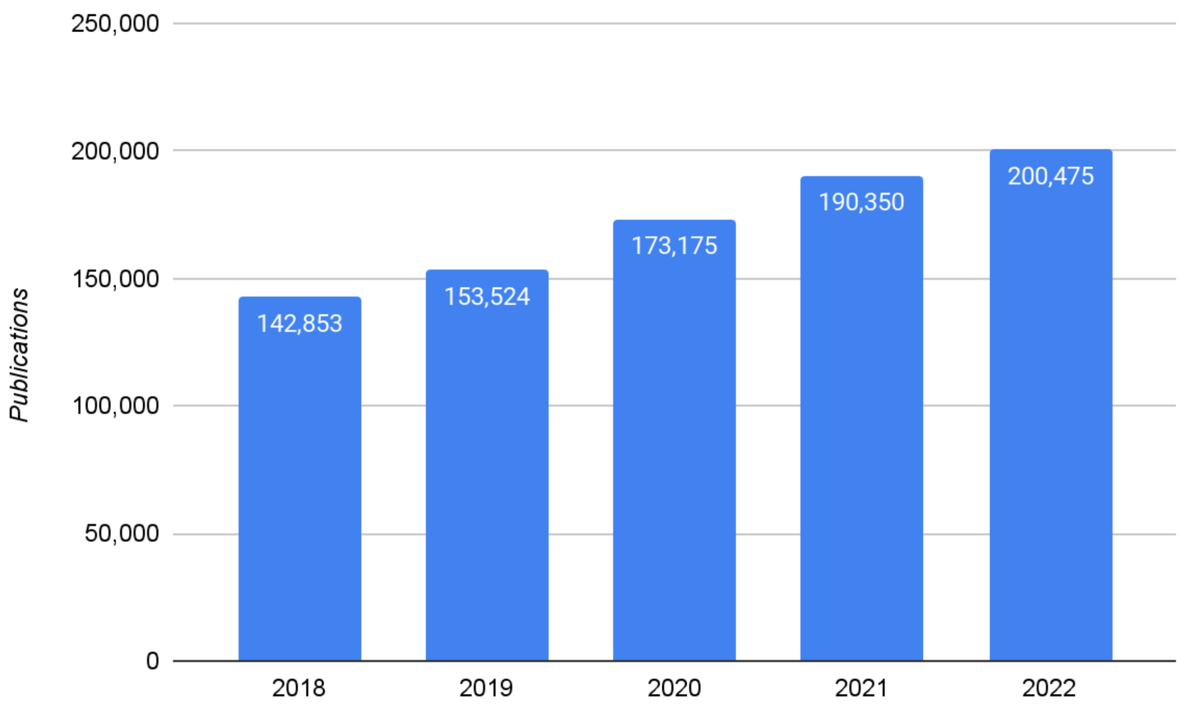

Figure 4: Publication output (India)

Source: Clarivate InCites, data extracted on 21st March 2024

Methodology: Location: India, Time Period: Individual years from 2018 to 2022, Schema: Web of Science

iv. Patents

India has witnessed a 25% rise in the number of patent applications from 61,573 in 2021 to 77,068 in 2022. However, there was a slight reduction in the number of patents granted from 2021 to 2022. There has been a rise in the share of resident patent applications filed from 16,289 in 2018 (32.5% of total applications) to 38,551 in 2022 (50.02% of total applications).

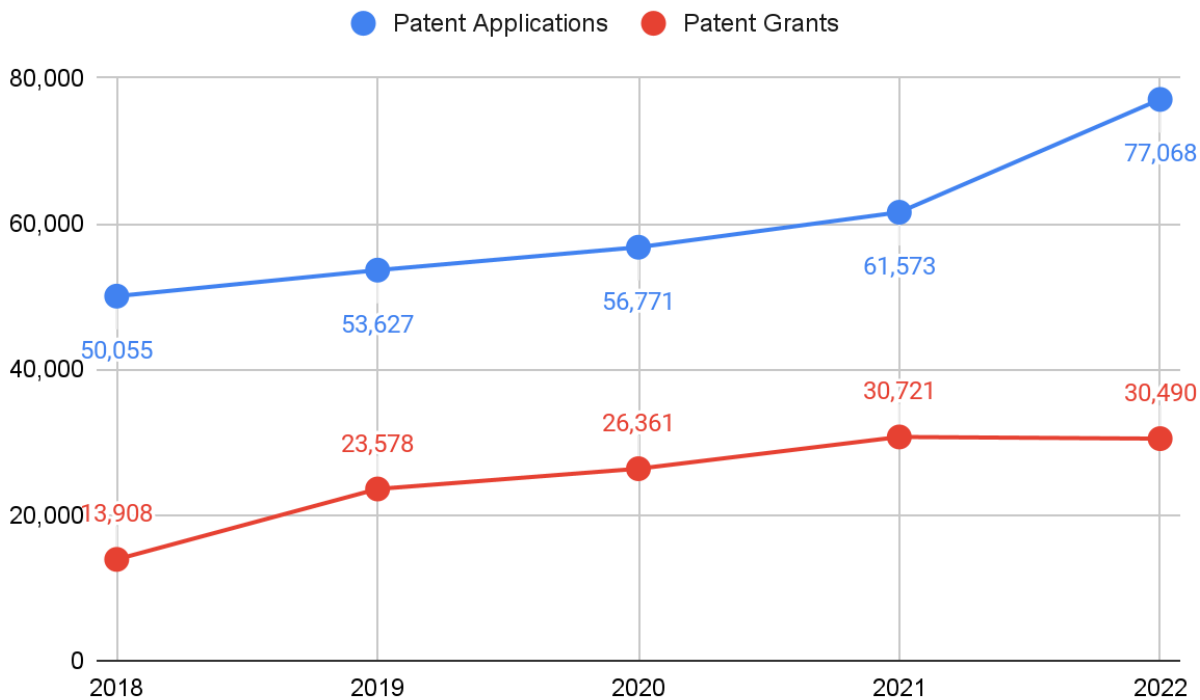

Figure 5 : Number of Patent Applications and Patent grants (India)

Source: World Intellectual Property Organisation (WIPO) IP Statistics data

2.1.3. Knowledge and Innovation Ecosystem

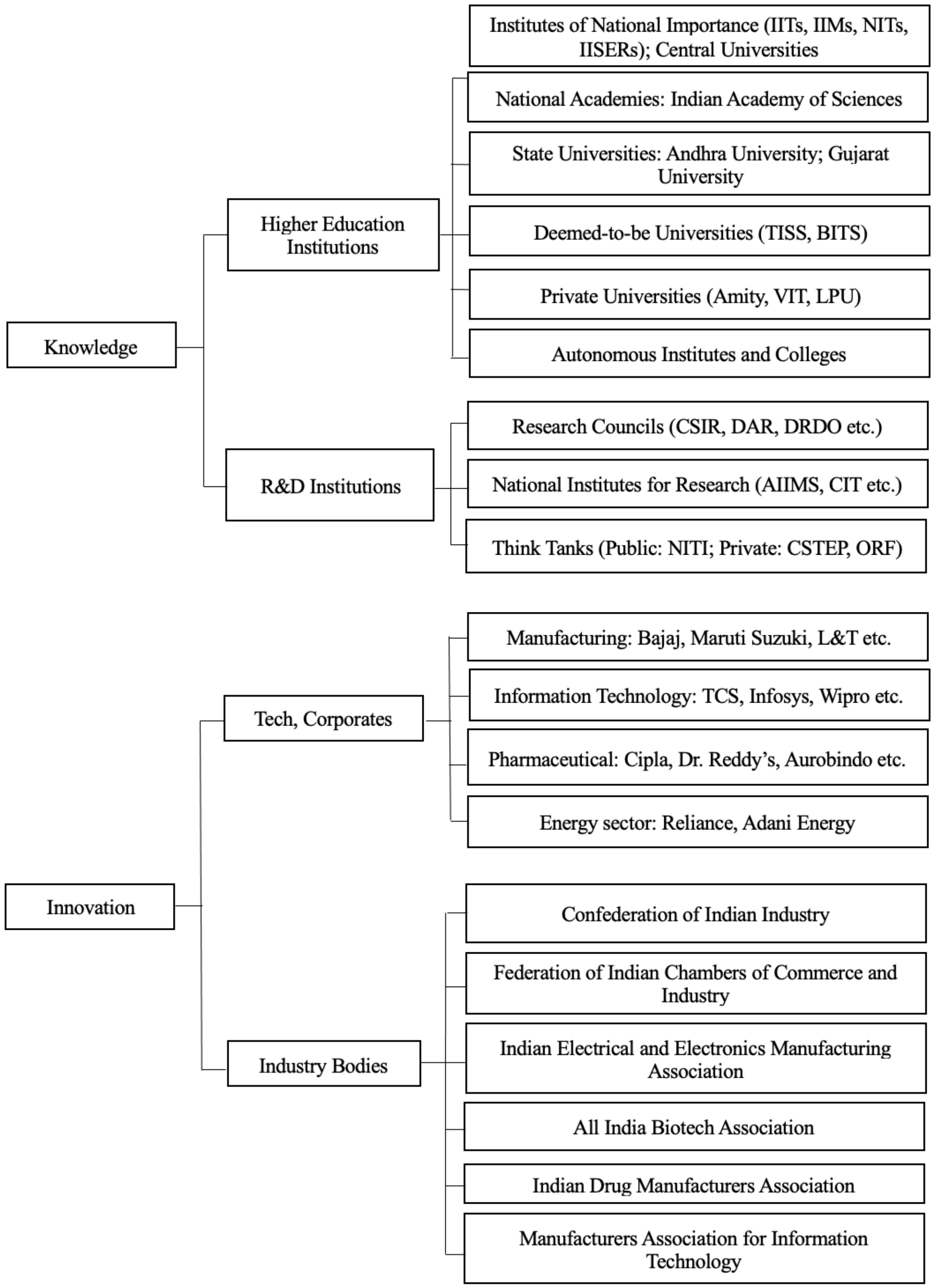

Figure 6: India's Knowledge and Innovation Ecosystem

Source: Author's interpretation of the country's Knowledge and Innovation ecosystem

India’s higher education landscape is characterised by a range of institutions, with 1,113 universities and university-like establishments, 43,796 colleges, and 11,296 standalone institutions (AISHE 2023). The University Grants Commission (UGC), which is a statutory body, facilitates the oversight and advancement of higher education. Within the higher education system in India are the Institutions of National Importance which include the Indian Institutes of Technology (IITs), National Institutes of Technology (NITs) and Indian Institutes of Management (IIMs) among other prominent institutions. Central universities, established by Acts of Parliament, fall under the purview of the Department of Higher Education, Ministry of Education. State universities are established by provincial or state acts. Deemed universities enjoy autonomy granted by the Department of Higher Education. Private universities are empowered to award degrees as specified by the UGC, and autonomous institutes autonomously confer degrees and fall under the Department of Higher Education’s control.

In R&D, India has prestigious research councils like the Council of Industrial and Scientific Research (CISR) and the Indian Academy of Sciences, alongside national research institutes such as AIIMS, Central Drug Research Institute, and Centre for Excellence in Basic Science. The country’s technology sector houses prominent corporates across manufacturing, IT, pharmaceuticals, and energy sectors, with Tata Consultancy Service, Infosys, and HCL Technologies ranking among the top IT powerhouses by market capitalisation as of 2024. Industry perspectives are integrated through representation from industry associations like the CII, FICCI, and Associated Chambers of Commerce and Industry of India, with sector-specific associations contributing to biotechnology, pharmaceuticals, and software industries. These educational institutions, councils, and centres together shape India’s knowledge and innovation ecosystem.

2.1.4. Agencies responsible for funding and governance of STI

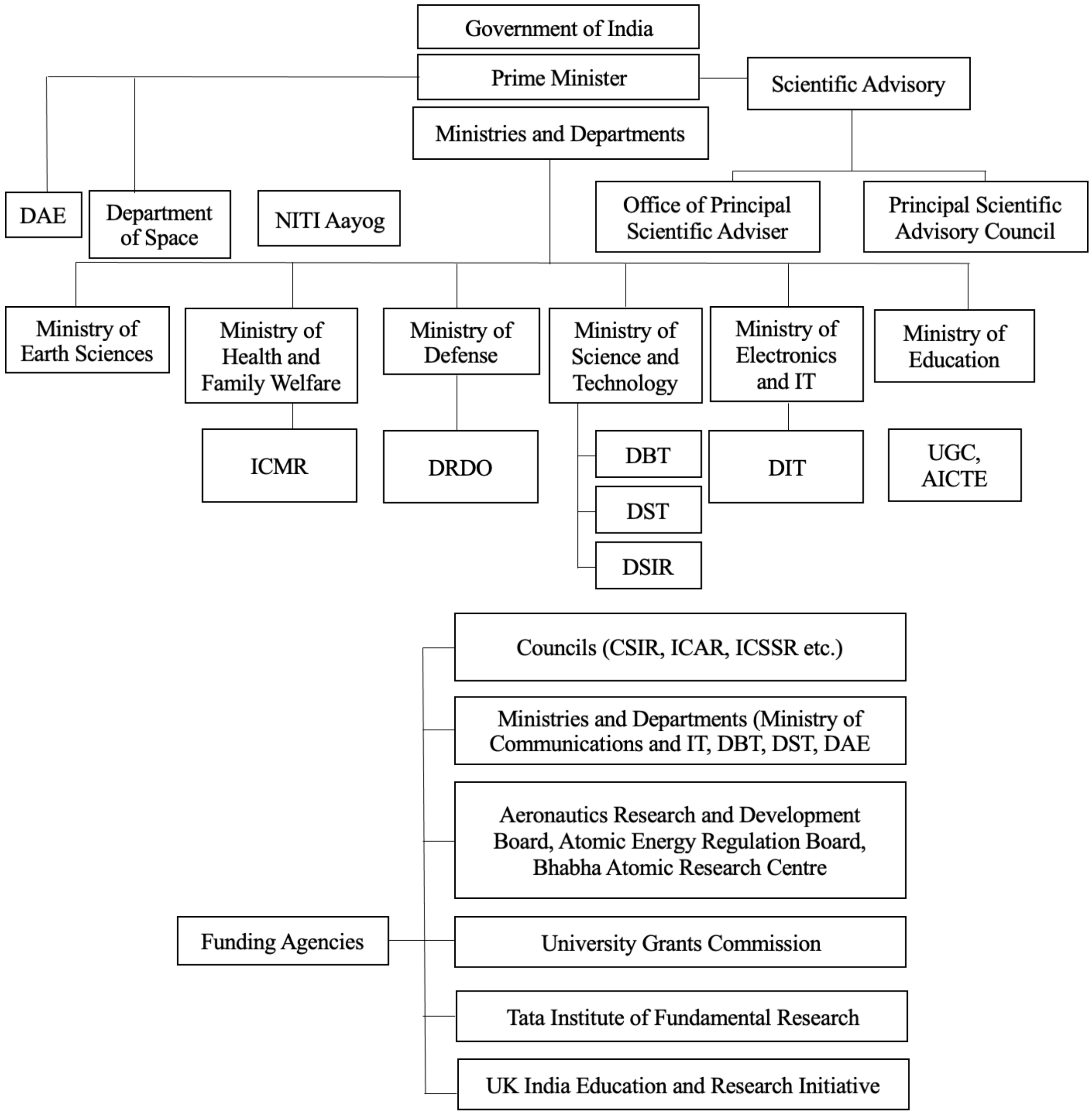

Figure 7: India's STI Governance structure

Source: Author's interpretation of the country's governance structure.

In India, several ministries, departments, and entities play key roles in the governance of the STI ecosystem. The Department of Atomic Energy and the Department of Space operate directly under the Prime Minister's authority. This emphasises the strategic importance that the government places on nuclear energy and space exploration. The Office of the Principal

Scientific Adviser (OPSA) advises the Prime Minister and the cabinet on Science and Technology matters. The PM's Science, Technology and Innovation Advisory Council (PM-STIAC) provides overarching guidance and develops futuristic visions. The Department of Science and Technology, a component of the Ministry of Science and Technology, serves as the nodal agency for formulating STI policies and coordinating with stakeholders. STI policy making also involves entities like the Ministry of Electronics and Information Technology, NITI Aayog, Ministry of Education and other ministries and departments along with various state S&T councils, reflecting a collaborative approach to advancing India's STI landscape.

Funding mechanisms within India's STI ecosystem include both domestic sources and funding from international collaborations. Country-centric research funds, alongside contributions from councils, departments, and research centres, support indigenous research initiatives. Moreover, partnerships with entities such as the Indo-US Science and Technology Forum, UK India Education and Research Initiative, and Global Innovation Technology Alliance provide cross-border collaboration and funding opportunities.

2.2. China

2.2.1 Overview

China is the world's second-largest economy, boasting a GDP of USD 17.7 trillion with a GDP growth rate of 3% in 2022 (IMF 2023). China has experienced accelerated economic growth in the past but has seen a gradual deceleration of the growth rate of its real GDP in recent years. China is recognised globally as a leading exporter and manufacturer, and produces a range of goods including textiles, electronics and heavy machinery (Xu et al. 2018). China ranked 12th in GII 2023, and first among the 33 upper-middle-income group economies. The country performed better in innovation outputs than inputs in 2023.

China's economic reforms since 1978 have propelled the country's GDP growth to an average of 8% to 9% annually. According to data from the IMF, between 1980 and 2012, the country experienced an average growth rate of 8.9%, slowing down to 6.4 % from 2012-2019 (Kenneth and Yang 2023). An essential element of China's economic ascendence is its ability to attract high Foreign Direct Investment (FDI), with technological spillover from investments playing a crucial role in driving China towards achieving new economic milestones. However, it is noteworthy that FDI inflows witnessed a significant reduction, from USD 344 billion in 2021 to USD 180 billion in 2022, indicating a shifting landscape in global investment trends.

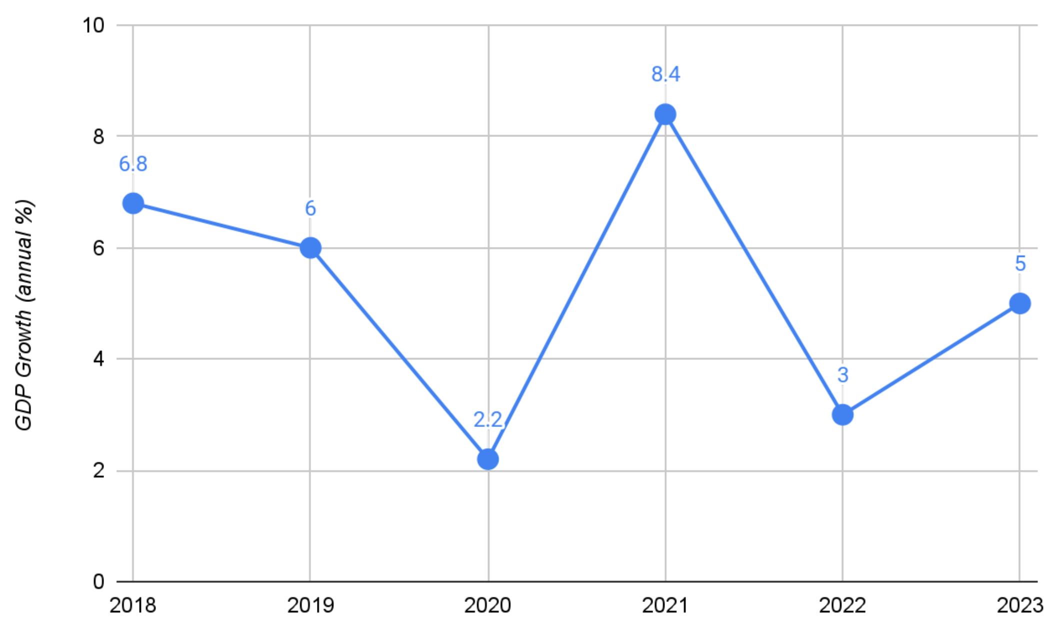

Figure 8: GDP Growth Rate (China)

Source: International Monetary Fund

2.2.2. China's Science and Technology Ecosystem

2.2.2.1. Background

The evolution of China's approach to STI Policy and technological development over the decades reflects a significant transformation from a centralised planning system to a more open, market-oriented and globally competitive stance. Initially modelled after the Soviet Union's centralised planning system, China's technological development during the 1950s and 1960s was marked by a hierarchical and bureaucratic R&D structure (Serger and Breidne 2007). This approach limited the country's ability to innovate, leading to a realisation of the disadvantages of relying on imported technology. The death of Mao and the rise of Deng Xiaoping marked a distinctive moment in China's economic and technological development and approach. Deng's reforms, particularly the four modernisations in agriculture, industry, science and technology, and national defence (Gao and Tisdell 2004) laid the foundation for the opening up of China.

Subsequent developments led to China establishing a comprehensive National Innovation System, characterised by subsystems focusing on technological, regional innovation and integration of military and civilian knowledge (Kong and Xu 2010). The NIS aimed to overcome the stark separation between S&T activities in public research institutions and manufacturing activities at state-owned enterprises.

China shifted its STI policy focus towards attracting FDI and enhancing its global trade position, particularly in high-technology exports. This shift began with the Key Technologies Research and Development Programme (1982) to address critical technological challenges for economic and social advancement. The Decision on Reform of Science and Technology Management System (1985) laid emphasis on improving research competitiveness, linking institutions and commercialisation of technology. China implemented a number of programs, including the 863 Program that aimed to achieve breakthroughs in biotechnology, space technology, and information technologies. The Torch Programme (1988) was introduced to facilitate market-oriented technological development, incentivise high-tech enterprises and parks, and promote technology commercialisation. During the 1990s, China began with a shift towards a more integrated, market-oriented R&D system that placed a pronounced emphasis on innovation (Jigang 2020). The National Medium and Long Term Program in 2006 set ambitious targets for the country in terms of R&D expenditure, patent creation, and the contribution of science to the economy. It aimed to position China among the top five global leaders in terms of innovation.

China's efforts have been fruitful in increasing its global visibility in the fields of STI and establishing itself as a leader in the manufacturing sector, on digital platforms, and R&D concerning basic science (Schoff and Ito 2019). The Belt and Road Initiative (BRI) and Made in China 2025 are a testimony to China's commitment towards indigenous innovation, adoption of technologies concerning the fourth Industrial Revolution, and enhancement of its technological independence and global competitiveness.

2.2.2.2. Indicators

i. GERD as a percentage of GDP

During the beginning of the 20th century, China's share in global R&D funding was less than 5%. By 2020, China's global share of R&D investments rose to over 24% (CRS, 2022). In 2022, China's GERD crossed the 3 trillion yuan mark to reach around USD 456 billion, reflecting a 10.4% year on year increase.

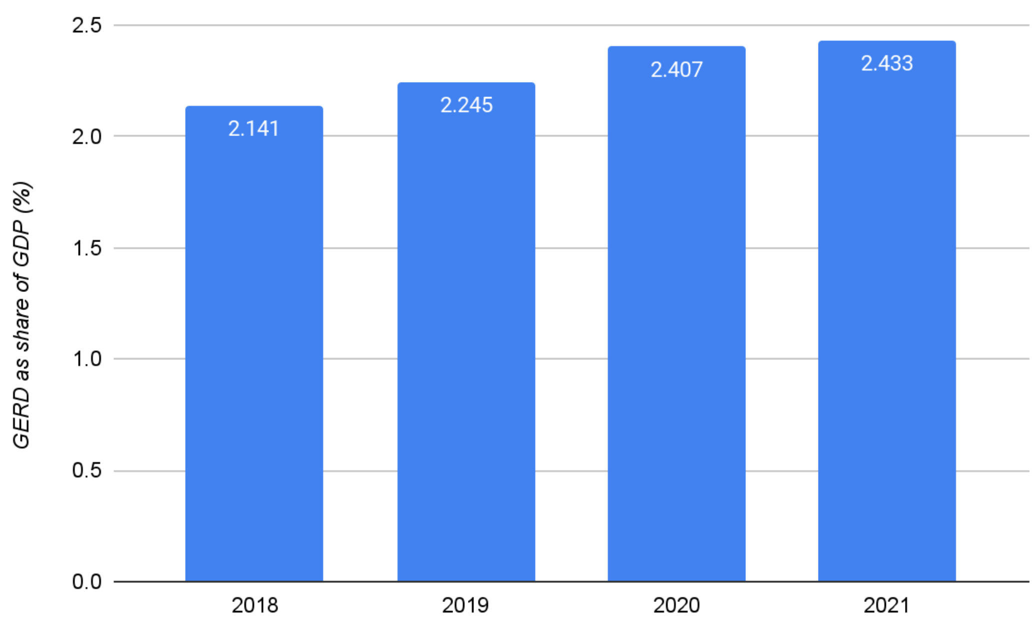

Figure 9: GERD as a share of GDP (%) (China)

Source: Gross domestic spending on R&D, OECD

ii. Total FTE Researchers per million

The total number of researchers per million population increased gradually from 1319.4 researchers per million in 2018 to 1687.1 in 2021. A report by UNESCO reveals that in 2018, China alone accounted for 21.1% of global researchers (UNESCO Science Report 2021). The average annual growth of researchers over the four years stands at around 7%.

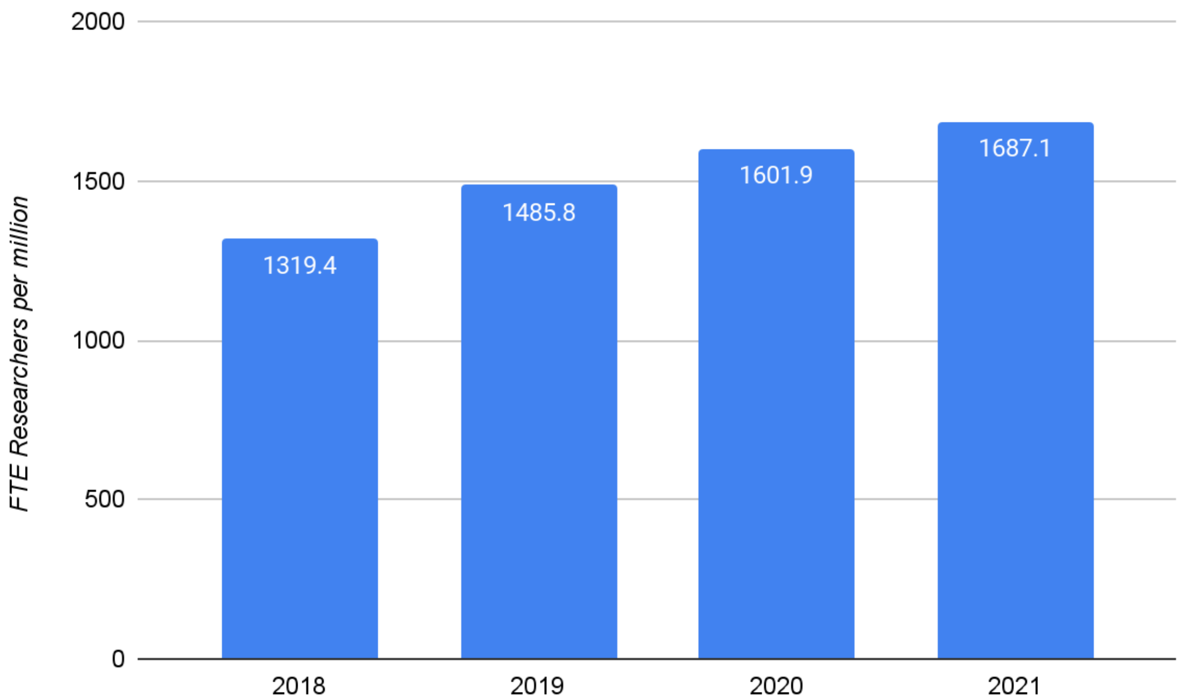

Figure 10: FTE Researchers per million (China)
Source: UNESCO Institute for Statistics

iii. Publications

As mentioned in the Global Research Report: China's Research Landscape (2023), China occupies a notable share in global research publications in areas of technology, and comprise a majority of articles in automation control, telecommunications and nanotechnology between 2017 and 2021 (Institute for Scientific Information, 2023). According to the Clarivate Incites database, the total number of publications produced by China saw an exponential rise from 522,127 in 2018 to 847,808 in 2022.

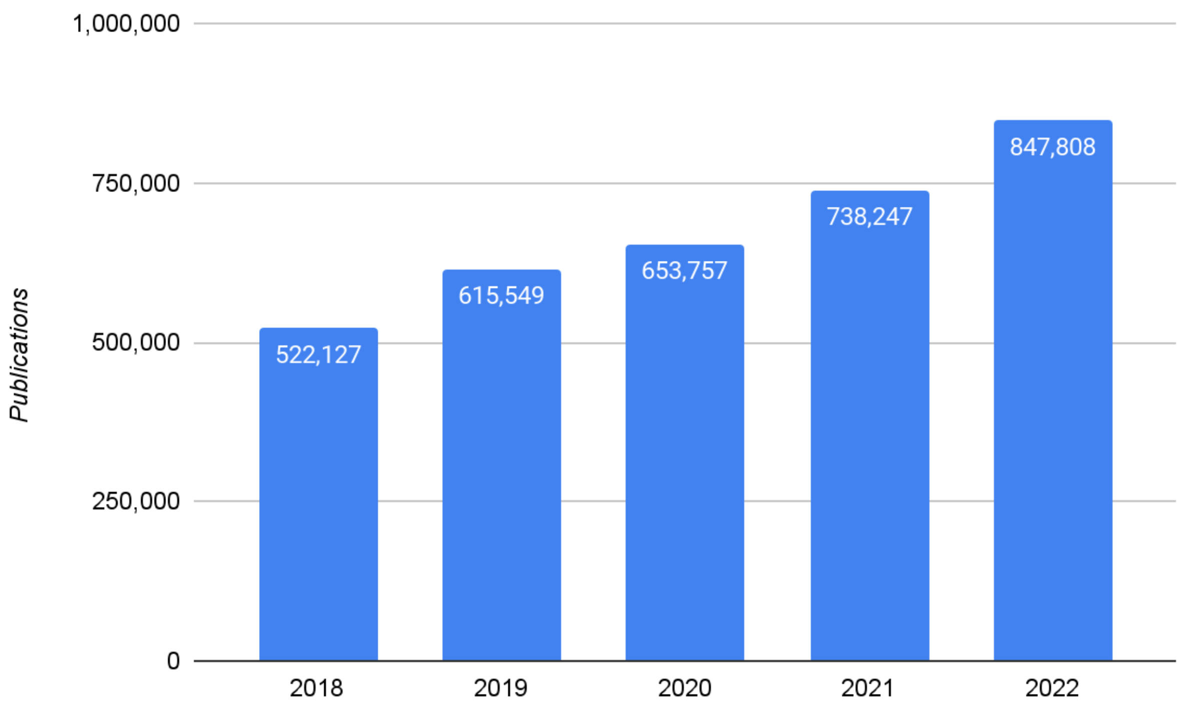

Figure 11: Publication output (China)

Source: Clarivate InCites, data extracted on 21st March 2024

Methodology: Location: China, Time Period: Individual years from 2018 to 2022, Schema: Web of Science

iv. Patents

In 2022, China accounted for 46.8% of the total patents filed worldwide (WIPO 2023). The country's patent count witnessed an upward trend from 2018 to 2022, with 798,347 patents granted in 2023. Only 10.5% of total patent applications in 2022 are non-resident applications. A similar trend can be observed throughout the other years as well. This is in stark contrast to India where nearly 49.8% of patent applications were non-resident applications in 2022. Notably, China and India had been responsible for the global growth of patent filings in 2022 (WIPO 2023).

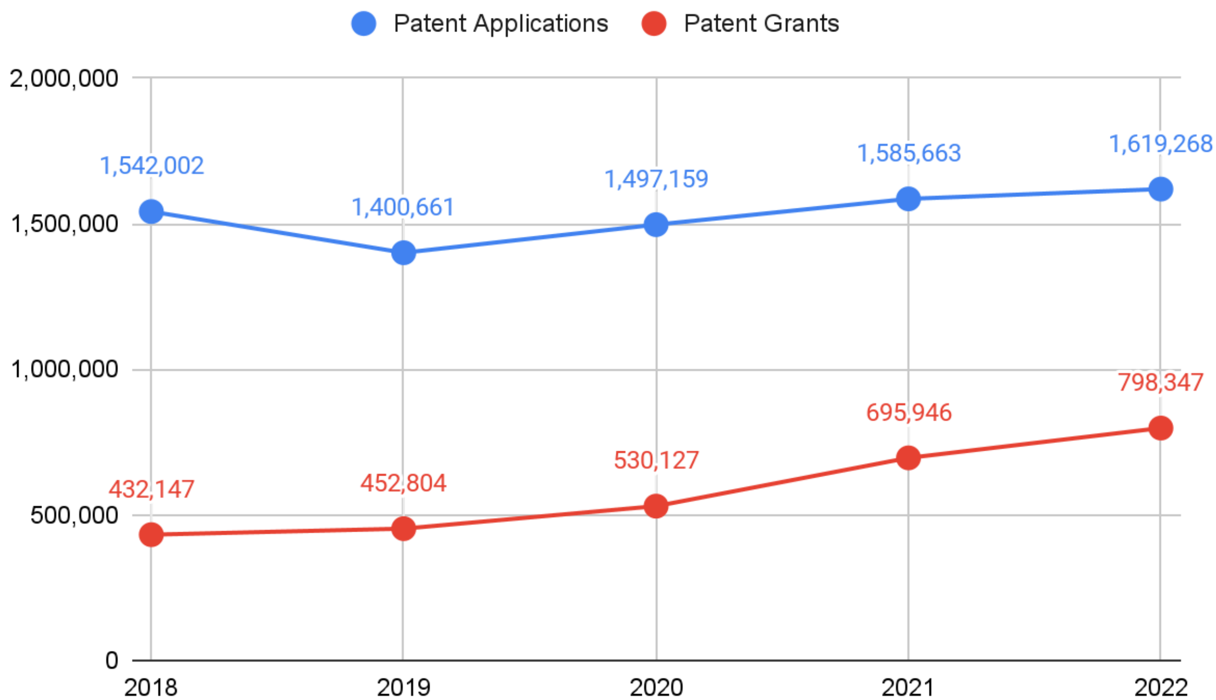

Figure 12: Number of Patent Applications and Patent grants (China)

Source: WIPO IP Statistics data

2.2.3. Knowledge and Innovation Ecosystem

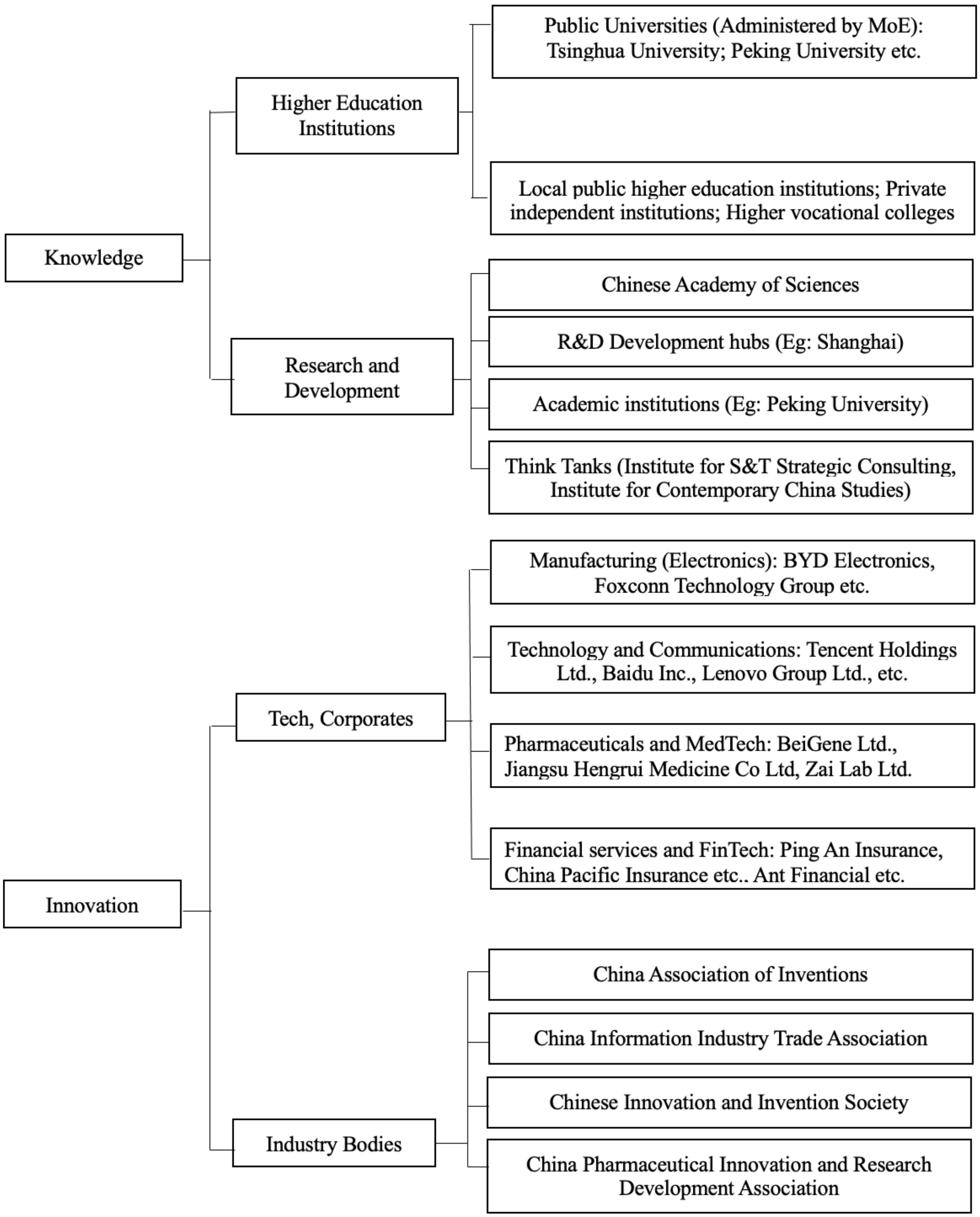

Figure 13: China's Knowledge and Innovation Ecosystem

Source: Author's interpretation of the country's Knowledge and Innovation ecosystem

A robust system of higher education and research institutions support the backbone of China's innovation ecosystem. The country has around 3,012 higher education institutions as of 2021 (MoE 2022) with over 50 institutions ranked in the QS World University Rankings as of 2022. These institutions along with premier R&D hubs, and steps taken by the government to encourage foreign investment (State Council 2023) are crucial in driving the country's research and innovation agenda. Government initiatives such as the National Key R&D Programmes highlight the commitment to leveraging S&T for societal benefits, and entities like the National Science and Technology Leading Group play a major role in deliberating on S&T strategies and policies.

The Global Data Report 2022 reveals that in the corporate sphere, technology giants such as the Alibaba Group Holding Ltd., Tencent Holdings Ltd., and Baidu Inc. are at the forefront of innovation (Global Data Report 2022). They highlight China's competitive edge in the global digital economy. According to the same report, China's top 10 pharma companies collectively reported an R&D investment of USD 5,114 million in 2021, showcasing the importance of private investments in driving innovation in China. Industry bodies and associations help foster an environment conducive to innovation and invention. The China Association of Inventions, established in 1985 with the support of state leaders and academicians; the Chinese Innovation and Invention Society (2009), led by the Premier and comprising members from critical governmental departments, along with the China Pharmaceutical Innovation and Research Development Association (1988), showcase collaboration and support across academia, industry, and government. These organisations, along with the efforts to encourage foreign investment in R&D and the strategic guidance provided by the National Science and Technology Leading Group, exemplify China's approach to innovation.

2.2.4. Agencies responsible for funding and governance of STI

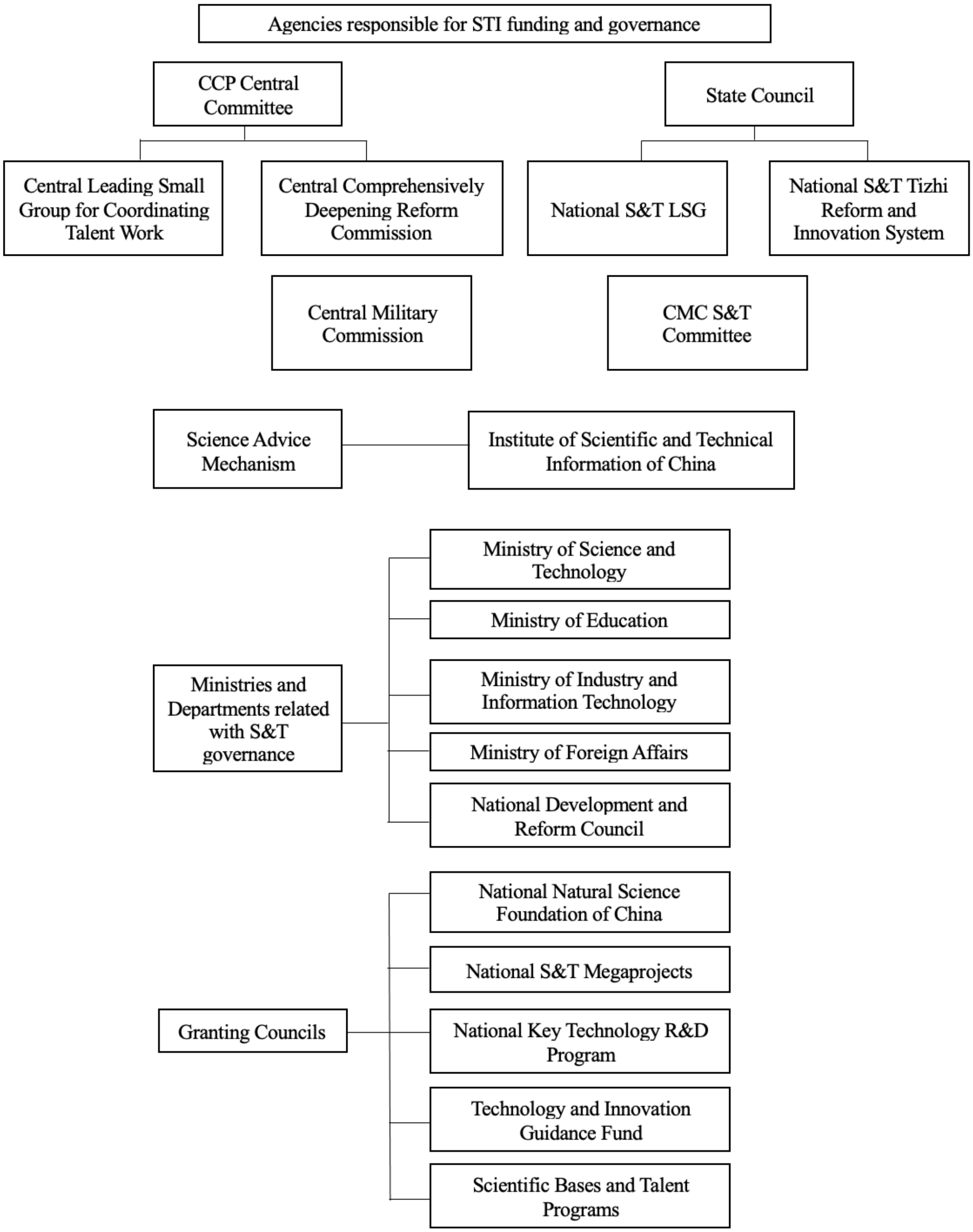

Figure 14: China's STI Governance structure

Source: Author's interpretation of the country's governance structure

In China, the Chinese Communist Party (CCP) Central Committee, the State Council, the National People's Congress and the Central Military Commission constitute the highest decision-making authorities and deliberate on the most significant policy issues concerning S&T. The Central Comprehensively Deepening Commission is a review and approval body for S&T policy initiatives. The Central Leading Small Group for Coordinating Talent Work takes responsibility for implementing plans.

Within the State Council, the "National Science and Technology Leading Small Group" is the highest decision-making body for developing and approving S&T plans. The National S&T Tizhi Reform and Innovation System Construction LSG looks after reforms. The Central Military Commission acts as one of the coordinating bodies on S&T matters. The "Institute of Scientific and Technical Information of China" is a national-level scientific and technological information research institute directly under the Ministry of Science and Technology and provides decision-making support for certain government departments. A number of other ministries including the Ministry of Education, Ministry of Industrial and Information Technology, Ministry of Foreign Affairs, National Development and Reform Council deal with S&T matters.

Policies regarding public research funding allocation abide by the plans formulated by the State Council under guidance of the CPC and are ultimately driven by strategies formulated by the party's National Congress. The "National Natural Science Foundation" of China is the most important funding agency for natural science research. National S&T Megaprojects funds around 32 megaprojects as of 2024. The National Key Technology R&D Program addresses S&T issues that are related to the socio-economic development of the country. The Technology and Innovation Guidance Fund focuses on funding in the areas of technology transfer and the startup ecosystem. The Scientific Bases and Talent Programs supports education, research, and training of S&T personnel.

2.3. South Korea

2.3.1. Overview

South Korea has been successful in combining accelerated economic growth with significant poverty reduction, with an average annual real GDP growth of 4.9% over the past three decades (World Bank 2022). The GDP (USD current prices) increased from USD 1.65 trillion in 2019 to USD 1.82 trillion in 2021 before slightly decreasing to USD 1.71 billion in 2023. The GDP growth rate in 2023 was 1.4%, which is a three-year low after a growth of 2.6% in 2022 and 4.3% in 2021. South Korea stood at 10th position in GII 2023. The country produces greater innovation outputs compared to its investments in innovation.

FDI has played a major role in the country's economic growth. However, according to UNCTAD's World Investment Report 2023, FDI to South Korea fell 18.4% to USD 18 billion in 2022 (UNCTAD 2023). Currently, Korea's experience offers rich insights for developing countries that are in a transition phase towards a dynamic knowledge economy.

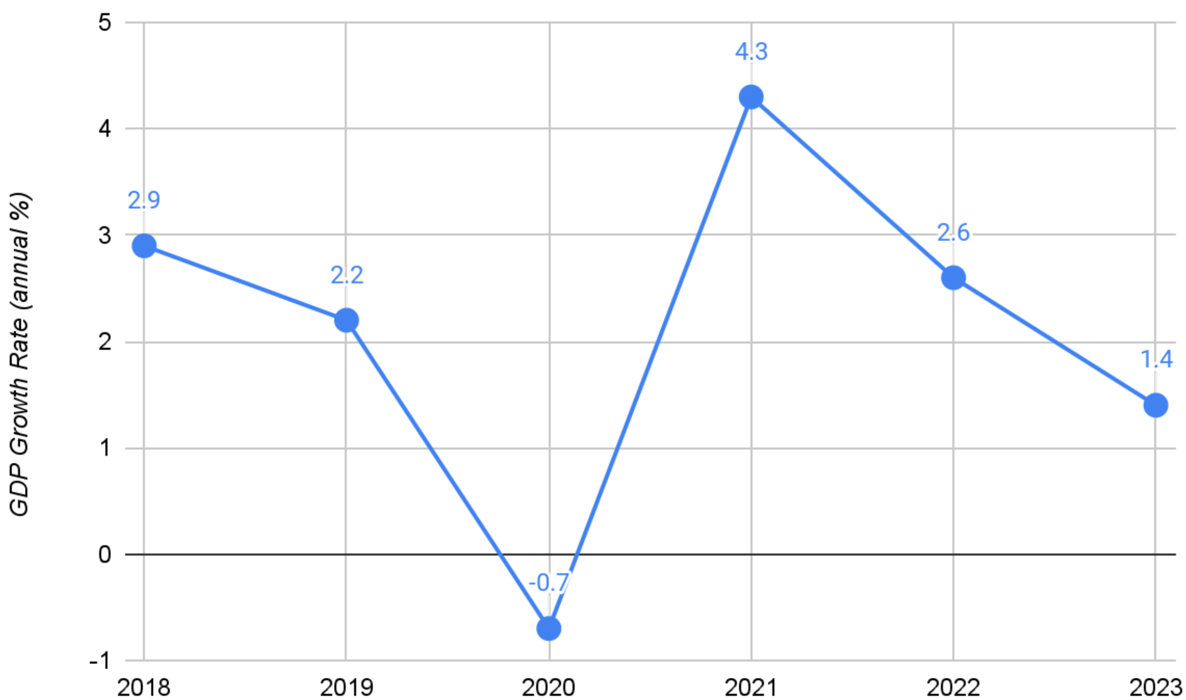

Figure 15: GDP Growth Rate (South Korea)

Source: International Monetary Fund

2.3.2. Science and Technology Ecosystem

2.3.2.1. Background

Korea's foundation in S&T was laid in the 1960s, when the country was introduced to modern developments in the field of S&T. The Ministry of Science and Technology (MOST) was established in 1967 and this ministry played a crucial role in Korea's transformative journey from a developing country to that of an advanced economy by the 1980s. From 1962 to 1997, South Korea experienced remarkable economic growth, averaging nearly 8% annually, widely attributed to a strong innovation system (Salami and Soltanzadeh 2012). The government also played a key role in this system, coordinating between various actors and ensuring an effective NIS. It took an active stance in resource allocation, targeting industries for promotion and backing them with the necessary incentives (Oh and Yi 2022). The government's commitment extended to developing technological infrastructure and creating a system facilitating dynamic interactions between different actors.

The country was at a critical juncture in 1987 when it experienced a major shift towards hi-tech industry when the Industrial Generic Technology Development Program was launched (OECD 2023). It was during the same time that the private sector companies began in-house R&D which led to a reduction in the dependence on technology imports. There was a pronounced focus on fundamental research during the late 1990s. A large number of R&D projects were taken up during the same period, and the five-year plans structured the policy processes. The Leading Technology Development Project in 2001 endeavoured to elevate Korea's status in S&T. This initiative also resulted in participation of private firms, setting precedence for collaboration even for the forthcoming projects (OECD 2023). A number of ministries and councils were set up during the 2000s, and the launch of the first Basic S&T Plan in 2002 was the first of many plans that led to nurturing of a robust innovation system in the country. Learning lessons from the Asian Financial Crisis (1997-1998), Korea increased its R&D spending to enhance flow of knowledge across the NIS. By 2006, the country was a leading R&D spender on a global scale. The country was successful in providing an enabling environment for the growth of innovation and industries. It had undertaken a number of measures including R&D tax support, tax benefits among a plethora of initiatives to ensure an ecosystem conducive for innovation.

2.3.2.2. Indicators

i. GERD as a percentage of GDP

South Korea is among the highest spenders on R&D globally. In absolute terms, the country's R&D spending is approximately USD 110,148 million in 2021, an increase from USD 88,136 million in 2017. Currently, South Korea's GDP to R&D stands at 4.93% as of 2021, standing second behind Israel, which has spent 5.56% of its GDP on R&D.

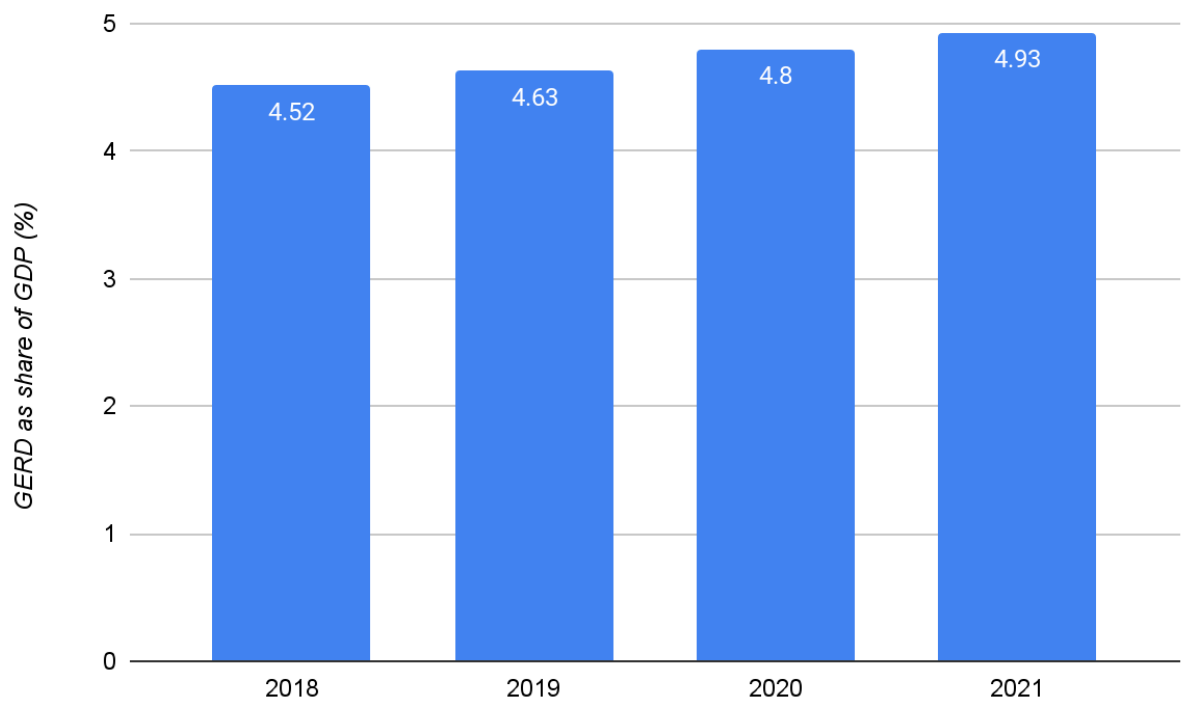

Figure 16: GERD as a share of GDP (%) (South Korea)

Source: Gross domestic spending on R&D, OECD

ii. Total FTE Researchers per million

The total FTE researchers per million population in Korea increased gradually from 7913.5 in 2018 to 9081.9 in 2021. This is certainly one of the highest in the world. The average annual growth in the number of researchers is noteworthy, with a percentage increase of nearly 5.4% from 2020 to 2021.

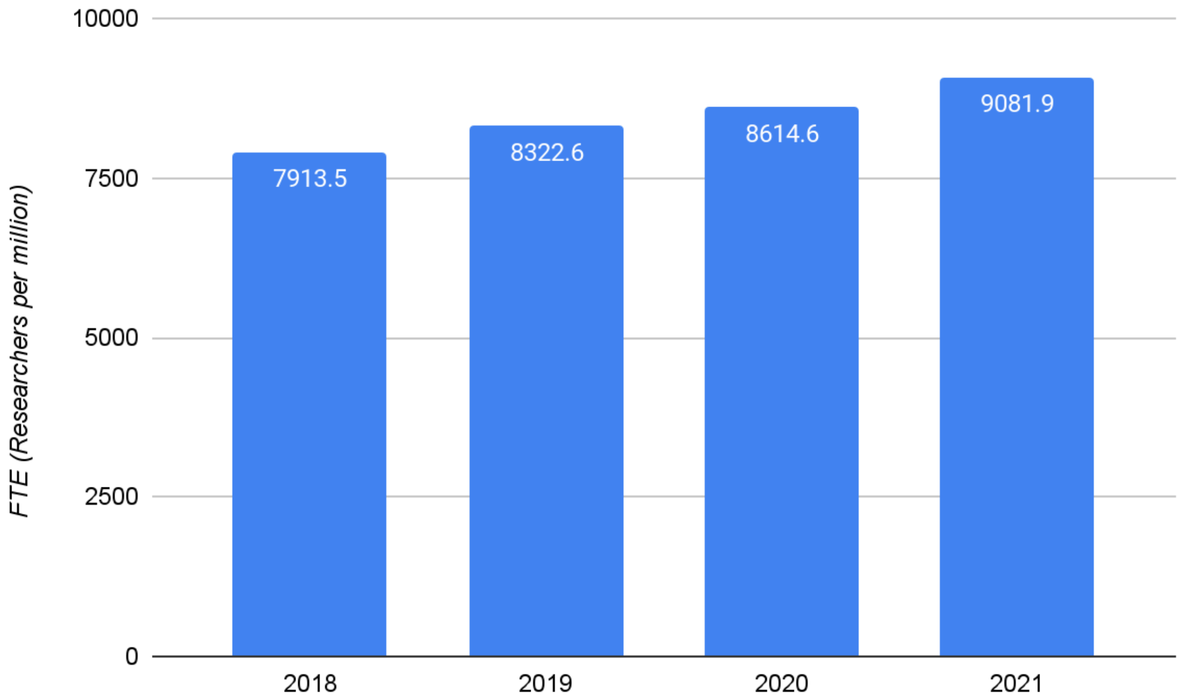

Figure 17: FTE Researchers per million (South Korea)

Source: UNESCO Institute for Statistics

iii. Publications

As per the Clarivate InCites database, the total number of publications witnessed an overall increase from 88,129 in 2018 to 101,816 in 2021, before the number slightly decreased in 2022. The top three areas that Korea has published from 2018-2022 include Materials Science, Engineering (Electrical) and Physics (Applied).

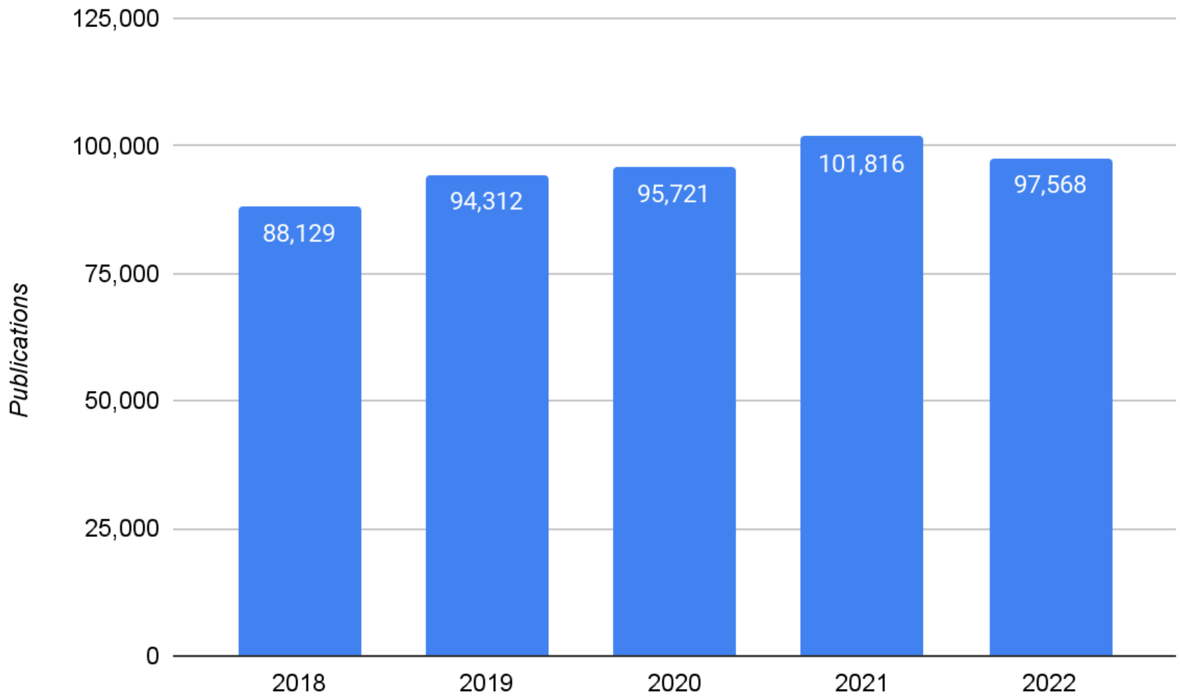

Figure 18: Publication output (South Korea)

Source: Clarivate InCites, data extracted on 21st March 2024

Methodology: Location: South Korea, Time Period: Individual years from 2018 to 2022, Schema: Web of Science

iv. Patents

A total of 209,992 patents were filed in 2018, and the number increased to 218,975 in 2022, registering an increase of around 4.2% over five years. The number of patent filings and grants peaked in 2021, with 145,882 patent applications and 237,998 patent grants. In 2022, non-resident patents accounted for 29.32% of the total patent applications.

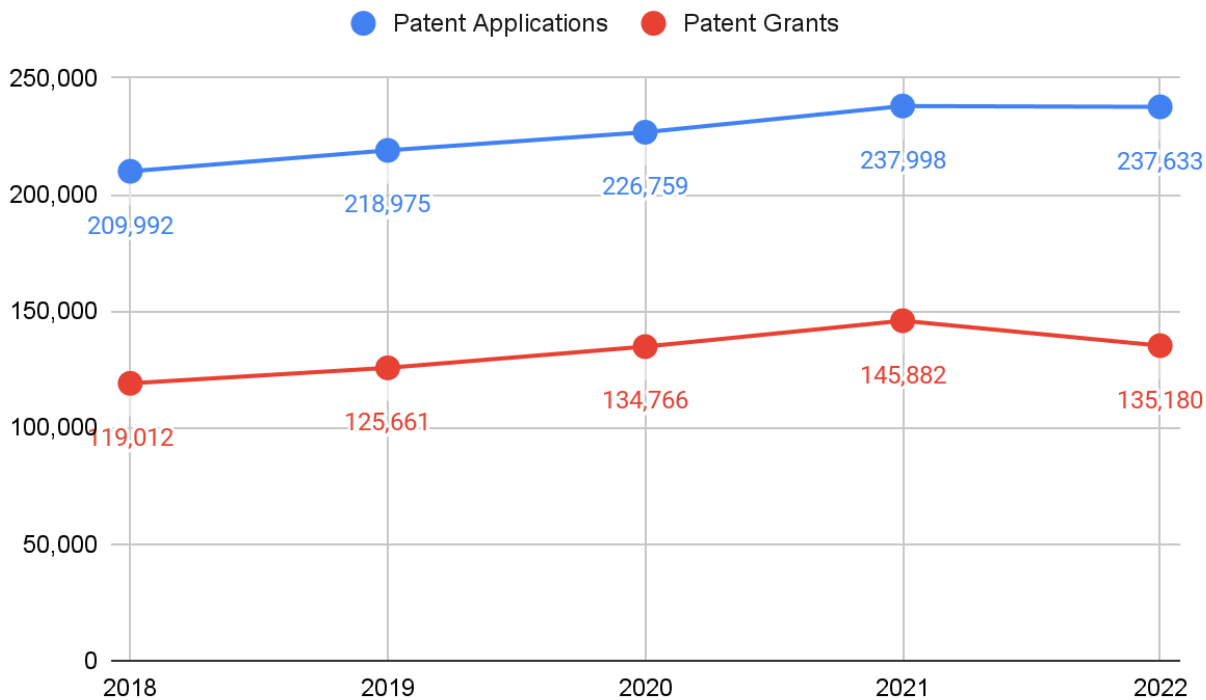

Figure 19: Number of Patent Applications and Patent grants (South Korea)

Source: WIPO IP Statistics data

2.3.4. Knowledge and Innovation Ecosystem

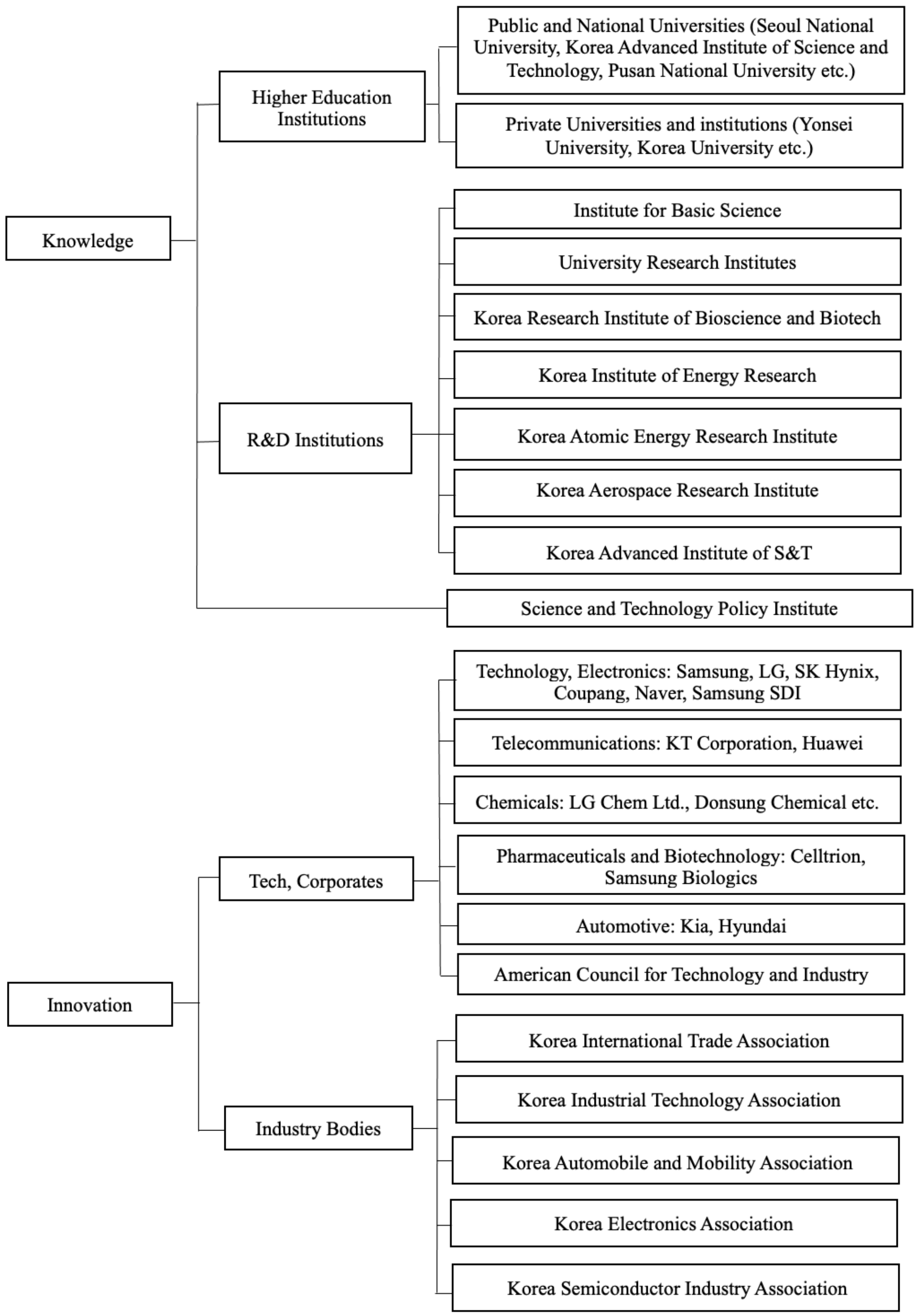

Figure 20: South Korea's Knowledge and Innovation Ecosystem

Source: Author's interpretation of the country's Knowledge and Innovation ecosystem

In South Korea, higher education is overseen by the Ministry of Education, with universities adhering to guidelines set by the Korea Council for University Education (KCUE) for accreditation. Public universities are managed by local governments and funded by the Central Government, while private institutions are supported by private non-profit education foundations. The country has numerous R&D institutes and university research centres across critical areas like biotechnology, aerospace and energy. The Korea Advanced Institute of Science and Technology (KAIST) is a leading R&D powerhouse with six specialised research institutes. Additionally, governmental organisations like the Science and Technology Policy Institute contribute to STI policy research. Such organisations look at various strategic areas, including R&D strategy, future innovation, and space policy, and aid in forming a robust knowledge system for fostering scientific and technological advancement.

The country houses leading tech corporates across various sectors. The important sectors are the electronics, IT, semiconductors, telecommunications, biotech, pharmaceuticals, and automotive sectors. Samsung Electronics stands out as a global leader in smartphones and consumer electronics. In the semiconductor arena, SK Hynix is renowned as one of the world's largest chip makers. Within the chemical industry, LG Chem Ltd. takes the lead as the largest Korean chemical company, contributing significantly to Korea's position as the world's fourth-largest chemical producer. In telecommunications, KT Corporation leads the charge in 5G technology, alongside SK Telecom and LG, with Huawei also playing a significant role in ICT infrastructure and smart devices. Biotechnology and pharmaceutical sectors are dominated by firms like Celltrion, which leads in biosimilar and new drug R&D. Hyundai, Kia, and GM Korea are dominant players in the automotive sector.

The country's key industry bodies across areas of trade, automobile, semiconductors and other areas play an important role in boosting the Korean economy by promoting trade, increasing technical competitiveness, and promoting growth and robust practices within the individual sectors. They also help foster collaboration, innovation, and policy advocacy within the electronics and semiconductor industries.

2.4.5. Agencies responsible for funding and governance of STI

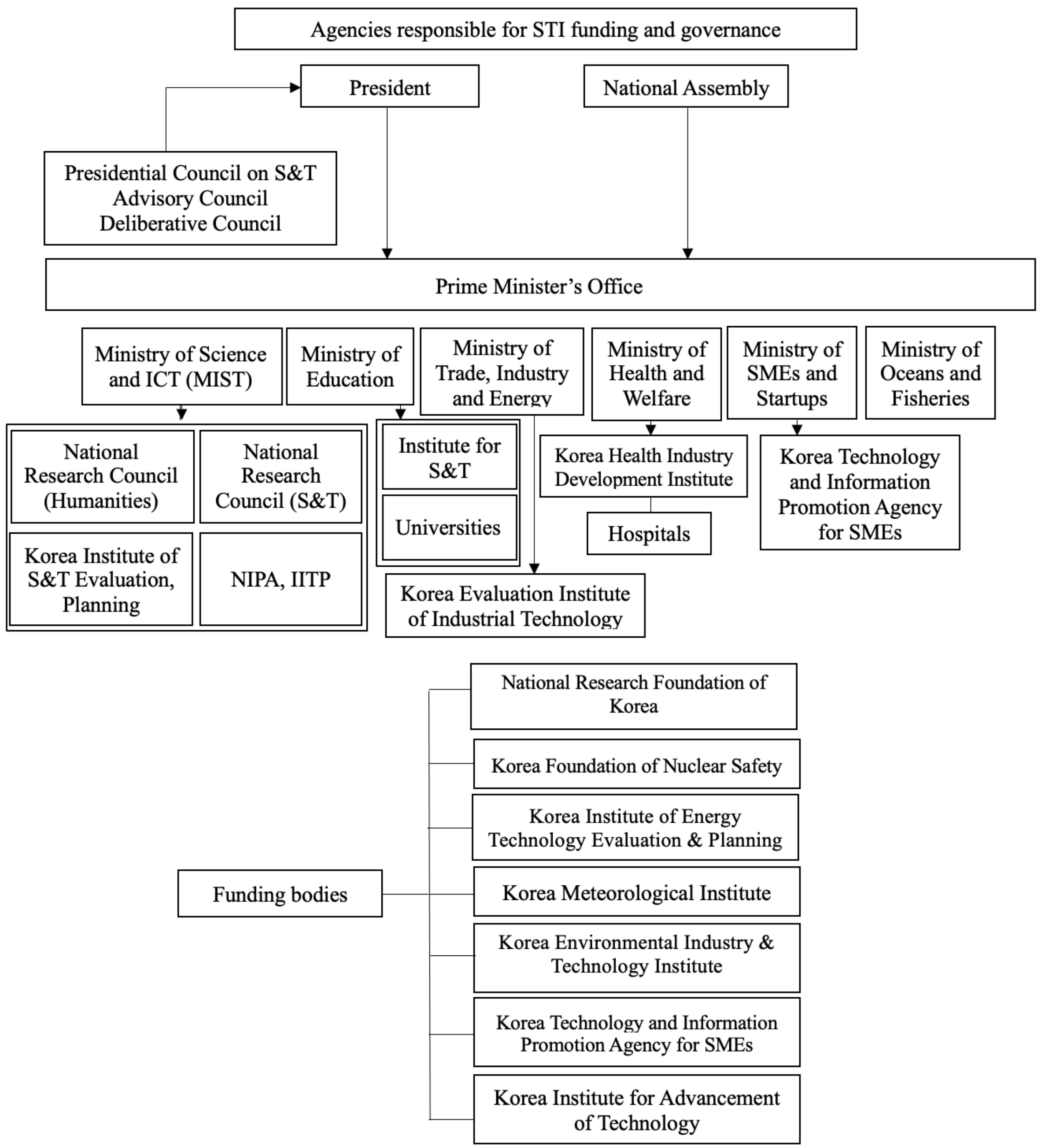

Figure 21: South Korea's STI Governance structure

Source: Author's interpretation of the country's governance structure, with reference from OECD Reviews of Innovation Policy (OECD 2023)

In South Korea, several ministries and bodies constitute the STI governance system. The Presidential Council on S&T (PACST), a prominent think tank, is responsible for laying down mid- and long-term policy directions, particularly addressing the Fourth Industrial Revolution. The Ministry of Science and ICT (MSIT) leads R&D efforts and is responsible for monitoring and evaluation of policy implementation. Other key ministries include the Ministry of Education, that focuses on digital transformation in education; the Ministry of Trade, Industry and Energy, that oversees economic policy and foreign investment; and the Ministry of Health and Welfare that works towards advancing healthcare technologies and services. In addition, the Ministry of SMEs and Startups is responsible for creating an environment conducive for enterprise growth and competitiveness.

The National Research Foundation, Korea Foundation of Nuclear Safety, and Korea Institute of Energy Technology Evaluation and Planning are key government funding bodies. They allocate resources and support R&D initiatives across disciplines. Sector-specific funding comes from funding agencies including the Korea Meteorological Institute, Korea Environmental Industry and Technology Institute, Korea Technology and Information Promotion Agency for SMEs, and Korea Institute for Advancement of Technology (KIAT). All of these agencies and bodies each play a vital role in advancing STI through appropriate and strategic funding.

2.4. United States

2.4.1. Overview

The US is one of the biggest and most advanced economies in the world. From 2019 to 2023, the country's GDP, at USD current prices, gradually rose from USD 21.3 trillion in 2019 to USD 26.9 trillion in 2023. Over the past decade, the share of the country's FDI inflows to the global FDI inflows increased significantly, from 13.5% in 2012 to 22% in 2022. According to the US Department of Commerce, the American workforce ranks among the most educated and innovative. The country has ranked consistently number 3 in the GII from 2018 to 2022, except in 2019 when it ranked 2nd. It is a leader in innovation, ranking 2nd in innovation inputs and 4th in innovation outputs.

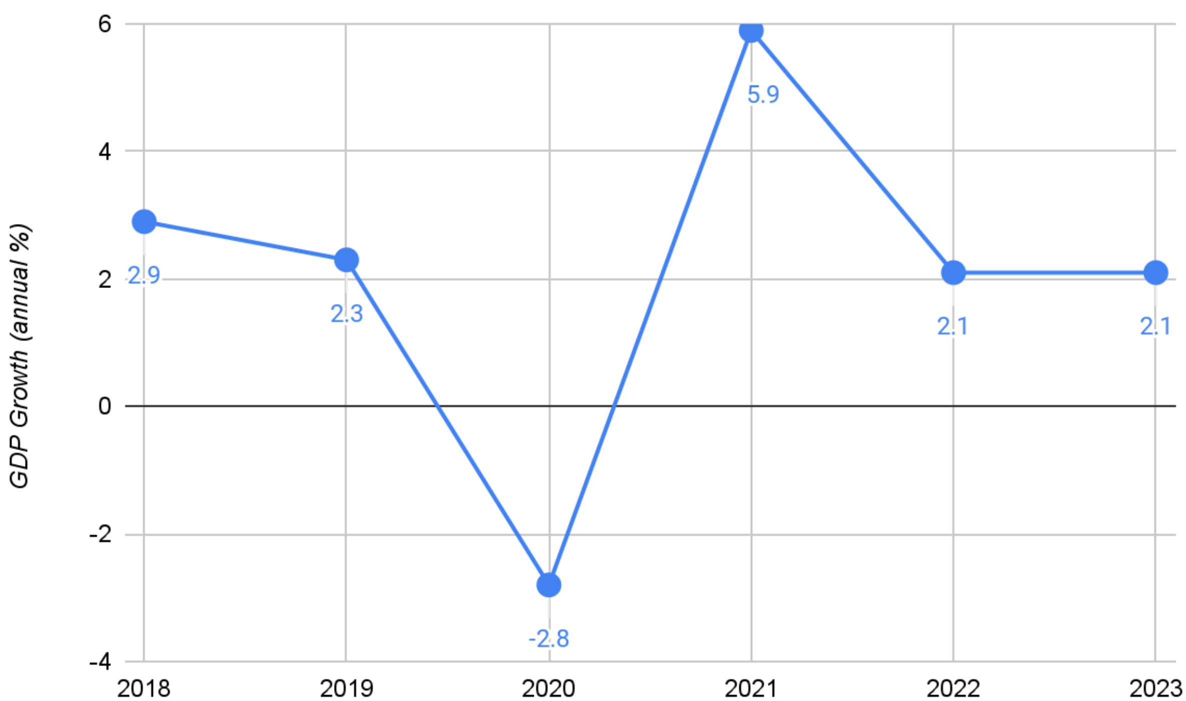

Figure 22: GDP Growth Rate (USA)

Source: International Monetary Fund

2.4.2. Science and Technology Ecosystem

2.4.2.1 Background

The history of S&T policy in the US dates back to the late 1700s. The passage of an Act concerning patents in 1790 marked the first formal S&T policy decision of the country (CRS

2009). This Act led to the establishment of the current-day Patent and Trademark Office. Initially, the country focused on 'science for policy' and 'technology for policy' (CRS 2009). As the nation grew, so did the importance of scientific and technical areas, such as the military and weaponry. The onset of the First World War brought a renewed focus on S&T for weapon development, communication and medical advancements. During the Second World War, S&T capabilities were directed towards chemical usage, aircraft building, and radar, among other technological applications (NRC 1997). It was during the same time that President Franklin D Roosevelt established the "Office of Scientific Research and Development" in 1941 to coordinate scientific research for military purposes. It was only during the post-war period that the federal government began promoting scientific progress.

After the two world wars, there was an increased emphasis on semiconductors and computers, with increased support for basic research at universities (NRC 1997). The 1950s and 60s witnessed the expansion of US companies to international markets, with smaller entrepreneurial firms playing a critical role in commercialising new technologies (NRC 1997). This can be considered unique compared to other countries. The country experienced a surge in R&D investment during the Cold War and the emergence of public-private partnerships to accelerate technology transfer from the lab to the market (Liu et al. 2011). Legislations including the Bayh-Dole Act and the Stevenson-Wydler Act enacted during the 1980s further contributed to the technology transfer (Shipp 2013). The country thus leveraged both the public and private sectors, along with a host of other legislative initiatives to drive innovation.

In the late 20th and early 21st century, the STI policy continued to evolve in response to shifting economic and strategic priorities. National archives of the US government suggest that S&T was central to the US development strategy during Clinton's administration. The 9/11 terrorist attack led to national security emerging as the national priority during the Bush administration (NRC 1997). The Report: Science for the 21st Century issued by the White House Office of Science and Technology Policy (OSTP) in July 2004 reconsidered science as a key factor for ensuring people's well-being. Subsequently, the American Competitiveness Initiative (2007) and the America COMPETES Act (2007) aimed to increase America's competitiveness through investments in research, education, and infrastructure. The America Invents Act (2011) aimed to modernise the patent system to encourage innovation and entrepreneurship. It is thus evident the US STI policies over the years have been adapted to suit the need of the hour.

2.4.2.2. Indicators

i. GERD as a percentage of GDP

The US spent USD 604 billion on R&D in 2019, and this spending increased to USD 885.6 billion in 2022. The GERD as a share of GDP has increased from 3.01% in 2018 to 3.46% in 2022, although there was a slight reduction when compared to GERD in 2020.

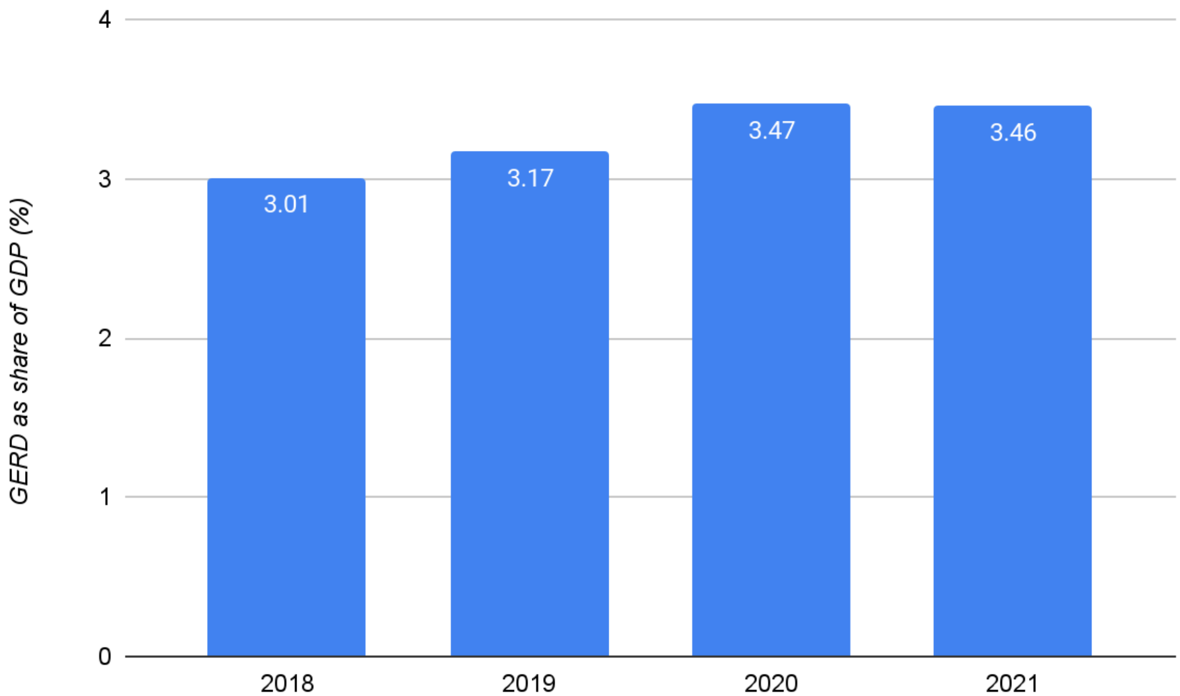

Figure 23: GERD as a share of GDP (%) (USA)

Source: Gross domestic spending on R&D, OECD

ii. Total FTE Researchers per million

As per data, there were 4262 FTE researchers per million in 2018. The number increased to 4451.8 in 2020. While this is lesser than the total FTE researchers in Korea, it is higher than that of China.

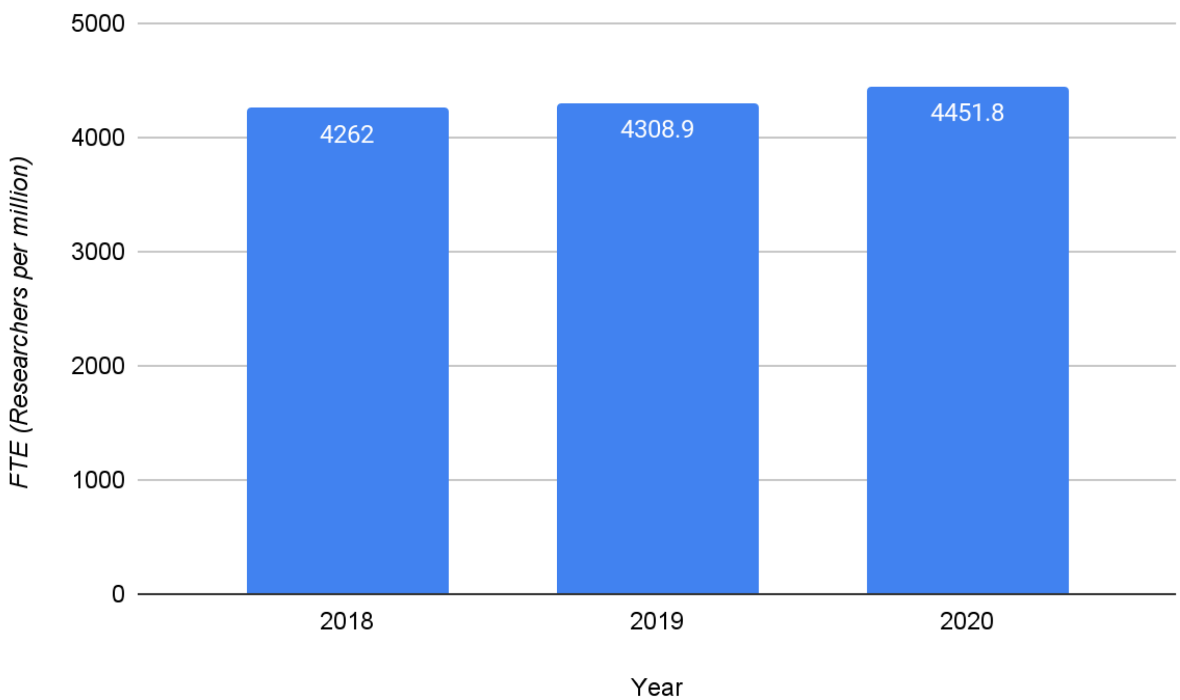

Figure 24: FTE Researchers per million (USA)

Source: UNESCO Institute for Statistics

*Data not available for the years 2021 and 2022

iii. Publications

According to the Clarivate Incites database, the number of publications have decrease in 2022 (761,401) when compared to 2018 (815,885). The top three areas of publication in the country over the time frame are Oncology, Engineering (Electrical and Electronic) followed by Surgery.

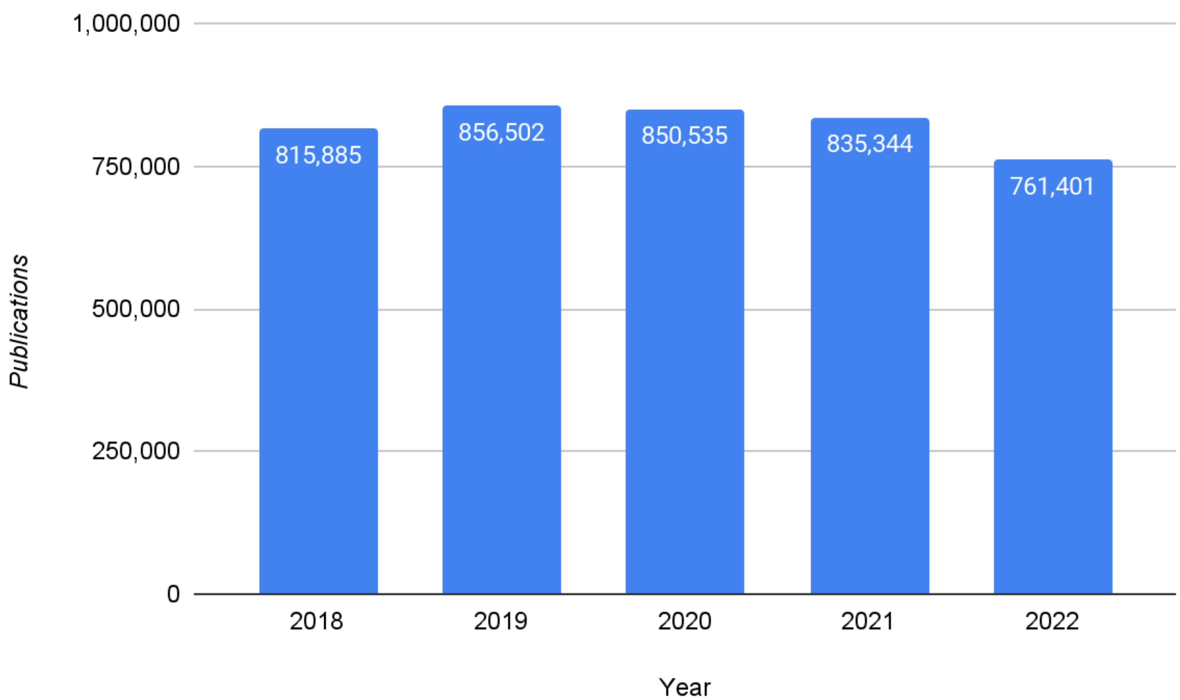

Figure 25: Publication output (USA)

Source: Clarivate InCites, data extracted on 21st March 2024

Methodology: Location: USA, Time Period: Individual years from 2018 to 2022, Schema: Web of Science

iv. Patents

In the United States, both the number of patent applications and patents granted have shown a similar trend between 2018-2022, and the number peaked in 2019 with 621,453 patent applications and 354,430 patent grants. An interesting observation is that in 2022, 57.54% of total patent applications were non-resident patents. This is similar to the trend in India but is in stark contrast to that of China and South Korea.

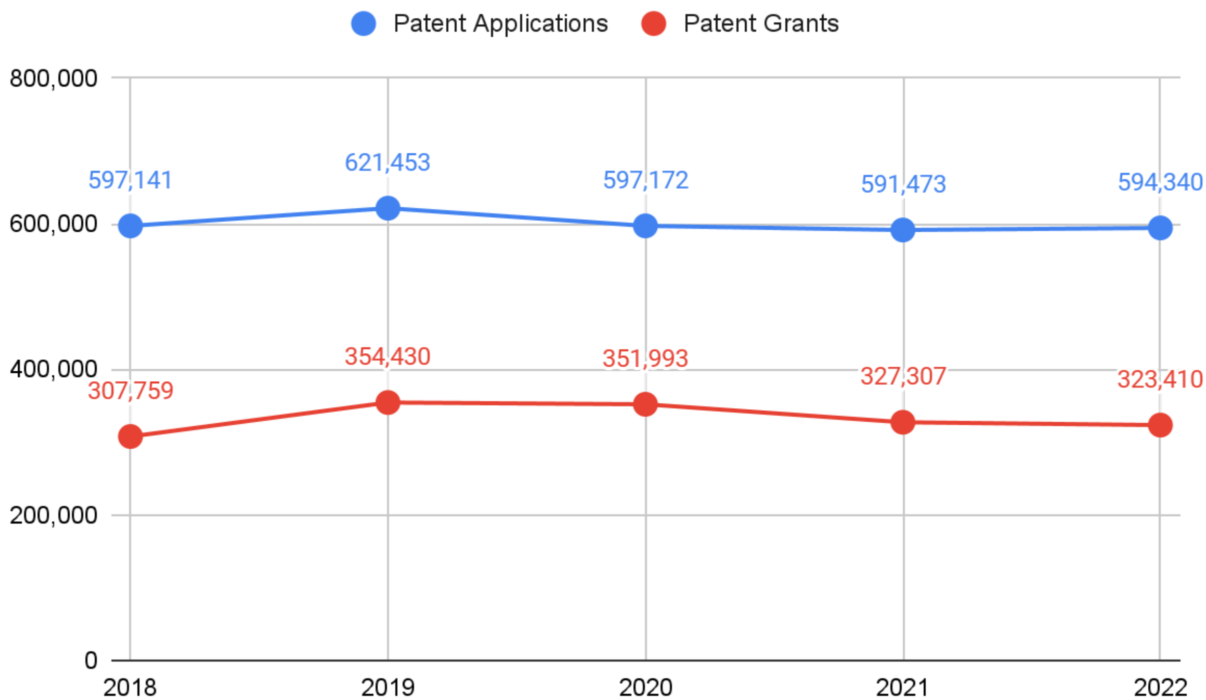

Figure 26: Number of Patent Applications and Patent grants (USA)

Source: WIPO IP Statistics data

2.4.4. Knowledge and Innovation Ecosystem

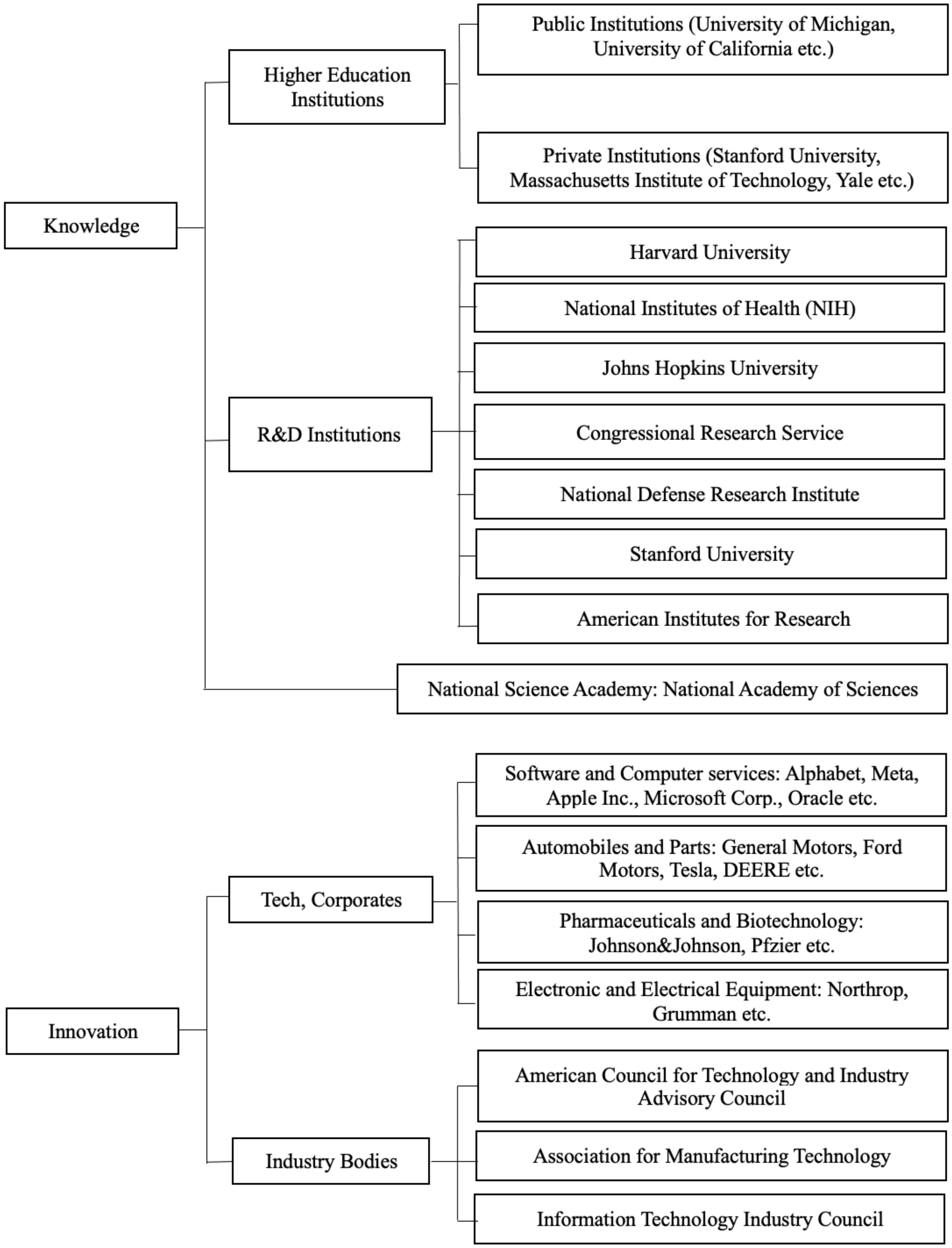

Figure 27: USA’s Knowledge and Innovation Ecosystem

Source: Author’s interpretation of the country’s Knowledge and Innovation ecosystem.

The landscape of higher education in the United States is characterised by nearly 4000 accredited universities. Higher education in the country is not centrally organised and managed but is accredited nationally or regionally by independent accreditation bodies. While publicly funded institutions such as the University of Michigan and Pennsylvania State University, among others, receive research funding from the government; Private institutions and universities like Harvard University and Massachusetts Institute of Technology rely on endowments, research grants and private donations. Key research institutions that are funded by the federal government, such as national institutes in defence and health among others, contribute significantly to advancing knowledge and innovation. The National Academy of Sciences is a premier institute dedicated to providing independent and objective advice to the government on matters related to S&T.

The country has leading companies across diverse sectors well-known for their R&D and innovation efforts. In the pharmaceutical and biotechnology sectors, the dominant firms include Johnson & Johnson, Merck and Pfizer. The software and computer services domains include firms such as Alphabet, Meta, Apple Inc., Microsoft Corp., and Oracle. In automotive and parts, General Motors, Ford Motors, Tesla, and Rivian Automotive stand out for their innovation. Supporting these industries are important industry bodies that facilitate collaboration between government and industry on technology issues. The Association for Manufacturing Technology is dedicated to advancing manufacturing technology through partnerships and knowledge enhancement. The Information Technology Industry Council is a global trade association advocating for ethical and equitable growth while promoting innovation and setting industry standards worldwide.

2.4.5. Agencies responsible for funding and governance of STI

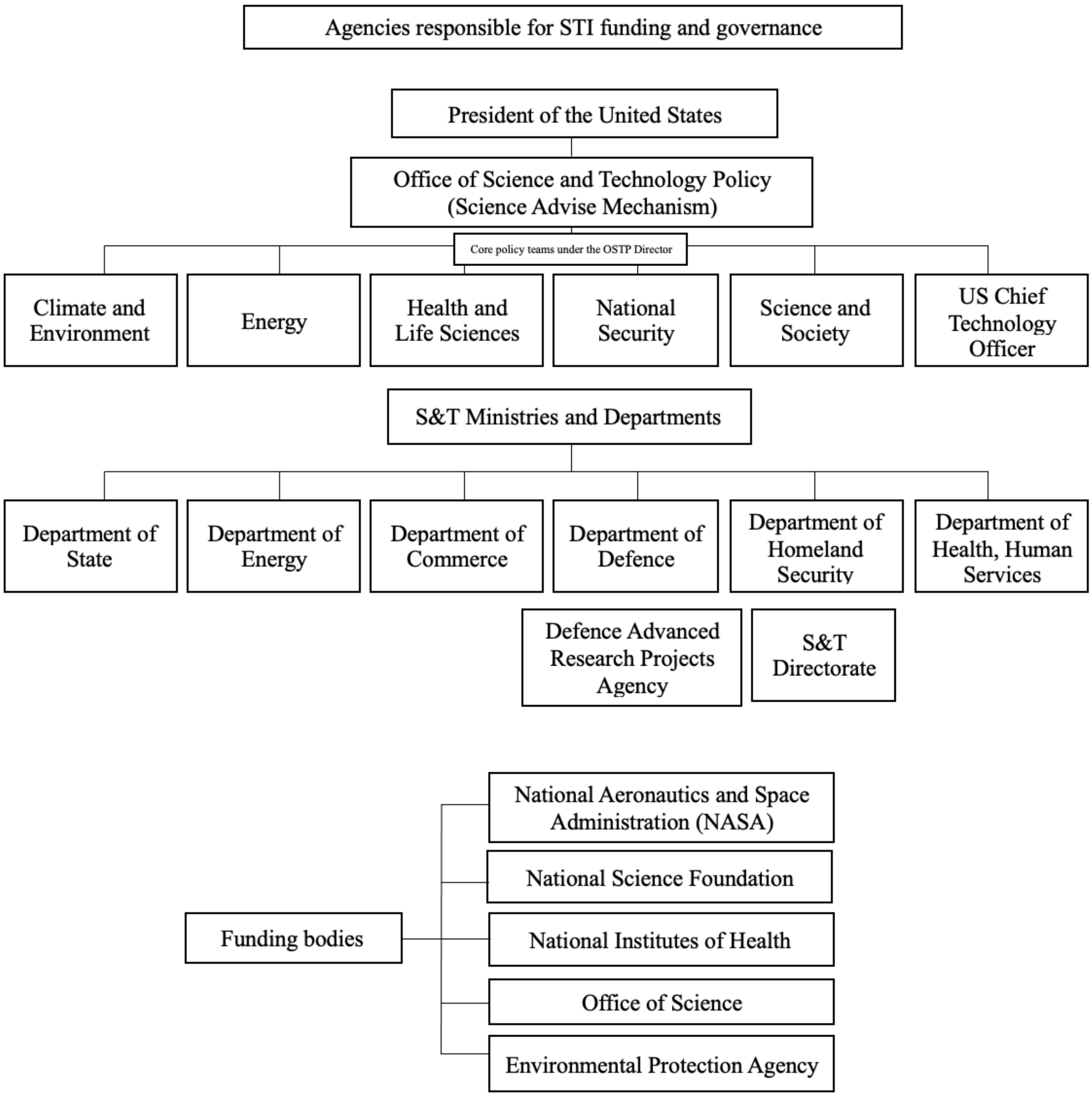

Figure 28: United States' STI Governance structure

Source: Author's interpretation of the country's governance structure

Key departments and agencies oversee the STI governance structure in the US and funding bodies at the federal level. The OSTP, along with six sector-specific core teams, provides the President and the Executive Office of the President with expert advice on S&T matters. The President's Council of Advisors on Science and Technology, the National Science and

Technology Council, and sector-specific offices on AI, quantum and nanotechnology support the OSTP.

The Department of State plays a key role in science diplomacy through bureaus like the Office of Science and Technology Cooperation. The Department of Energy, Commerce and departmental laboratories drive research in emerging technologies. Defense Advanced Research Projects Agency, part of the Department of Defense, drives R&D for military applications. The Science and Technology Directorate, part of the Department of Homeland Security, focuses on R&D for homeland security challenges. The Department of Health and Human Services, through the National Institutes of Health, leads biomedical and public health research efforts to enhance the country's health and well-being.

Funding bodies like the National Science Foundation support fundamental research, the National Aeronautics and Space Administration (NASA) supports space exploration, and the Environmental Protection Agency supports environmental protection. These agencies provide substantial funding for research, education, and training across various disciplines. The Office of Science, part of the Department of Energy, also plays a significant role as the lead federal agency supporting fundamental scientific research for energy and physical sciences.

In conclusion, India, China, South Korea and the United States have their individual and unique trajectories within their S&T ecosystems. While India was a forerunner in establishing its S&T ecosystem in the early 1900s, China only began its journey during the late 1970s post the death of Mao. Korea's remarkable trajectory had humble beginnings in the 1960s with the establishment of a dedicated ministry for S&T. All of these countries stand as a testimony of the importance of S&T to national development. Amidst this, the United States, with its stellar journey dating back to the late 1700s continues to lead the technology landscape. A deeper understanding emerges from the comprehensive assessment of individual country profiles, with an analysis of parameters ranging GERD, patents, publications and number of researchers. This would facilitate meaningful insights into the comparative analysis that would be performed in the next chapter.

Chapter 3: Comparative Analysis

A comparative analysis of S&T indicators, Knowledge and Innovation ecosystems and the Governance structure of countries is crucial as it allows for a better understanding of the overall technological landscape and policy management across countries. Such an analysis would also provide insights into the strengths and weaknesses of countries, providing India with an opportunity to learn from their experiences. This chapter would provide a comparative analysis of input and output indicators that have been discussed in the previous chapter. It would also compare the knowledge and innovation ecosystems, governance structures and major STI policies of the four countries, and provide insights for India based on individual countries' best practices.

Input and output indicators

The trajectories of individual countries reflect diverse patterns in economic growth, which certainly influences their current S&T standing. India has come a long way since the economic reforms of the 1990s and has emerged as one of the fastest growing economies. China's market reforms during the late 1970s has resulted in the country's sustained economic expansion, beginning in the 1980s to the current phase. South Korea's economic growth accelerated during the past decade, although it has experienced a slowdown in the past few years. The United States is a highly developed economy with its current GDP being much higher than the GDP of other economies. As per the IMF data (2023), the United States, followed by China stand at the largest economies of the world. India stands as the fifth largest economy in the world in terms of GDP (current prices).

India's position relative to the three countries on innovation competitiveness, particularly China, highlights certain deficiencies in education, research capabilities and innovation inputs. According to the GII 2023, which ranks countries according to their innovation capabilities based on 80 indicators, India ranked 40th. This contrasts with China's ranking (12th) with the country having a stronghold over knowledge and technology outputs. The United States and South Korea ranked 3rd and 10th, respectively, indicating their strong innovation frameworks. While India, China and South Korea perform better in innovation outputs than inputs, the USA performs better in innovation inputs than in outputs. India must thus address its deficiencies to secure a better position in the GII.

The number of researchers in a country has a correlation with the quality of education, research output and the R&D industrial collaborations (Bhattacharya, n.d.). The UNESCO Institute of Statistics in 2020 has revealed that the total number of FTE researchers per million in India stands at 260.4. This is considerably low in comparison to China which had 1601.9, South Korea with 8614.6 and the United States with 4451.8 FTE researchers per million during the same time. This translates to India proportionately having about 16.25% of FTE researchers in China, 3% that of South Korea and 5.8% of the FTE researchers in the United States. These numbers are a reflection of policies, expenditures and the emphasis these countries lay on research and manpower. It also highlights the need for India to increase its expenditures on R&D, while also adopting reforms within the higher education system that cultivate the right culture for research activity.

An analysis of the number of publications by countries could potentially give insights into the quality, quantity, citation count, research areas among other insights. However, the project limits this to the total number of annual publications by countries. While there has been an increase in the overall publications in India, with over 200,475 publications in 2022, it certainly stands behind China (847,808 publications), and the United States (761,401 publications) during the same time period. A deeper analysis of the Clarivate Incites database reveals that China and the United States lead in the number of publications in the areas of Computer Science, Artificial Intelligence and Quantum Technologies with 112,157 publications and 75,879 publications from 2018-2022. India merely publishes 26% of the number of publications in China and 42% of that of the United States in AI and Quantum during the same time period.

3.1. Comparative Analysis of Research and Development Expenditure

Innovation policy encompasses a broad spectrum of institutions and instruments that generate technology (Mani 2002). Innovations emerge from formal R&D activities undertaken by firms, universities, research institutes and non-R&D activities. Government funding in R&D, while not the sole factor, is crucial in cultivating an environment conducive to innovation. Historical trends from other countries highlight the significant role of government support in advancing both science and practical innovations. Vannever Bush, credited with shaping US government research policy during World War II, laid the foundation for S&T and R&D policies in the United States. His revolutionary report, Science: The Endless Frontier (1945), highlighted the importance of government support for science, especially basic research, as a driving force for the disbursal of new knowledge and nurturing of scientific talent. Economist Kenneth Arrow further argued for government intervention in invention and innovation, asserting that the market alone cannot be relied upon to sustain a sufficient rate of inventive activity.

Government funding agencies play an important role in providing grants and promoting research across countries. India has sector-specific funding agencies in the areas of aeronautics, atomic energy, specific councils, among grants provided by ministries and the UGC. As understood from the governance structures and country-specific government portals, China receives huge funding from bodies like the National Natural Science Foundation and the National S&T Megaprojects. Korea also has sector specific funding apart from centralised funding bodies like the National Research Foundation. The United States receives funding from a range of government agencies and independent organisations. However, India's government R&D funding remains stagnant at nearly 0.7% of the GDP from the past several years.

Besides support from the government, Forbes (2022) highlights that technical change has been the primary driver behind more than 50% of the economic growth of the United States, China and South Korea. According to him, technical change manifests as innovation in the economy, as doing new things for commercial advantage. He says that innovation largely happens within firms, and the ability to innovate is influenced by both the internal actors and broader institutions that operate around them. Government-funded research can certainly boost scientific progress, but the area of research would impact how well it is connected with the industry.

3.1.1. R&D spending by countries

Table 1 reflects individual countries' investments in R&D over the past three decades. India was certainly an early investor in R&D when compared with the other three countries whose GDP was certainly higher than India in 1992. However, India's GERD has stagnated over the past three decades, ranging between 0.6% and 0.8% of GDP. Meanwhile, China, South Korea and the United States have seen exponential growth in R&D investments over the years. Data from the IMF World Economic Outlook Database (April 2020), reveals that the top five spenders accounted for around 73% of USD 1.7 trillion spent on global R&D in 2019 (Forbes 2022). This goes on to highlight that R&D is highly concentrated within the hands of a few countries.

Table 1: R&D Intensity as % of GDP (Comparative)

Country	R&D as % of GDP				
	1992	2004	2011	2018	2021
India	0.7	0.7	0.8	0.7	0.64
China	0.73	1.21	1.78	2.2	2.43
South Korea	1.8	2.44	3.59	4.8	4.93
United States	2.54	2.49	2.74	3.01	3.46

Source: OECD for data on China, South Korea, and the United States; UNESCO Institute of Statistics and Research and Development Statistics at a Glance (2021-22 and 2022-23) for data on India

3.1.2. India and its spending on R&D compared to other countries

Table 2: Institutions responsible for R&D expenditure within countries (2019)

Country	Total R&D Expenditure (USD Billion)	Business enterprises (% of total)	Government	Higher education (% of total)
India	18	37	56	7
China	292	77	15	7
South Korea	83	80	10	10
United States	584	73	10	17

Source: UNESCO Institute for Statistics; Research and Development Statistics at a Glance 2019-20; Forbes (2022)

A notable observation in India's R&D landscape is the substantial funding provided by the government (%). India's private sector contribution (37%) differs distinctly from other countries where business enterprises invest 70% to 80% in R&D expenditure and the government merely invests 10% to 15% of the total investment. As of 2020-21, in India, the government continues to be the most significant contributor to GERD, with the Central government contributing 43.7%, State governments contributing 6.7%, higher education and public sector industry contributing 4.4%, and the private sector contributing 36.4% during 2020-21 (DST 2023). As derived from the EU Industrial R&D Investment Scoreboard 2023, Indian firms do not have a presence in the top ten R&D-intensive sectors around the globe or in the fifty R&D spenders globally. The share of R&D by businesses in India is considerably low, even in the pharmaceutical, automotive and software industries, where India is doing considerably well. This could be attributed to a lack of deepening technical capabilities, otherwise observed in South Korea and China (Forbes 2022).

3.1.3. Insights from other countries

China's economic opening and liberalisation process was accompanied by a focus on R&D and innovation through S&T policy, reflecting the government's core priorities. China embarked on a multitude of programs with a specific focus on high-growth industries and technology-intensive exports (OECD 2012). Learning from US history, China recognised the necessity of public investment in basic science research (Bai et al. 2021). All of this led to China revamping its innovation infrastructure along with a significant increase in R&D spending.

From 1970 to 1990, South Korea witnessed a remarkable increase in the share of industry R&D to total R&D, increasing from 13% in 1970 to 36% in 1980 and 81% in 1990 (UNESCO Institute of Statistics, n.d.). Forbes (2022) observes that during this period, real-term R&D investments by the South Korean industry increased by almost 1000 times. Chinese industries also heavily invested in R&D, and the share of investments increased from 43% in 1996 to roughly 77% in 2018. The emphasis on technological advancement driving economic growth had led to a shift in the American economy from investments in tangible capital, like machinery, to intangible capital, like R&D, with US companies surpassing spending on R&D and commercialisation compared to tangible capital assets by the mid-1990s (CRS 2022).

Competitive research funding, which involves allocating core funding with an output-oriented approach, is an important reform adopted by the US and China (CTIER 2022). This enabled them to allocate the public funds available for research efficiently. In the US, the National Science Foundation has adopted a competitive research funding model that employs an efficient peer-review process for project funding and evaluation. China had adopted the 1985 Decision on Reform of Scientific and Technology Management System, which led to a reduction in core funding from government research institutions, which led to researchers having to secure external funding. The National Natural Science Foundation, established in 1986, led to a mechanism whereby central government grants for basic and applied research were facilitated through a peer review process. Later, the Knowledge and Innovation Program (1998) by the Chinese Academy of Sciences led to the establishment of a robust evaluation process and competitive funding, contributing to a more competitive research environment in China. India could also explore similar competitive funding mechanisms through a renewed emphasis on peer-reviewed research and evaluations while encouraging institutions to diversify their funding sources.

3.1.4. Fiscal measures and incentives

A research conducted on the impact of government R&D spending on corporate innovation based on the firm's location in China from 2008-2018 reveals some interesting observations (Tang et al 2022). Government subsidies play a vital role in encouraging companies to ease financial constraints concerning capital factors. They aid in enhancing the creative capabilities of human capital and ensure the effective functioning of management institutions. China has tax and fee incentive policies, corporate tax exemptions, cash compensations, tax deductions, and other policies that encourage establishing industries and corporate innovation. The Chinese government in 2023 has put forth policies to promote foreign-funded R&D through stronger official support in terms of land, equipment and infrastructural usage. Additionally, the country began offering incentives not only when companies decided to invest in China but also for the particular technologies the companies brought into the country (PRC 2023). Institutions have also been promised incentives to conduct basic research and innovation.

The US largely focuses on ex-ante tax incentives such as tax deduction and tax credits for qualified R&D spending (Nguyen and Maine 2022). It is evident from government portals that the government which plays a substantial role, engages in measures such as federal investments in university R&D programs, subsidies for private research initiatives, and incentives to foster the commercialisation of products and services.

In South Korea the government gives tax incentives comprising tax credits to stimulate R&D activities (PwC 2024). There are tax credits for developing research and manpower, technology transfer, and for Merger and Acquisition of small enterprises that focus on innovation. The R&D tax credit in Korea is the largest when seen as a percentage of the total tax credit for corporate investments (PwC 2024).

Based on best practices by countries, India, the government can provide corporates with key fiscal benefits which include tax deductions for R&D activities, tax rate reduction, and customs duty exemptions. It could draw on China's practices of enhancing the creative capabilities of individuals by creating a competitive environment. While there are other incentives as well in place, particularly for startups, R&D policies in many states seem to be largely sector-specific, and some other states do not even have policies in place. India needs targeted policy interventions in industry-academia collaborations, strategic sector-specific R&D and state-government R&D incentives.

3.1.5. Analysis of India's R&D spending

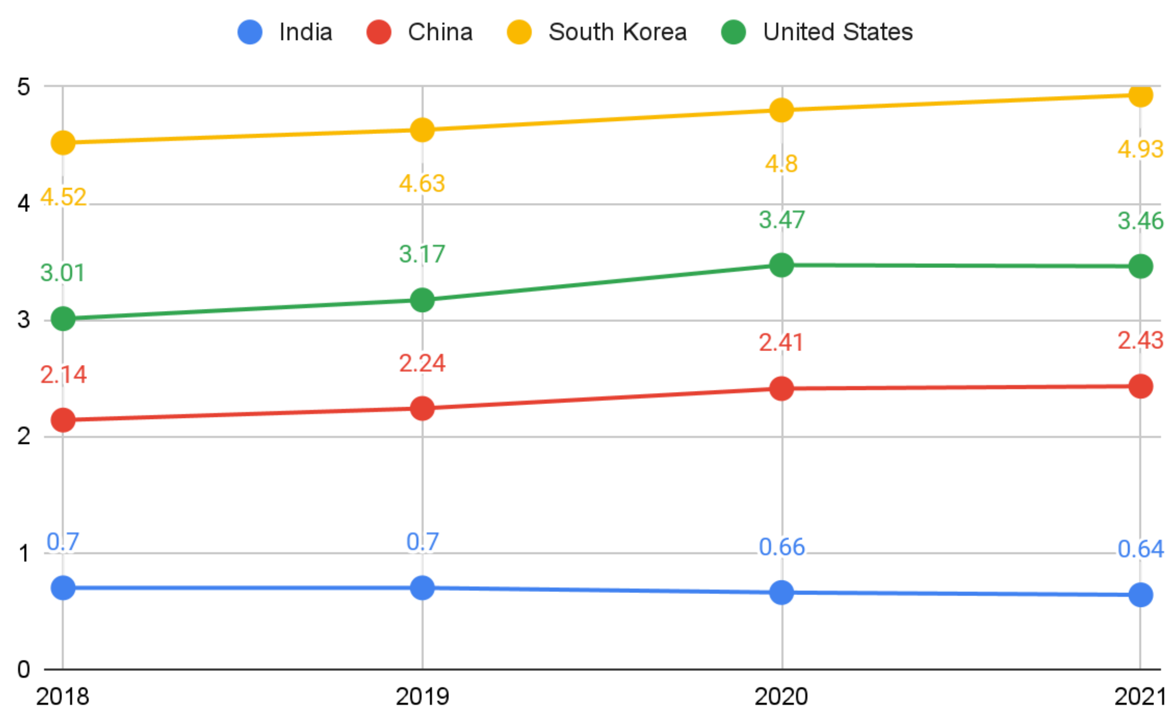

Figure 29: R&D spending by countries as percentage of their GDP (comparative)

Source: Main Science and Technology Indicators, OECD

In India, though university education witnessed a considerable expansion, the focus of R&D has been historically confined to mission-oriented science agencies, primarily due to the fact that top scientists in the post-independence era belonged to these agencies. The proportion of university expenditure in total R&D expenditure was at lower than 6% per annum for three decades from the 1960s (Krishna 2022). In India, the sector funding R&D mostly conducts R&D itself. This implies that a major portion of the central government's R&D funding is carried out by autonomous institutions like DRDO and DAE, among others, which operate under ministries and authorities (CTIER 2023). The following figure represents the R&D expenditure by select key scientific agencies under the Government of India (2020-21).

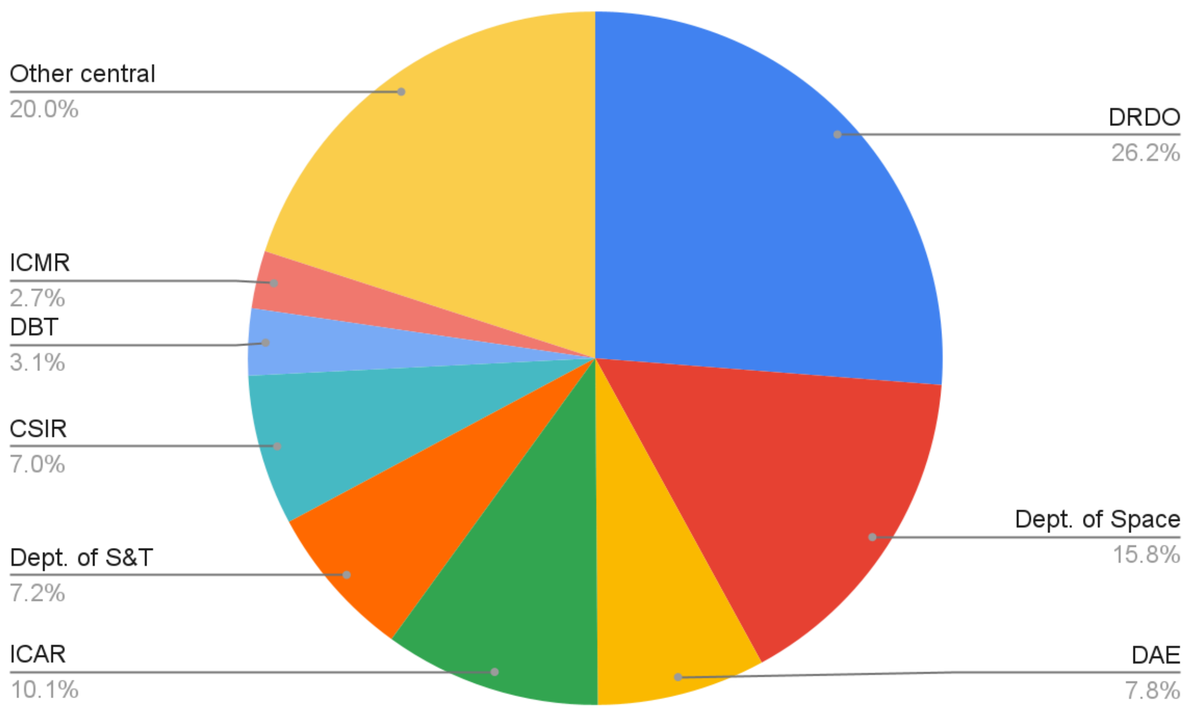

Figure 30: R&D Expenditure by Select Key Agencies and the Central Government of India (2020-21)
Source: Adapted from CTIER, 2023 (Based on Demand for Grants; Union Budget 2022-23; Standing Committee on Defence; State Budget Accounts).

Note: This figure represents the R&D expenditure by the Central Government that accounts for 44% of the total 54% government expenditure (the latter includes State Government expenditure as well).

3.1.6. Recommendations for India's R&D Spending

India's STI Policy 2013 aimed to improve India's GERD to 2% of the GDP, a target that has long been elusive. Reaching this would require that the industry in India increase its share of R&D investments from 0.3% to 1.5% of GDP and the state increasing its investments from 0.05% to 0.4% (Forbes 2022). Particularly, the MSME sector requires significant R&D and technological assistance to remain competitive against manufacturing giants like China. Emphasising competitive manufacturing and the production of superior products with advanced technologies would assist India in maintaining and enhancing its industrial standing. Indian firms can also prioritise developing proprietary technology by investing in learning and R&D. Hence, India could implement mechanisms that attract further investments from the private sectors. Despite lower spending on HEIs, their significant contribution to about 80% of total publication outputs (CTIER 2023) is an evidence of their capabilities. India could thus greatly benefit from enriching the existing talent pool within HEIs through better collaborations and investments. This highlights the urgent need for increasing public investment in higher education and promoting industry-academia collaboration to enhance the research and innovation landscape in India.

3.2. Comparative Analysis of Patent Filing and Grants

A patent is a key element in the innovation ecosystem that grants an inventor exclusive right to exploit an invention for a fixed time in the country of application (OECD 2004). Patenting activity by residents is a measure of a country's innovation potential and it serves as an indicator of commercially viable knowledge (Dhar and Saha 2014). Patents play a critical role in facilitation of technology transactions between countries. Alongside, a robust Intellectual Property Rights (IPR) regime is foundational to a knowledge-based economy, that helps in fostering technological innovation and scientific research. There is a positive relationship between a country's imitation potential and its innovation capabilities (Han and Lee 2016), suggesting that patents can serve as a proxy for a country's technological level and its capacity to close the technology gap over time. Patents can thus influence the creation and diffusion of technology, with the level of patent protection and activity can reveal disparities between nations.

3.2.1. Trends in Patent Filing and Grants by Countries

According to the WIPO IP Facts and Figures Report 2023, the global number of patents in force increased by 4.1%, reaching 17.3 million, with China leading the patent count. China, the US, Japan, South Korea and the European Patent Office together constituted 84.9% of the total patent applications in 2022. South Korea filed the most patents per unit of GDP. Six of the top ten patent offices received a higher volume of patent applications in 2022 than in 2021. India experienced the most significant surge, receiving roughly 25.2% more applications than in 2021 (WIPO 2023).

Table 3: Patent filing and grants by countries (year-wise data from 2018 to 2022)

Year	India		China		South Korea		United States of America	
	Filing	Grants	Filing	Grants	Filing	Grants	Filing	Grants
2018	50,055	13,908	1,542,002	432,147	209,992	119,012	597,141	307,759
2019	53,627	23,578	1,400,661	452,804	218,975	125,661	621,453	354,430
2020	56,771	26,361	1,497,159	530,127	226,759	134,766	597,172	351,993
2021	61,573	30,721	1,585,663	695,946	237,998	145,882	591,473	327,307
2022	77,068	30,490	1,619,268	798,347	237,633	135,180	594,340	323,410

Source: WIPO IP Statistics data

While there has been a notable increase in the number of patent applications in India compared to other countries, India lags in terms of patents filed and granted, coupled with an additional burden of longer processing time. In 2022, the number of patents filed in India stood at 77,068. This represents only 4.7% of the filings in China, which had 1.61 million applications, and around 13% in the United States, which saw 594,340 applications. The patent application process in India is considerably long, nearly 58 months, compared to 20 months in China and 23 months in the United States (Arora and Sanyal 2022). Best practices suggest a disposal time of 2 to 3 years, but in India, it extends to nearly 5 years, and sometimes even 9 years, in fields such as biotechnology. Such a delay is attributed mainly to a manpower shortage in the patent office

(Arora and Sanyal 2022). The absence of a fixed timeline and extensive compliance requirements impede efficiency.

Another interesting observation that could be made is that the share of resident patents in India is merely 50.02% of the total patent applications in India in 2022, an increase from 42.66% in 2021. The WIPO Report 2023 reveals that nearly 37% of all patent applications received by the Indian Patent Office have come from the leading countries in terms of patent applications.

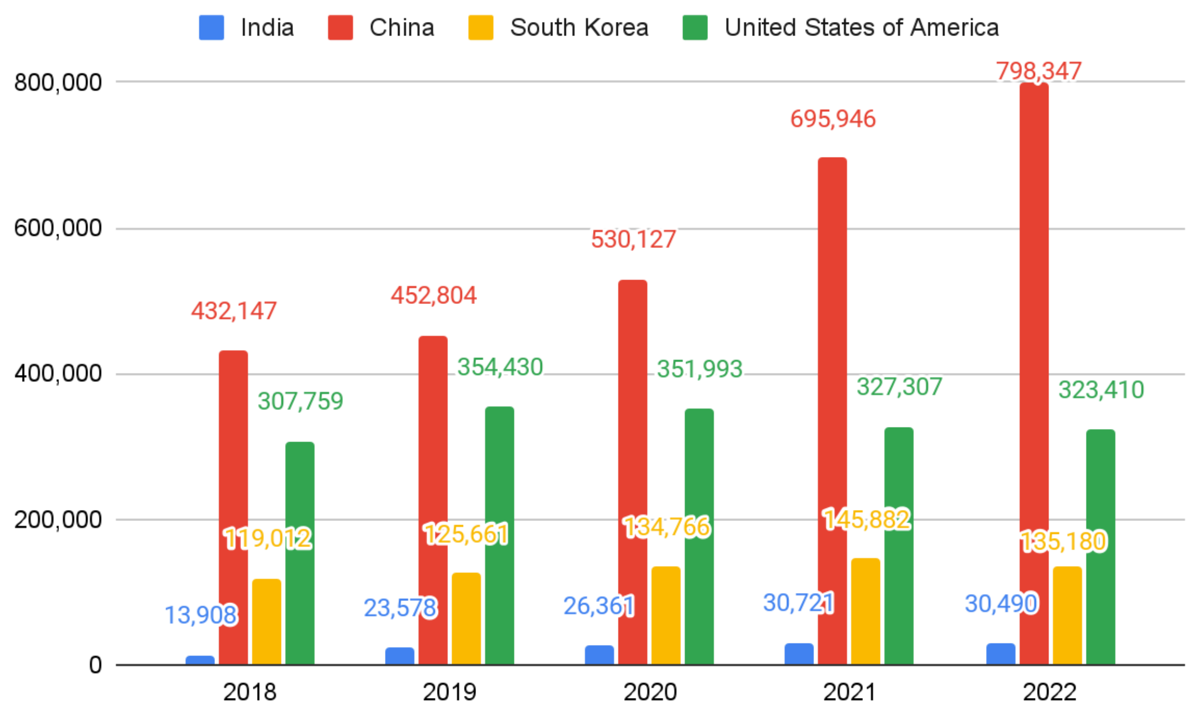

Figure 31: Number of Patent grants by countries (comparative)

Source: World Intellectual Property Organisation (WIPO)

3.2.2. Learnings from patent systems of other countries

A significant part of criticisms concerning the patenting system in the United States revolves around the low patent quality, budgetary constraints and reliance on revenue collected from the patent fee, which is linked to the issuance of low-quality patents. In response to these concerns, the Report on Patents and Innovation Policy (2022) by the Congressional Research

Service suggests that the government may consider implementing reforms in patent administration and exploring policy options to enhance patent quality through improvements in the examination process (CRS 2022). Furthermore, it is notable that efforts have been made to ensure that the US Patent Policy adopts a more inclusive approach towards fostering innovation, and steps have been taken to collect biographic and demographic information to promote a more equitable innovation system. India could certainly benefit from these learnings and introduce a system on similar lines to create a more equitable system. India can work on bridging the gender gap and increasing diversity in patent applications by taking up initiatives to increase awareness and grant better access to education and IP systems through targeted initiatives.

While the Chinese patent system also has a number of problems, it has taken actions to accelerate the adjudication of IP cases. It is working on capacity-building measures in terms of patent eligibility and lowering costs (Hideki and Sujai 2023). Korea has been recognised for its quick and high-quality examination of patents for a long time. India could also work towards strengthening its IP system on similar lines by overcoming the gaps and loops within the system. It could focus on increasing its manpower in patent offices and work on having a timeline for various stages to accelerate patent processing.

3.3. Comparative Analysis of Knowledge and Innovation ecosystem

3.3.1. Higher Education Institutions

Higher Education Institutions play a significant role in R&D activity of a country and in nurturing innovation. Understanding the structure and number of higher educational institutions, along with looking at the QS world ranking, would facilitate a more comprehensive understanding of the higher education systems in the four countries. According to the AISHE (2020) Report, India has 1113 registered universities or university-like institutions. The Ministry of Education of the PRC reveals that there are 1238 higher education institutions. According to South Korea's Ministry of Education, the country has around 200 four-year comprehensive universities. According to the Digest of Education Statistics, the US Department of Education, the US has nearly 4000 degree-granting institutions as of 2021-22. While India does fare decently well in terms of the number of educational institutions, the quality of education of India versus other countries necessitates deeper introspection.

The Quacquarelli Symonds (QS) world university rankings based on a range of indications including student experience, university partnerships, research activity and faculty qualification provide an authoritative and independent evaluation of institutions. According to QS World University Rankings 2024, Massachusetts Institute of Technology (Rank 1), Harvard University (Rank 4) and Stanford University (Rank 5) from the United States claim their spot within the top 5 universities. Peking University (Rank 17) and Tsinghua University (Rank 25) from China have secured their positions among the top 25 universities. Seoul National University (Rank 41) was among the top 50. In India, IIT Bombay (Rank 149), IIT Delhi (Rank 197) and Indian Institute of Science (Rank 225) find their spot in the top 250. An analysis of factors within the ranking reveals that while India does not fare well in academic and employer reputations, it exhibits noteworthy achievements regarding the papers per faculty metric. Its research network indicator is below the regional average, which indicates the need for the country's educational institutions to enhance their appeal to international students and match global trends. While countries have high-ranked private universities, India does not feature private universities ranked among the top in QS Rankings. Indian universities must certainly participate in the global knowledge of the economy to reap the benefits of advancements in S&T.

3.3.2. R&D Institutions

R&D by higher education institutions is an integral component of the overall R&D system across countries. Apart from educational institutions, countries have a number of R&D institutions that facilitate research activities. Across the four countries, R&D institutions cover a wide range of disciplines. In the United States, there is an emphasis on biomedical sciences, engineering and technology, whereas China has key interests in bioscience, energy and aerospace. Korea has further invested in key technology areas such as AI, nanotechnology and aerospace. India's R&D institutions focus on healthcare and pharma, with an emerging emphasis on basic sciences.

While countries like the United States and China have a strong presence of public and privately funded R&D institutions, India has yet to have a robust network of privately funded R&D institutes. India could learn from China's strategy of attracting foreign investments in

R&D, and collaborating with countries to establish R&D hubs, similar to those in Shanghai and Beijing. In India, within industrial R&D, Drugs and Pharmaceuticals had the most share of industrial contribution (33.6%), followed by Textiles (13.8%), Information Technology (9.9%), Transportation (7.7%), Defence Industries (7.3%) and Biotechnology (4%), respectively during 2020-21 (DST 2023).

It is essential that India has a dedicated institute in India that supports R&D investments and provides independence and objective advice regarding S&T. Having a targeted approach toward investment with a focus on emerging fields and areas is key. Institutions like the National Academy of Sciences in the United States and Korea's Advanced Institute of S&T, which have attracted significant private investments into strategic sectors in the country, offer key insights for India to adopt a similar strategy.

3.3.3. Technology Corporates

The four countries feature leading corporates in the technology and innovation sectors. While India has a thriving IT industry that is at the top in terms of market capitalisation, along with a notable presence in the pharmaceutical sector, Korea has established dominance in the electronics, semiconductors, telecommunications, and automotive sectors. Chinese companies have a strong presence in electronics manufacturing, technology, pharmaceuticals and fintech. The USA is a leader in the pharmaceutical, software, automotive and electronic equipment markets. Going forward, India could develop a more strategic plan to develop competitive advantages in certain sectors and collaborate with particular companies to emerge as a global leader in those sectors.

3.3.4. Industry Bodies

Industry bodies play a crucial role within a country's innovation ecosystem. They help firms enhance their industry specificity within external innovation search. The four countries have a strong network of industry bodies and associations that help in catalysing the global innovation process, through a sector-specific approach. Industry bodies in the United States are largely within the areas of technology, manufacturing and IT sector. In China, there is a particular focus on inventions, IT, and pharmaceuticals, as well as trade associations. Korea promotes innovation across sectors such as trade, technology, automotive, electronics, and semiconductors. India has industry bodies that focus on biotechnology, pharmaceuticals and IT. The country also has chambers of commerce that help foster innovation across industries through cross-collaboration. India could also diversify its network of industry bodies beyond traditional sectors to focus on emerging sectors. Fostering collaborations across industry bodies and chambers of commerce could facilitate better knowledge sharing, leading to more innovative outcomes.

3.4. Governance and Funding Agencies

STI governance within this context covers institutional arrangements responsible for the supervision and coordination of actors engaged in S&T. India's S&T governance is a blend of central and state-level coordination with the strategic direction emerging from the centre. The central government, with the DST at its core, and advisory bodies including the OPSA and PM-STIAC are responsible for primary deliberation of S&T-related matters in the country. Policy implementation is largely through collaborative efforts of ministries and other stakeholders at the centre and the state level.

Table 4: Comparison of governance structures of the four countries

Main criteria	India	China	South Korea	United States
Main deliberation council	Department of Science and Technology	The State Council	Ministry of Science and ICT	National Science and Technology Council
Advisory body	Office of Principal Scientific Advisor Principal Scientific Advisory Council	National S&T Leading Group	Presidential Advisory Council on Science and Technology STI Office	Office of Science and Technology Policy The President's Council of Advisors on Science and Technology
Characteristics of the system	A decentralised system with individual ministries given autonomous decision-making power. However, it is largely a top-down model of governance.	Centralised system. Directions from the Chinese Communist Party and the Central Military Commission. Ministries and Departments are largely within the purview of the CPC.	Well-established three-tier governance structure. Institutions have clear mandates to perform the essential functions necessary to coordinate and implement STI policies.	Emphasis on decentralisation and diversification Deciding policy through collaboration

Source: Based on the author's observation of the governance structures of the four countries

Within China's STI governance, the State Council and the CCP Central committee are pivotal decision-making bodies on S&T matters. The Ministry of Science and Technology in China formulates and implements strategies and policies for S&T development. Also, the Ministry of Education, Industrial and Information Technology, Ministry of Foreign Affairs and the National Development and Reform Council play an equally important role in S&T matters. Policy implementation in China is under the control of central authorities, ensuring alignment of S&T strategies with national goals.

South Korea's governance structure has a blend of centralised and decentralised systems, with ministries like MIST and MOST coordinating activities; and departments leading sector-specific activities. The Presidential Advisory Council on Science and Technology and the MIST have a particularly powerful mandate and are responsible for cross-government coordination. Such a governance structure has ensured coherence during Korea's STI structural expansion from a catch-up period to emerging as a technological leader in certain high-growth areas (OECD 2023). A notable reform in Korea is the National R&D Innovation Act of 2021, which aims to streamline R&D agencies and set up an autonomous ecosystem to support R&D activities. The policy implementation mostly follows a coordinated approach under the direction of key ministries.

In the United States, the Department of State is responsible for executing public diplomacy programs promoting the value of science to citizens. The Office of Science Technology Policy advises the President on S&T matters. Numerous other departments also have overlapping S&T functions, important of which include the Departments of Energy, Commerce and Defense. Policy implementation is through agencies and departments, but the country has sector-specific focus through which it implements policies, which is evident through its sector-specific policies.

Based on a comparative analysis, it is understood that India could benefit from Korea's hybrid governance model that combines centralised direction with decentralised execution. The governance mechanism should be such that there is autonomy of stakeholders responsible for implementing the policy. Similar to Korea's National R&D Innovation Act, having a research body that facilitates and coordinates R&D activities would be beneficial for boosting India's much needed research endeavours. India could also learn from China's central coordination and long-term planning concerning STI governance. The coordination between various bodies in China is evident through its robust policy and implementation framework. India could learn from the same to strengthen coordination mechanisms between relevant ministries, especially in missions where cross-collaboration would be necessary. Apart from the above, ensuring that India's institutions are empowered with an enabling environment to ensure funding and support is crucial in addressing the current shortcomings.

3.5. Comparison of Science, Technology, and Innovation Policies

3.5.1. Major policies and strategies by countries

Table 5: Comparison of STI Policies of India, China, South Korea, and the United States

	India	China	South Korea	United States
Major policies and strategies	Science, Technology, and Innovation Policy (2013)	14th Five-Year Plan (2021-2025); National Innovation-driven Development Strategy (2019); China's Belt and Road Initiative (2013)	The 6th Science and Technology Foresight (2021-2045); National Strategic Technology Nurture Plan (2022); The Digital Strategy of Korea (2022); Korea's S&T Future Strategy for 2045 (2020);	National Security Strategy (2022)
Sector-specific policies				
Semiconductor	India Semiconductor Mission (2021)	Part of the Made in China 2025 (2015)	Strategy for South Korea to become a semiconductor powerhouse (2022)	CHIPS Act; National Semiconductor Technology Centre (2023)
AI	National Strategy on Artificial Intelligence (2018)	New Generation AI Development Plan (2017)	National Strategy for Artificial Intelligence (2019)	Executive Order on the safe, secure, and trustworthy development and use of AI (2023); National AI R&D Strategic Plan (2023)
Quantum	National Quantum Mission (2023)	Megaproject for Quantum Communications and Computing (Part of China's 13th FYP: 2016-2020)	Quantum Science and Technology Strategy (2023)	National Quantum Strategy (2018)
Policies targeted towards the Fourth Industrial Revolution	SAMARTH Udyog Bharat 4.0 (2014)	Made in China 2025	Presidential Committee on the Fourth Industrial Revolution (2017); New Deal 2.0 Initiative (2022)	No specific policy

Source: Table is based on major S&T policies by countries. Information compiled based on the author's interpretation of the policies.

Note: Climate and health-related S&T policies are outside the scope of the paper.

Each of the four countries, India, China, South Korea and the United States, have distinct objectives and priorities for driving innovation and technological advancements. India's Science Technology Innovation Policy 2013 aimed at promoting scientific temper, enhancing science application skills, and making career opportunities within S&T attractive. As part of the policy, India expressed its ambitions to establish a world-class infrastructure and position itself among the five leading global scientific powers by 2020 by doubling the global scientific publications and quadrupling publications in leading journals. While the aim of the 2013 STI policy was to increase the GERD to 2% of the GDP and increase public sector R&D investment to 1:3, it has been unable to achieve this. The policy also recommended incentives to publicly funded R&D centres for outcomes leading to public and strategic goods. It had also laid emphasis on attracting private sector investments in R&D through establishment of a dedicated foundation. The draft STI Policy released in 2020 envisions achieving technological self-reliance and position India among the top three superpowers in the decade ahead, have a people-centric STI ecosystem, double the number of FTE researchers and GERD and increase private sector contribution to R&D. Within the draft policy, the country looks at open science, capacity building, science communication and international engagements.

China's STI strategies prioritise technological innovation as the cornerstone of national development. According to its 14th Five Year Plan (2021-25), the country aims to increase its R&D spending by over 7% annually over the next five years, beginning 2021. It aims to modernise industrial chains, balance urban and rural development, and establish international S&T centres. It is looking at enhancing the innovation capacities of enterprises by incentivising enterprises to increase their R&D investments. The country also aims to foster international cooperation through initiatives such as the BRI. The National Innovation Strategy (2019) prioritises technological innovation for national development. It aims to transform China into an innovative country by 2020, a leading innovator by 2030, and achieve innovation by 2050.

South Korea's STI vision is evident through its various policies that revolve around strengthening intellectual capability, fostering public-private partnerships, strengthening international collaboration, ensuring that S&T contributes to the well-being of humanity and positioning itself as a global S&T powerhouse. The country's Presidential Agenda broadly provides directions for future reforms. The 6th Science and Technology Foresight (2022) document, which is a precursor to the country's upcoming Basic Plan for S&T policy predicted 5 megatrends and 12 trends in the future technology landscape. The Basic Plan largely aligns with the Presidential Agenda and lays down targeted orientations for a better direction. The National Strategic Technology Nurture Plan (2022) has identified twelve national strategic technologies, and the country vouches to expand R&D investments in these technologies. The Digital Strategy of Korea (2022) emphasises that beginning in 2023, the country would focus its R&D investments on six major innovative technologies, including AI, AI semiconductors, 5G and 6G communication, Quantum, Metaverse and Cybersecurity. The country endeavours to build a nationwide 5G network by 2024 to have global digital competence, gain dominance in 6G communication standards and patents by 2026, and pioneer a pre-6G service demonstration in 2026. Through the Digital New Deal 2.0 Initiative (2022), the government aims to strengthen the data ecosystem, develop hyper-connected industries and achieve digitisation of social overhead capital. It is also noteworthy that the country also has dedicated policies on 5G+ Strategy, Metaverse and Biohealth, and is a reflection of how Korea wants to carve itself a distinct space in these specific technologies.

The United States does not have a major strategy for S&T, but the National Security Strategy (2022) reflects the country's ambition. The country aims to leverage its strength by investing in modern industrial and innovative strategies. It aims to secure its national supply chains, including public-private partnerships and use public procurement in critical markets to stimulate demand for innovation. It also emphasises reducing biological risks associated with technological advancements.

India's aspirations, including technological self-reliance, private partnerships and achieving global leadership, align with China and South Korea. In South Korea, top-priority policies fall within three primary frameworks: a long-term vision, the presidential programme agenda and Basic Plans for S&T. Such well-structured plans with quantitative targets serve as a basis for evaluation. India could certainly drive inspiration from the same to formulate plans that have a long-term vision with mid-term targets. The United States, which has established a robust STI ecosystem, is working towards building on its already existing strengths. However, India, at this juncture is finding it challenging to translate STI aspirations into tangible outcomes, particularly concerning R&D expenditure and attracting private-sector investments. Therefore, India needs to learn from the strategies and implementation mechanisms of China and South Korea to realise its ambitious targets effectively.

3.5.1.1. Recommendations for India

1. India could adopt a more diversified approach to increase its R&D expenditure to be able to meet the required targets. India can have fiscal and non-fiscal measures and incentives to increase the private sector's contribution to R&D, as observed in China and South Korea.

Measures like public-private partnerships and incentivising enterprises to increase their R&D investments could be explored.

2. Through alignment of R&D investments with key technological trends, India can position itself as a leader in critical technology sectors and drive economic growth through innovation.
3. South Korea and China's targeted policy approach with set quantifiable goals and targets and medium and long-term plans is something India can focus on in the decades to come to be able to take maximum advantage of the Fourth Industrial Revolution.
4. South Korea and China have taken a strategic approach of identifying their existing strengths and building on various policy measures for furthering the same. India could also conduct a similar foresight exercise where it can lay greater focus on certain technologies and prioritise them to achieve better gains.
5. India can look at expanding its international collaborations and partnerships, drawing inspiration from China's Belt and Road Initiative. Such partnerships can aid in knowledge sharing and technology transfer, ultimately helping India gain access to global markets.
6. India could look at ways in which policy implementation mechanisms could be streamlined, that would help the country in creating a conducive environment for innovation and entrepreneurship. It must explore ways in which regulatory processes could be simplified and incentives could be provided for the commercialisation of innovation. By creating a robust ecosystem that nurtures R&D, the country could facilitate the translation of R&D outcomes into applications that could enhance the well-being of its citizens.

3.5.2. Policies specific to the Fourth Industrial Revolution

In the era of the fourth Industrial Revolution, countries have formulated policies, both overarching and sector-specific, to harness the transformative power of technology to drive economic growth. As part of the SAMARTH Udyog Bharat Initiative (2014), the Indian government emphasises resource sharing and smart manufacturing. It aims to increase the manufacturing sector's contribution to 25% of GDP by 2025, underlined by the Make in India initiative. Its emphasis on self-reliance and capacity building makes it similar to the Made in China 2025 (released in 2015). While both strategies endeavour to transition from low-end manufacturing to high-end production, China's strategy is much more comprehensive. With the

Made in China 2025 strategy, the country seeks to acquire leadership in sectors such as information technology, robotics, and clean energy. The country aims to become competitive by 2020, elevating its quality standards and technology by 2025, aiming for global leadership in innovation by 2035, and establishing dominance in major manufacturing sectors by 2049.

India's efforts to establish smart manufacturing hubs align with South Korea's focus on developing smart manufacturing technologies, as mentioned in South Korea's Manufacturing Industry Innovation 3.0 strategy (2014). The country's commitment to the Fourth Industrial Revolution is reflected in its institution of the Presidential Committee on the Fourth Industrial Revolution. This consultative body adopts a comprehensive approach to navigating the forthcoming challenges. Initiatives like the Digital New Deal 2.0 focus on public digital transformation, promoting the utilisation and expansion of AI and 5G to implement government initiatives and promote the use of blockchain in various fields. India could deliberate on constituting such a committee that solely focuses on emerging technologies concerning the fourth Industrial Revolution where it could derive maximum gains from the ensuing global shifts.

India could benefit from the USA's approach to the Fourth Industrial Revolution through the Advanced Manufacturing Partnership (2011), which aims to bring together industry, academia and the government towards enhanced manufacturing capabilities and competitiveness. It is noteworthy how the US began initiatives focused on the Fourth Industrial Revolution right from the inception of the revolution in 2011. The country's efforts centred on enhancing domestic manufacturing capabilities in critical industries, streamlining the development and deployment of advanced materials, advancing next-generation robotics and pioneering energy-efficient manufacturing methods.

3.5.2.1. Recommendations for India

1. India can consider a more comprehensive strategy for the Fourth Industrial Revolution, considering the benefits it could offer. India could derive inspiration from the Made in China 2025 Strategy to outline specific goals and timelines for achieving leadership in key technology areas.

2. India could potentially look at the indirect influences of the technologies of the Fourth Industrial Revolution as in Korea, where technologies like AI and blockchain could be used to enhance the well-being of people.
3. The USA Advanced Manufacturing Partnership Model could serve as an inspiration for India to forge stronger collaborations with various stakeholders within the ecosystem. Such partnerships could help in knowledge sharing and drive innovation to enhance India's manufacturing capabilities.

3.5.3. Sector-specific policies

3.5.3.1. Artificial Intelligence

India, within the National Strategy on Artificial Intelligence (2018) released by the NITI Aayog, emphasised that the country's approach to AI would be around the concept of #AIforAll with an emphasis on inclusive technology leadership that is tailored to suit the needs of India. The strategy aims to leverage AI for economic growth, social development and inclusive growth. Five sectors, agriculture, education, healthcare, smart cities, infrastructure, and smart mobility and transportation, have been identified as benefiting immensely from AI, especially concerning societal needs. The document also highlights that India currently faces barriers in terms of expertise, data ecosystems, resources, awareness and regulatory frameworks hindering harnessing the full potential of AI.

China highlights its aim to become the world's primary AI innovation centre by 2030 in its New Generation AI Development Plan (2017). Within this plan, it laid out its ambition to achieve significant progress in AI in foundational theories and core technologies, alongside cultivating numerous AI backbone enterprises by 2020. By 2025, the country aims to achieve major breakthroughs in basic theories, establish regulations and promote industrial transformation through AI. Similar to India, China is also looking at AI to promote and improve people's livelihoods and implementation of people-centric development.

South Korea, in its National Strategy for Artificial Intelligence (2019), emphasises enhancing AI infrastructure, securing technological competitiveness, regulatory innovation and nurturing AI startups. The Presidential Initiative for AI (released in October 2019) by President Moon Jae-in aims to further build on Korea's strengths. The initiative aims to establish AI competitiveness with a focus on building a robust AI ecosystem, promoting AI utilisation across industries, all while focusing on people-centricity.

USA's Executive Order on the safe, secure and trustworthy development and use of Artificial Intelligence (2023) sets standards for governing the use and development of AI across industries. The National AI R&D Strategic Plan (2023) focuses on R&D investments in AI, human-AI collaboration, ethical considerations, safety and security of AI systems, data sharing, workforce development, public-private partnerships and international collaborations. The plan also emphasises the importance of responsible AI innovation, rights and safety and promotion of democratic values.

Overall, India's AI strategy stands out for its emphasis on addressing sector-specific challenges. On the other hand, China, the USA and South Korea have a broad vision focusing on technological advancement and industrial transformation. While India's approach to AI research is through initiatives like the Centre of Research Excellence that focuses on core and applied AI research, China's focus on fundamental research within AI is noteworthy. The US has taken a similar approach, with the country prioritising long-term investments in fundamental AI research. South Korea has taken a forward-looking, long-term approach by focusing on next-generation AI technologies. A common theme that emerges across countries is the need for regulatory frameworks to promote responsible AI adoption and address ethical, legal, and societal implications. Similarly, the four countries look to develop the workforce, with an emphasis on skilling, reskilling and nurturing talent to meet the demands of the AI-driven industry.

3.5.3.2. Quantum Technologies

The four countries seem to have realised the transformative potential of quantum technology in driving the Fourth Industrial Revolution, reflected in dedicated policies and strategies put forth by countries. India, through the National Quantum Mission (2023), aims to foster scientific and industrial R&D in quantum technologies, and emerge as a leader in quantum technologies and applications. One of its primary objectives include developing intermediate-scale quantum computers to satellite-based secure quantum communications. The mission also emphasises on academia, industry and research collaboration through the setting up of thematic hubs in academic institutions and domain-specific R&D institutes.

China's approach to quantum can be found in its 13th FYP, where it announced the Megaproject for Quantum Communications and Computing. The plan outlines the need for strengthening R&D and promoting key quantum technologies, including quantum chips, quantum programming, quantum software, and related materials.

South Korea, through its Quantum Science and Technology (2023), laid down a medium to long-term vision through which it envisions the country as a global hub for the quantum economy by 2035. The country aims to raise the quantum S&T level to 85% in comparison to leading countries by 2035, and train 2500 quantum professionals. The strategy outlines defence integration, international collaboration and sustainable support systems. It also promotes mission-oriented R&D, and emphasises on enhancing infrastructure and establishing an industrial foundation for the quantum economy.

The United States, through its National Quantum Strategy, focuses on six key policy areas: workforce, industry, infrastructure, economic security, and international cooperation. Through the strategy, the country aims to advance quantum research, develop a skilled workforce, promote public-private partnerships and foster international collaborations. Similar to India, the US is forging partnerships to establish Quantum Information Science Centres at its national laboratories to promote research.

Overall, the four countries have a similar approach, focusing on advancing quantum technology and emphasising industry, research, and collaboration. However, Korea seems to be particularly ambitious when it comes to quantum with its elaborate strategy of establishing leadership in the quantum industry.

3.5.3.3. Semiconductors

India's Semiconductor Mission (2021) aims to build a robust semiconductor and display ecosystem to position India as the global electronics manufacturing and design hub. Notably, India provides up to 50% fiscal support to projects for setting up semiconductor fabs, display fabs, and compound semiconductor facilities. It has also put forth the Design Linked Incentive Scheme, offering financial incentives and infrastructure support for semiconductor design development for a period of five years.

China's strategy for semiconductors is enclosed within the Made In China 2025 Plan that aims to achieve 70% self-sufficiency in semiconductors by 2025. It has formulated policies encouraging technology transfer, IP acquisition and R&D collaborations. Like India, China also offers incentives, tax benefits, and IP protection to companies establishing their centres in China.

South Korea, in its strategy for becoming a semiconductor powerhouse (2022), adopts a similar approach that focuses on relaxing regulations, providing incentives for corporate investments, and expanding the workforce through talent training. It also emphasises talent acquisition for system semiconductors, strengthening materials, parts and equipment for supply chains.

The United States has passed the CHIPS Act (2022) to enhance economic and national security. It aims to boost the domestic manufacturing of semiconductors while focusing on design and research. The United States, along with investment tax credits, provides grants and research investments. It plans to allocate over USD 5 billion for R&D and workforce training through the National Semiconductor Technology Centre.

3.5.3.4. Recommendations

1. India must continue to invest significantly in core and applied AI research, similar to investments by other countries. India could benefit from developing comprehensive AI regulations similar to those put forth by China and the USA to address the ethical, legal and social implications of AI. India could also explore fostering international collaborations with these countries in developing collective governance frameworks for AI regulation.
2. Besides investments in research hubs and education, India must prioritise developing a pool of skilled workforce in technologies, especially sector-specific technologies which require specialised skills and training.
3. While India continues to focus on building a robust semiconductor industry, it is important that it attracts larger foreign investments. For the same, it must consider creating a conducive regulatory environment and better incentives, especially for establishing semiconductor fabrication facilitie

Chapter 4: Conclusion

India is emerging as one of the leading countries on a global scale in S&T and innovation. This era of digital transformation and the fourth Industrial Revolution would provide developing countries, especially India, with an opportunity to scale up its capabilities at an unprecedented scale. In this changing landscape, it is crucial for India to redefine its S&T priorities. Based on the insights gained from the comparative analysis, the following are some recommendations that India can consider as it navigates the ever-evolving technological landscape:

1. **Develop a comprehensive national S&T strategy for India**: Countries that are at the forefront of the changing technology landscape and the fourth Industrial Revolution, such as China and South Korea have strategically drafted their policy documents to outline mid- or long-term policy roadmaps. These countries have also developed innovative infrastructure and networks for implementing these policies. India lacks such a targeted approach. To develop such a targeted framework for a policy, India needs to conduct a foresight exercise to identify priority technologies and develop a holistic vision aligning the country's S&T strategies with departments and bodies. It is imperative that India undertakes a whole of a government approach with policy coordination on key priority areas. Collaboration among research institutes, universities, local governments and industries, with tight coordination mechanisms is essential. While most initiatives in India have been framed well, they lack a detailed implementation plan. Thus, a clearly articulated strategy for India to harness the global technological developments and chart its path is necessary. India must identify sectors and specific activities where it can exhibit competitive advantage. Reframing policies to strategically frame them to position India as a 'leader' in certain sectors, rather than the current approach of having a mere plan is essential.
2. **Increase funding for R&D activities and create an enabling environment**: While the government has been the primary funding agency for R&D activity in India, it is important that adequate initiatives are taken up to increase private sector investments in R&D. Recognising the pivotal role of companies as drivers of innovation, the government must incentivise them further to lead R&D and innovation efforts. Given that India has a limited number of companies that compete on a global scale, the government must motivate

companies to innovate through an approach of 'survival of the fittest'. There must be emphasis on efficient and effective allocation of resources. A targeted approach towards R&D investments in sectors displaying a competitive edge, specially in sectors demonstrating capabilities including pharmaceuticals, biotechnology, IT, and auto components is necessary. India must also learn from individual country's approaches. China's strategic investment in R&D across IT, electronics, life sciences and other sectors has successfully elevated its global standing in supercomputing, nanotechnology, and clean energy. South Korea's initiatives for fostering a culture of innovation, robust investments, government support in R&D, and proactive industry-academia collaboration have yielded its outcomes. The United States has continued to maintain a stronghold over its leadership in S&T owing to its robust governance system, top-tier academic institutions, and continued investments in R&D. Such insights underlines the necessity for India to redefine its approach to innovation, adopting focused and adaptive strategies to ensure significant outcomes and compete on the global stage.

3. **Create a conducive policy environment and ensure coordination**: Most policies in India cut across multiple departments and ministries, necessitating a coordinated and holistic approach. However, it has been observed that India currently lacks such an approach. A holistic approach, focusing on the entire innovation system is required. There is a need for a common platform to ensure the policy effectiveness and coordination. It is also imperative that government strategies need to be elaborated and refined to build social and economic systems that can respond in a more flexible manner. A conducive policy environment that nurtures innovation, while being adaptive is necessary. In addition, specific and detailed policies that encompass local governments, industries, research institutes and universities are important to establish the required infrastructure to lead policy initiatives.
4. **Nurture India's demographic dividend and its talent pool**: India boasts one of the biggest, if not the strongest pool of scientific and technological talent. The country also currently lacks a culture that fosters innovation. It is important that higher education institutions work on improving on an inquiry-based learning methodology. This must begin within primary education, where critical thinking needs to be encouraged. For India to harness its S&T talent within this growing demographic dividend, it must constantly redefine the role of universities and educational institutions to meet the changing needs. Considering that India's

international co-publication is considerably less compared to other countries, it must maximise its potential by increasing international collaborations. India's social security system must be reformed to facilitate a mutual flow of R&D personnel between enterprises, research institutes and universities. Like China, India must attract and nurture R&D personnel by allowing them to benefit from commercialising their innovation.

5. **Partnerships with other nations**: The Indian innovation ecosystem must be better integrated into the international ecosystem to nurture the flow of ideas and take better advantage of global opportunities. Alignment of interests and development of an engagement strategy with a particular focus on S&T initiatives is crucial for targeted initiatives. An international technology engagement strategy with select countries on specific technologies can be the way forward for developing targeted and strategic partnerships. India can envision developing large-scale scientific infrastructure with neighbouring countries by building on these partnerships. Additionally, India should consider attracting more FDI and establishment of tech parks and R&D hubs in collaborations with countries, by offering the right kind of environment and incentives.

The aim of this project was to look at India's standing within the global technology landscape with a particular focus on three countries: China, South Korea, and the USA. Examining country-specific evolution and background of S&T policies reveals the critical role that policymaking assumes in navigating significant technological advancements. Analysing knowledge and innovation ecosystems across countries led to valuable insights into factors that drive knowledge diffusion. The governance system of a country certainly plays a critical role in creating a conducive environment for innovation, and a comparative analysis has led to the identification of key considerations for India's future endeavours. A comprehensive assessment of input and output indicators highlights that India needs to spend at least 2% of its GDP on R&D, with a major part of the investment driven by the industry. Patent analysis reveals the need for India to strengthen its IP system and address manpower issues in the patent office. A comparative analysis of technology landscapes has thus led to an enhanced comprehension of policy making and policy implementation across countries, offering valuable insights for India, particularly within this ever-changing technology landscape.

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