4 Production, circulation and use of knowledge for a new era of innovation in Korea

This chapter provides an overview of the research and development performance of Korea's higher education institutions (HEIs) and public research institutes (PRIs). Following an introduction of different bodies constituting the HEI and PRI system, the chapter explores different aspects of the HEIs and government research institutes. Finally, it investigates whether the missions, the funding structure and the governance system of each body support high-quality research and the reallocation of resources to new areas of economic and societal relevance.

The Korean research and education system receives worldwide recognition for its high expenditure on research and development (R&D) and for producing a high calibre of graduates, in particular in science-related fields. Despite having significant strengths in innovation inputs and outputs by some measures, the research system could be even more conducive to innovation by fully exploiting the potential which internationalisation has to offer. Research collaboration with foreign counterparts, as well as a diversification of the increasing influx of foreign students, have further room for growth. Diversity and collaboration across borders hold significant potential for new ideas and creativity and can instil entrepreneurial mindsets, thereby contributing to innovation. When it comes to research, there are few universities that dominate the academic landscape in terms of top-quality scientific outputs and collaboration with industry and international partners.

This chapter presents the overall research and innovation performance of Korea's National Innovation System by addressing the inputs and outputs of research and innovation. Subsequently, it discusses international research collaboration and student mobility, the performance of Korean universities as measured by rankings and a more detailed overview of quality and quantity produced per higher education institution (HEI). Finally, the first section explains the extent to which skills in Korea correspond to the demands of the 21st century and the digital transformation. Second, the chapter reviews the framework of the different types of HEIs and public research institutes (PRIs) by giving an overview of their respective mission, funding structure and the governance framework they are subject to. Third, this chapter elaborates on linkages among these institutions and with the private sector. Finally, the last section synthesises the main achievements and challenges in improving Korea's research system.

In order to obtain a comprehensive understanding of the Korean research and education system, this chapter has given particular consideration to the different contexts and roles of the major research-producing organisations, namely higher education institutions and research institutes. The main findings and recommendations of this chapter are as follows.

First, Korea's research system looks back on a rather unique trajectory as the concept of academic institutions performing activities other than teaching and establishing themselves as research-intensive institutions is comparatively recent. To increase resilience and impactful research being done by universities, the government should seek to strengthen their autonomy, for instance, through long-term funding. When considering the underlying funding structures of research institutes, it becomes apparent that a traditional focus on project-based funding may have contributed to short-term priorities over long-term impact. The government has recognised the need for easing funding rules and increasing autonomy for universities as well as adjusting the evaluation framework for research institutes, but it is still early to see the full effect of recent policy action.

Second, a cornerstone of disruptive innovation is high-risk research, which holds the potential to bring high rewards and transformative research, which could be strengthened at both Korean universities and research institutes. Diversifying the funding landscape and introducing a portfolio management approach could be effective policy measures in this regard.

Thirdly, linkages and scientific collaboration between higher education institutions and research institutes have the potential for further growth. Most collaboration between academia and industry takes place with SMEs driven by large government subsidies, while co-operation with chaebols is less evident. Creating proper incentives and governance arrangements by making collaboration an official mission of universities and GRIs is important. Encouraging young researchers to go abroad, and making better use of returning post-docs' international networks, are two measures that could help encourage cross-border co-operation in research.

4.1. Korea's research and innovation performance

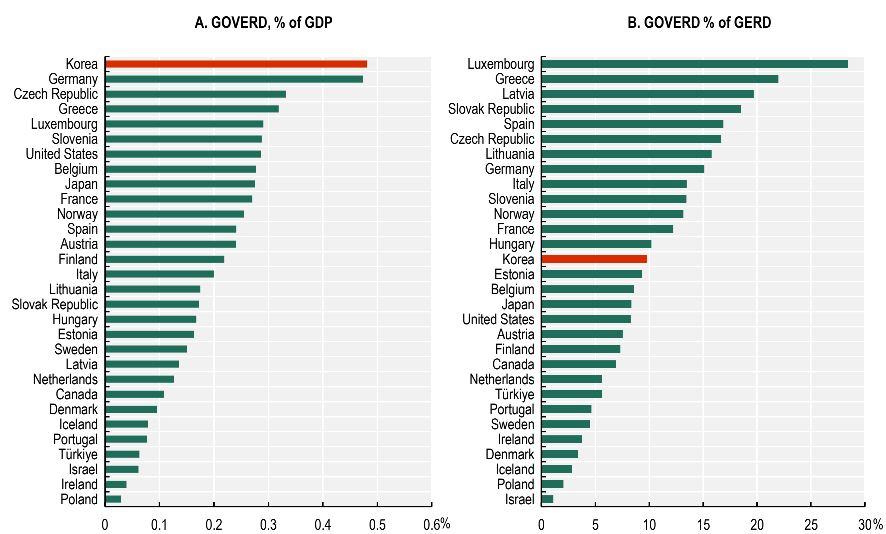
4.1.1. Although innovation inputs are strong, outputs remain average

Among OECD countries, Korea stands out for its high government expenditure on research and development (GOVERD) as a percentage of gross domestic product (GDP) with close to 0.5% in 2021 (Figure 4.1) (see also Chapter 2). However, when measured as a fraction of gross expenditure on research and development (GERD), GOVERD accounted for 9.8% in 2021, close to the OECD average. This indicator includes expenditures incurred by government units, such as PRIs, including government research institutes (GRIs), which are relevant to Korea's research system, as outlined later in this chapter.[1]

Korean higher education expenditure on research and development (HERD) in 2021 is on par at 38%, slightly lower than the OECD average (46%) (Figure 4.2, Panel A). Despite the fact that, unlike the practice in most OECD countries, Korean universities do not receive general university funding for their research activities, most higher education spending on research and development (HERD) in Korea is funded by the government, amounting to close to 80% in 2021 (Figure 4.2, Panel B), followed by the business sector at 13.8%. A relatively low share comes from the higher education sector itself as well as private non-profit (PNP) funding, at 6%, significantly less than Japan (45%), the United States (36.9%) (see Box 4.1) and France (15.3%). In addition, funding from abroad is the third lowest, at 0.56%, after Mexico (0.21%) and Japan (0.13%).

Figure 4.1. Government expenditure on R&D in Korea and selected countries, 2021

As a percentage of GDP and percentage of GERD



Note: GERD: Gross expenditure on research and development. Provisional data
Source: OECD *Main Science and Technology Indicators* (database), oe.cd/msti, June 2023.

Box 4.1. Higher education funding for R&D in Japan and the United States

Japan

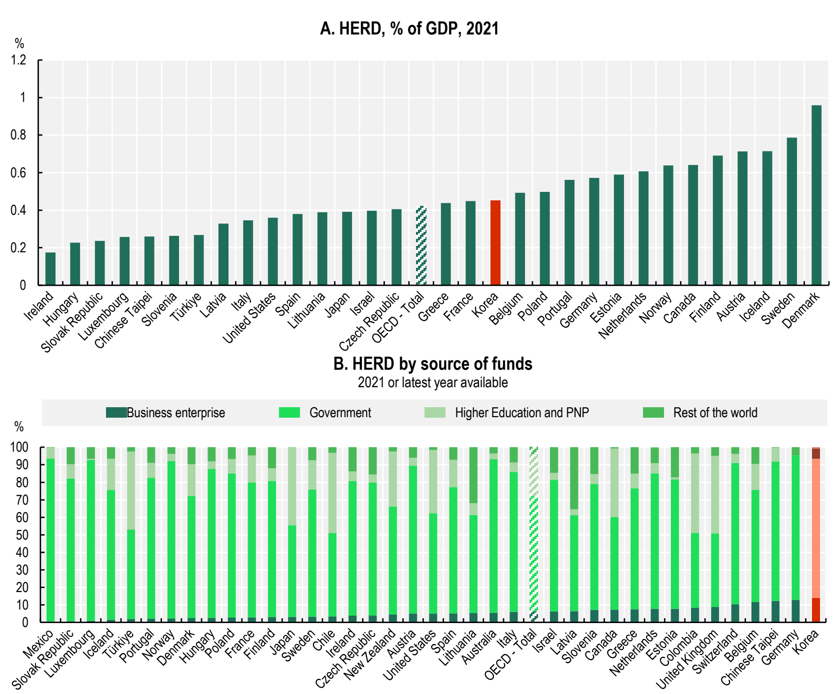
Most Japanese universities are private institutions (72%) that need to raise their own funding for research and development (R&D), notably through partnerships with the private sector. Until recently, the government has only provided grants to national universities to expand their postdoctoral programmes. In 2022, however, the government earmarked around USD 95 billion over time towards a university endowment fund, which, if fully realised, would constitute one of the world's largest endowment funds supporting scientific research.

United States

The federal government is the largest funding source for academic R&D funding at US universities, with about 53% or around USD 42 billion in 2018. The second-most important source (USD 21 billion in the same year) is the academic institutions themselves, many of which preside over large endowments, which include thousands of philanthropic donations to support scientific research. Non-profit organisations and the business sector are also significant sources of academic funding, albeit to a lesser extent, with USD 5.4 billion and USD 4.7 billion, respectively, in 2018.

Source: (American Council on Education, 2022[1]); *US-Japan Higher Education Engagement Study*, https://www.acenet.edu/Documents/USJP-HEES-Findings-Research-FactSheet.pdf; (National Science Foundation, 2022[2]). *Academic R&D in the United States*, https://ncses.nsf.gov/pubs/nsb20202/academic-r-d-in-the-united-states.

Figure 4.2. Higher education expenditure on R&D



Note: PNP: Private non-profit. Funding from abroad corresponds to the rest of the world. Provisional data.
Source: OECD *Main Science and Technology Indicators* (database), oe.cd/msti, April 2023; OECD *Research and Development Statistics (RDS)* (database), oe.cd/rds, June 2023.

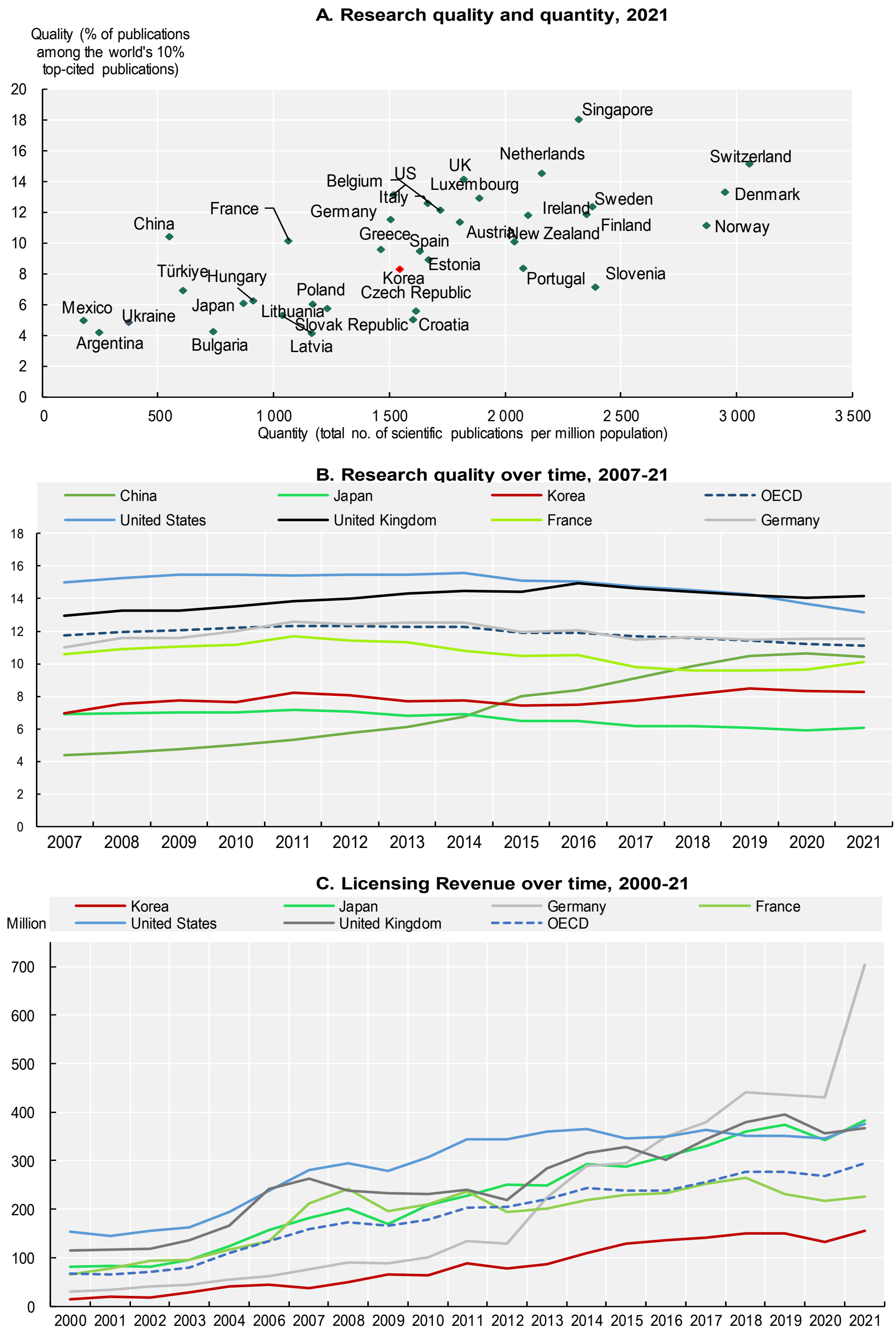
Despite leading gross expenditure on R&D (see Chapter 2), Korea's research performance, as measured by the share of scientific publications among the world's 10% top-cited, lags behind many leading OECD countries and other economies, such as Singapore; its share is at 8% below the world average (Figure 4.3, Panel A).

However, Korean research performance fares considerably better when considering the 1% top-cited publications, as some databases do, such as the UK Department for Business, Energy and Industrial Strategy's database. It shows that in 1996, Korea had a share of 0.4% of the world's 1% top-cited publications. Since then, it has increased almost sevenfold to 2.7% in 2020 (Department of Business, Energy and Industrial Strategy, 2022[3]). The discrepancy in performance between the 1% and 10% top-cited publications may indicate a vast performance gap between a few top-performing universities and the rest, lagging significantly. Intellectual property (IP) revenues are significantly lower than those of leading OECD countries, which is only about half the OECD average (Figure 4.3, Panel C). Moreover, these revenues have been stagnating, and interviews with stakeholders indicated it is expected that the contribution of start-ups founded by university researchers, notably professors, to universities' revenues, albeit still relatively small, will grow in importance, as opposed to revenues from licensing technology to companies.

Overall, it is difficult to measure industry-academia collaboration. Several indicators should be considered, including the number of co-publications, number of patents, number of copyright licences, technology transfer revenues and various metrics concerning spin-offs and joint ventures (Seppo and Lilles, 2012[5]). However, such data are rarely collected on a systematic basis. A proxy often used is the indicator of industry-academic co-publications, even though most industry-academia collaboration projects do not result in co-publications. Pohl finds that while such co-publications stagnate worldwide at about 2.8% of all publications,[2] their field-weighted citation impact (FWCI) is 1.70, meaning that co-publications have an impact of 70% higher than that of all publications. This effect is much higher still for Korea, where industry-academia co-publications reach an FWCI of 3.50. Sungkyunkwan University is quoted among the top-ten academic actors in industry-academic co-publications globally, where such co-publications represent 16% of all publications.[3] It focuses mostly on medical and natural sciences (biological sciences, mathematics, chemistry, physics) and has a balanced portfolio of corporate partners, with half of its top-ten partners from Korea and another half from foreign countries. Samsung figures among the top-ten global corporate players in academia-industry co-publications, with 82% of its publications being in collaboration with academia; all of the top-ten academic partners are Korean (Pohl, 2021[6]). The global leadership role of Samsung in its fields of focus may explain the high citation impact of industry-academia co-publications. Nevertheless, industry-academic co-publications are declining in Korea, unlike most other leading OECD countries, for which the trend is stagnant or slightly increasing (Figure 4.4).

Kang et al. (2019) studied patenting behaviour in the electric vehicle domain. They found a strong concentration on the corporate side, with Hyundai Motors in the lead and significant contributions from LG Electronics and LSIS Co. On the academic side, the leading actor is the Korea Advanced Institute of Science and Technology (KAIST), followed by Kookmin University and Korean Aerospace University (Kang et al., 2019[7]). In Chapter 3, it was shown that in Korea, international co-operation in patenting is particularly low in all three categories, i.e. the percentage of patents owned by foreign residents, invented abroad and with foreign co-inventors. Similarly, co-inventions with other countries are significantly lower than the OECD average and also than the share in benchmarking countries, such as Japan and the People's Republic of China (hereafter, "China") (Figure 4.5).

Figure 4.3. Research quality and quantity (2021), research quality over time (2007-21) and revenue from intellectual property (2000-21) in Korea and selected countries



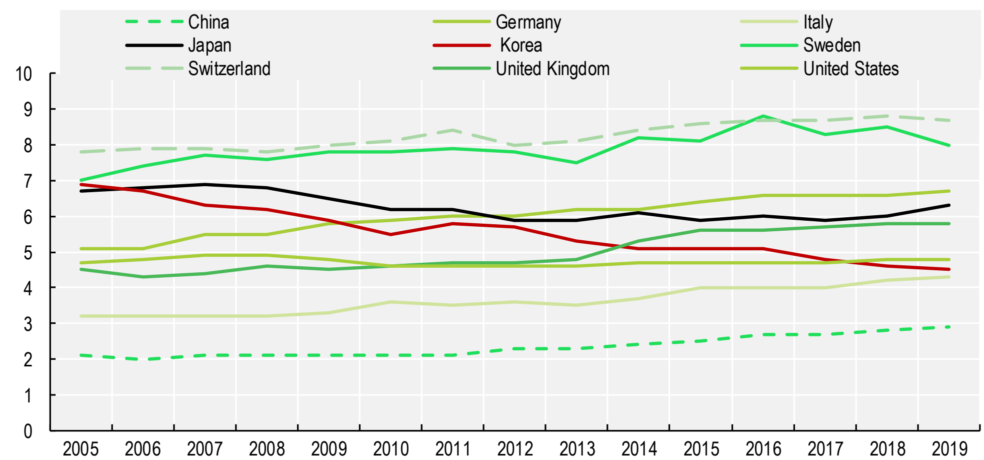
Note: Charges for the use of intellectual property includes revenues from patents, trademarks, copyrights, and industrial processes for the economy as a whole from the private and public sector.

Source: Panels A and B: OECD calculations based on *Scopus Custom Data*, Version 6.2022, September 2022; (SCImago Journal Rankings, 2022[4]).

Panel C: OECD calculations based on IMF Balance of Payments Statistics Yearbook data and OECD Labour Force Statistics, oe.cd/il/54K, June 2022.

Figure 4.4. Share of academic-corporate co-publications in Korea and selected countries, 2005-19

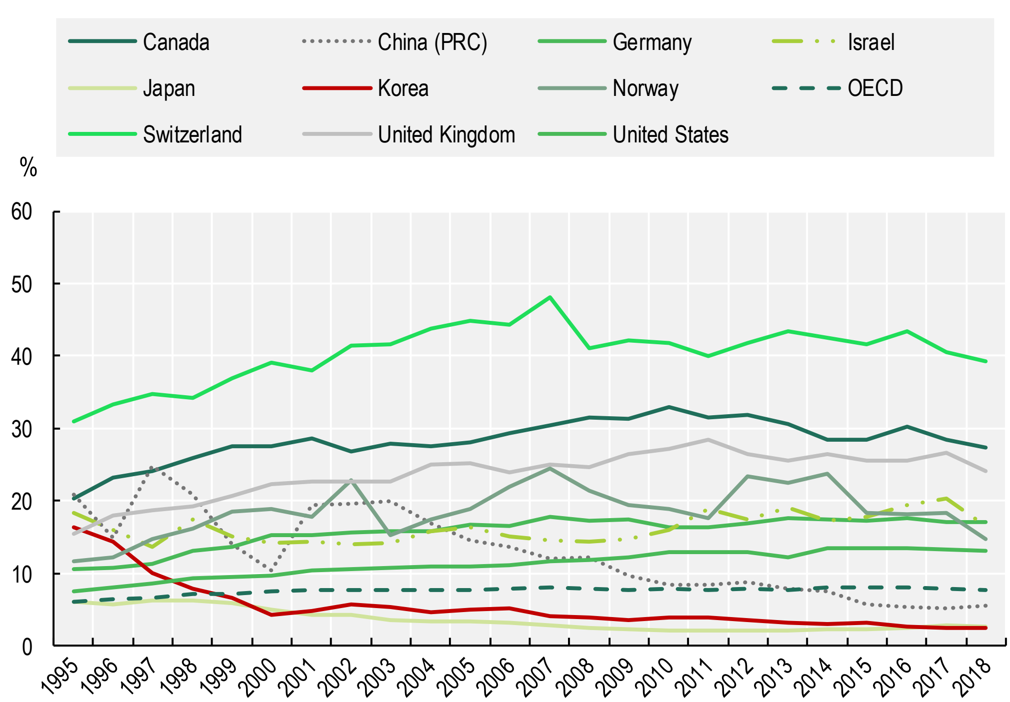
As a percentage of total publications



Source: Elsevier (2021[8]), *Scopus Custom Data*, Version 5, May 2022.

Figure 4.5. International co-inventions

As a share of total domestic patent inventions

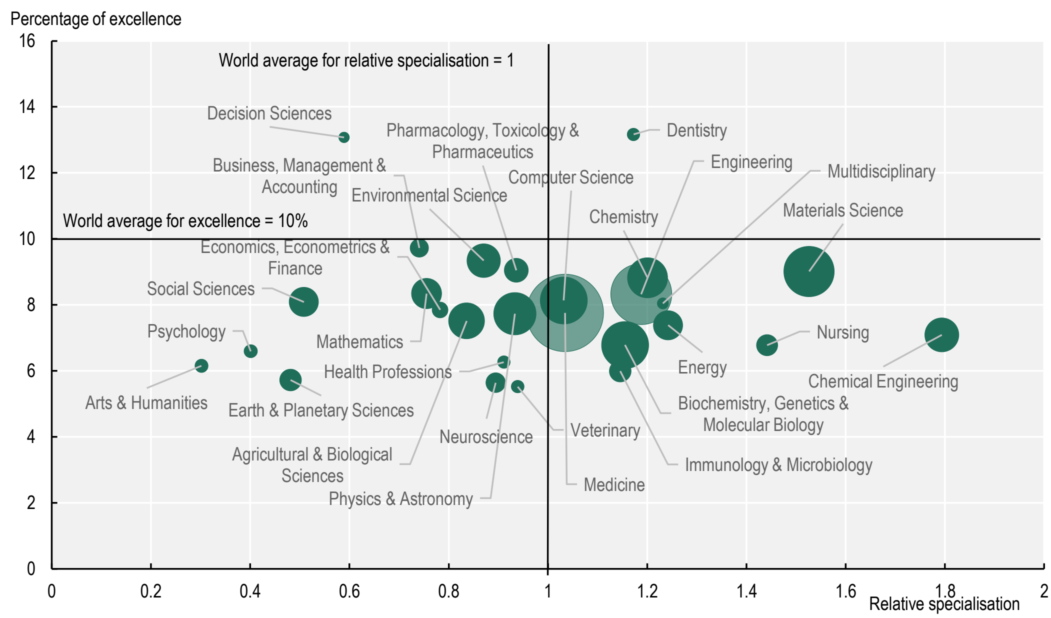


Note: As measured by patent applications filed under the Patent Cooperation Treaty. Co-inventions refer to the share of patents with at least one inventor located abroad as a share of total patents developed domestically.
Source: OECD (2022[9]), *Patent Statistics* (database), oe.cd/4Fj, August 2022.

Examining research performance by field (Figure 4.6), it becomes apparent that in most fields, the percentage of 10% top-cited publications is below 10%, which is by definition the world average, except for decision sciences and dentistry, which constitute a small share of total publications. Most publications are in medicine, engineering, materials and computer science, with relatively few publications in the social sciences, arts and humanities and business-related sciences. It is in these fields that Korean research has among the lowest relative specialisations, thus implying that these are not seen as priority subjects in research. Following Leach and Wilson (2010), the value of arts and humanities research lies in developing people's responsiveness to (societal) problems, to see failure not as a wasted opportunity but to acknowledge the possibility of reusing ideas and concepts over time. It also invokes a sense of freedom and space for experimentation, critical for creativity and innovation (Leach and Wilson, 2010[10]).

On the other hand, Korean research is highly specialised in the advanced fields of chemical engineering, materials sciences and, to a lesser extent, engineering, (bio)chemistry and energy, corresponding to the traditional strength of Korean conglomerates and the economy more broadly. Nevertheless, its relative specialisation in the more fundamental sciences of mathematics, physics and astronomy is lower than the world average.

Figure 4.6. Specialisation and citation impact in science, Korea, 2020



Note: Scientific publications are measured in fractional counts. Percentage of excellence is the share of 10% top-cited publications of total publications. Relative specialisation is the thematic occurrence in publications compared to the world average. A relative specialisation above 1 denotes a specialisation higher than the world's average. The bubble size indicates the number of publications.
Source: OECD calculations based on Scopus Custom Data, Elsevier, Version 5.2021, September 2021

4.1.2. International research collaboration has the potential to grow

International collaboration in research is traditionally a means to enhance the flow of ideas, accelerate the emergence of new concepts, and cross-fertilise scientific endeavours across scientific institutions and countries. It supports the generation of new knowledge, solves complex problems and enables innovative practices in public institutions, private enterprises and academia (Sergi, Parker and Zuckerman, 2014[11]). The COVID-19 pandemic has demonstrated the increased role of international collaboration in solving societal challenges, as the science and innovation response to the COVID-19 pandemic has been largely an international effort (OECD, 2021[12]).

Even so, international collaboration has experienced rapid growth, as international co-publications have evolved from 10% of all publications in 1996 to 21% in 2019. Shares of international co-publications vary, ranging from 8.4% in humanities to 23.5% in natural sciences and 24.9% in agricultural sciences (Pohl, 2021[6]). International collaboration has been shown to enhance citation impact over institutional collaboration by 49% in the United States and 70% in Europe (Science Europe and Elsevier's SciVal Analytics, 2013[13]). Pohl also finds that FWCI enhanced by 70% in Korea (Pohl, 2021[6]).

Korean involvement in intergovernmental institutions, international partnerships, bodies and fora

Korea has been a full member of the International Fusion Experimental Reactor (ITER) since 2003, based on its national experience with KSTAR (Korea Superconducting Tokamak Advanced Research). Korea supplies superconducting magnets, vacuum containers, and tritium transport and storage systems for the facility, bearing 9% of the total cost (ITER, 2022[14]).

Although Korea is not a member of CERN, the European Particle Physics Laboratory,[4] 45 teams from 29 Korean institutions participate in 17 experiments at CERN, the most significant being the Compact Muon Solenoid experiment (CMS), A Large Ion Collider Experiment (ALICE) at the Large Hadron Collider facility, and a theoretical physics exchange programme, governed under the International Co-operation Agreement signed in 2006 (CERN, 2022[15]). CMS is one of the largest international research collaborations that ever existed, with 5 500 participants (scientists, engineers and support staff) representing 241 scientific institutions from 54 countries worldwide (CERN, 2022[16]). Korea established computing centres for these flagship experiments.

Korea has a longstanding collaboration with the European Union under the 2007 Agreement on Scientific and Technological Co-operation between the European Community and the Government of Korea and Decision 2007/241/EC, establishing a formal co-operation framework. The collaboration has resulted in more than 130 joint research projects since 2007, including 82 projects under Horizon2020 (Korea-EU Research Centre, 2022[17]). As of 2017, the success rate of Korean applicants (25.7%) was higher than that of their international counterparts (14.7% overall) (Chung and Lee, 2019[18]). In addition, the 2006 agreement between Euratom and Korea defines the framework for collaboration in fusion energy research. Furthermore, exploratory discussions are underway on the association of Korea to Horizon Europe following Korea’s expression of interest dated 14 February 2022.[5] An association would bring the collaboration to a higher level. Furthermore, as announced in June 2022, Korea has become a full member of Eureka, the world’s largest R&D platform, as the first country in Asia (Ministry of Trade, Industry and Energy, 2022[19]).

While Korea has extensive co-operations in other major international research infrastructures, it currently has no formal co-operation with the European Molecular Biology Laboratory (EMBL), which could offer the opportunity to increase international co-operation in the biological sciences. Although primarily a European organisation, EMBL is open to partnerships, as evidenced by the Associate Membership status of Australia, with a network of seven Australian universities forming an EMBL Partnership Laboratory.[6] Korea is also not a member of the International Space Station, even though a possible Korean membership was mentioned in 2010 by the Head of the European Space Agency, Jean-Jacques Dourdain (de Selding, 2010[20]).

In 2019, the Korean Ministry of Science and ICT (MSIT) signed a Memorandum of Understanding (MOU) with the Science and Technology Directorate of the US Department of Homeland Security to deepen bilateral co-operation in science and technology (S&T) R&D with regard to a variety of issues, including disaster relief, public safety and infectious diseases. The partnership is envisioned to identify mutual challenges as well as shared opportunities and priorities and, therefore, the most efficient areas of investments in technology. Furthermore, the co-operation entails joint research, researcher exchanges, and conferences between the two countries' research institutes, academic institutions, and R&D-related public agencies. It therefore promotes contact and linkages between S&T institutions, including academia, government, science academies, national centres for S&T research and funding bodies. The agency-to-agency agreement is the first step toward the eventual objective of establishing a government-to-government agreement (Department of Homeland Security, 2019[21]).

Korea and Japan have more productive and stronger-growing research co-operation with China than with each other. This is because research collaboration between Korea and Japan tends to occur based on personal relationships rather than through large-scale government-led initiatives. For instance, Seoul National University (SNU) set up a new laboratory of the University of Tokyo's Institute of Solid State Physics and the Center for Correlated Electrons at the Institute of Basic Science in Korea, initiated by Se-Jung Oh, the President of SNU and Korea's Institute of Basic Science. Researchers tend to remain in their research institutes and do not change jobs regularly, which has been conducive to establishing impactful long-term relationships. Furthermore, the export of equipment between the two countries is relatively simple compared with China, where these are subject to strict controls (Fuyuno, 2021[22]).

The Korean Academy of Science and Technology (KAST), the Korean Social Science Research Council (KOSSREC) and the National Academy of Sciences of the Republic of Korea (NAS) are members of the International Science Council.

Large Korean firms with strong global market presence also create and acquire R&D centres internationally. Such centres pursue two types of strategies: acquisition of new technology and "localisation" of production, i.e. adaptation to local consumer needs and tastes. Examples include the following:

- The LG Zenith Lab in Lincolnshire, Illinois, United States, resulted from an acquisition of Zenith, a US company, which enabled LG to enter the digital TV industry during the 1990s. Another centre for electric vehicle components was set up in Troy, Michigan, United States. In connected car solutions, LG teamed up with Qualcomm in 2017 to develop a range of next-generation car solutions.
- R&D centres for local adaptation exist in India (LGEIL), Beijing, China and northern France for adaptation to European consumers (Ramaswamy, 2007[23]).
- Samsung Electronics set up 16 R&D centres in 14 countries, with 7 centres focused on artificial intelligence (AI) in Korea, the United States, the United Kingdom and Canada, among others (Samsung Electronics, 2022[24]).
- LG Electronics partnered with the University of Toronto and set up an AI lab focusing on neural networks for deep learning (University of Toronto, 2018[25]). Of a total of about 20 000 workers in its R&D operations, roughly one-quarter are foreigners. Nevertheless, according to the project team interviews, the integration of foreigners into Korean companies is still a cultural challenge.
- SK Hynix established Gauss Labs, an AI company financed with USD 55 million (Jung, 2020[26]).

Government initiatives for internationalisation

The International Co-operation Programme in S&T is a group of programmes funded by the MSIT and operated by the National Research Foundation (NRF) since 2009. Its objectives are to strengthen institutional infrastructure for international co-operation in science, technology and innovation (STI); support Korean universities' co-operation with their foreign counterparts; attract excellent overseas research institutes; promote global R&D co-operation and networking; and support developing countries through S&T-focused overseas development assistance (ODA) projects. Its main components are researcher exchanges, joint research projects, ODA, and co-operation centre support programmes.[7]

The MSIT operates Korea Innovation Centres (KICs) in Silicon Valley (KIC Silicon Valley), Washington, DC (KIC Washington), Berlin (KIC Europe) and Beijing (KIC China) to provide step-by-step accelerating programmes for Korean start-ups and small and medium-sized enterprises (SMEs) to expand their business in global markets (https://www.kicsv.org/). In addition, the India Korea Center for Research and Innovation (IKCRI) was established in 2020 to do joint research on digital transformation, future manufacturing, future utilities and healthcare. Eight "K-startup centres" have been established across European countries, Asia and the United States to act as a globalisation support platform for start-ups.

The Korea Institute for Advancement of Technology (KIAT) has an international technology co-operation division,[8] which has diverse international collaboration programmes, including joint R&D on quantum technologies, with most advanced OECD countries as well as India and China, multilateral joint R&D projects, including Eureka, Eurostar 3, Horizon Europe and M-ERA-NET, and Korea-Association of Southeast Asian Nations (ASEAN) technical co-operation. It also runs a number of international centres in the United States, Europe and Asia, a bilateral programme with France, and industrial technology ODA support.

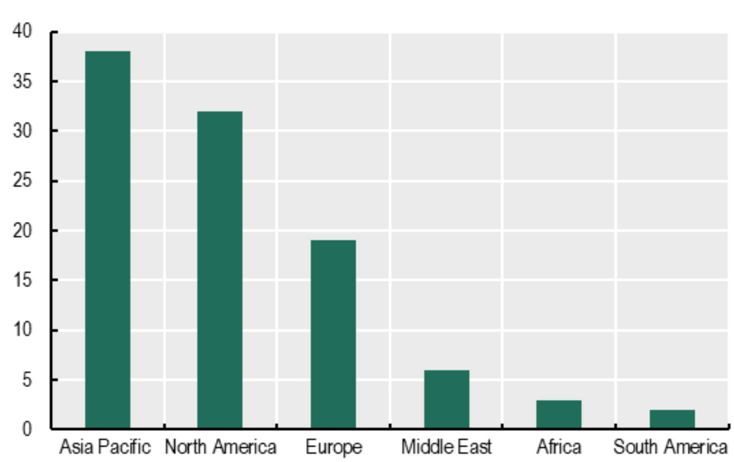
International co-publications

Between 2018 and 2020, Korea had 81 000 international co-publications (i.e. co-authored publications with at least one author having an institutional address/affiliation outside Korea). In terms of regional distribution, the Asia-Pacific region accounted for the largest share of total co-publications (38%), followed by North America (32%) and Europe (19%) (Figure 4.7). Looking at individual countries, the United States is by far Korea's most important research partner, measured in terms of co-authored publications, with 33 600 joint publications between 2018 and 2020, followed by China (15 600 co-publications), Japan and India with 8 600 and 8 200 co-publications, respectively. Among the top 20 countries with which Korea has the most co-authored publications, between 2018 and 2020, Korean co-publications increased by far the fastest with Viet Nam, followed by Saudi Arabia, China and Pakistan (Table 4.1).

Compared to other OECD countries with significant research expenditures, Korea has relatively few international co-publications, both as a share of total publications and in relation to the size of its population (Figure 4.8). For example, countries such as Australia, Costa Rica, France, Germany, Italy, New Zealand, Sweden, Switzerland and the United Kingdom had more than twice as many internationally co-authored publications per capita than Korea, while Japan and China had fewer.

Figure 4.7. Korea's co-publications with selected regions, 2018-20

Percentage of total co-publications



Note: All publication types. Fractional counts.
Source: Elsevier, *Scival Data*, SciVal, October 2021.

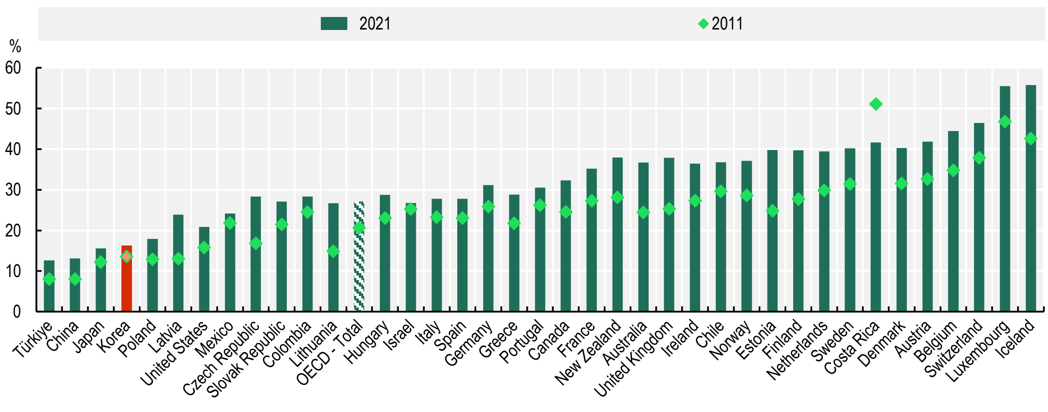
Table 4.1. Korea's co-publications with selected economies, 2018-20

	Top research collaboration partners	Number of co-publications	Increase (%)
1	United States	33 475	7.1
2	China	15 632	37.6
3	Japan	8 552	6.7
4	India	8 186	27.3
5	United Kingdom	7 056	23.3
6	Germany	6 343	16.3
7	Australia	4 908	28.3
8	Canada	4 193	33.5
9	France	4 035	15.7
10	Italy	3 964	33.5
11	Pakistan	3 745	36.3
12	Viet Nam	3 271	104.5
13	Spain	3 046	27.4
14	Chinese Taipei	2 985	9.5
15	Switzerland	2 500	21.2
16	Singapore	2 292	33.7
17	Saudi Arabia	2 289	52.7
18	Islamic Republic of Iran	2 045	31.9
19	Netherlands	2 030	24.4

Note: All publication types.
Source: Elsevier, *Scival Data*, SciVal, October 2021.

Examining internationally co-authored papers as a share of total publications, international research collaboration has increased for many OECD countries in the past decade (Figure 4.8). In the case of Korea, international co-publications accounted for a significantly smaller amount of the country's total publications in 2009, with less than 14%, increasing to about 16% in 2019. In comparison, France, Germany and the United Kingdom had a higher share of co-publications in 2009, 27%, 26% and 25%, respectively, and their shares increased to 36% for France and the United Kingdom and 31% for Germany in 2019. China, which had significantly lower shares of internationally co-authored papers compared to Korea in 2009, saw its shares increase more quickly, with a growth rate of 76% during the period compared to 16% in Korea. Between 2009 and 2019, the number of internationally co-authored publications in Korea grew more quickly than in France, Germany, Japan, Switzerland, the United Kingdom and the United States. This indicates that while international research collaboration has increased in absolute terms, the increase has not exceeded the simultaneous growth in total research output to the same extent as it has done for the other countries examined.

Figure 4.8. Percentage of total scientific publications involving international collaboration



Note: International collaboration refers to publications co-authored among institutions in different countries. Estimates are computed for each country by counting documents for which the listed affiliations include at least one address within the country and one outside. Single-authored documents with multiple affiliations in different countries count as institutional international collaboration.
Source: OECD calculations based on Elsevier (2022[27]), *Scopus Custom Data*, Version 6.2022, September 2022.

In particular, given rising societal challenges, such as climate change, which are global and systemic in nature, with wide-ranging effects on economies, from agriculture to energy, the need for international co-operation is becoming greater. Priority setting in national agendas needs to address questions about what to fund and which requirements must be fulfilled. For instance, in the European Union, the Horizon 2020 programme sets out international collaboration as a requirement by stipulating that a project must involve participants from at least three member states and associate countries. As part of the 2021-27 funding programme (Horizon Europe), efforts to increase internationalisation have further been extended to include exceptional funding for participants from non-EU third countries to encourage topics that support internationalisation and the implementation of multilateral agreements. Furthermore, the funding channel provides a mechanism to incentivise long-term-oriented financial support for co-operative research addressing societal challenges. For this purpose, separate advisory groups have been established with industry, academia and civil society stakeholders to help implement related work programmes. It is worth noting that Korea is one of 20 countries with whom the European Union has entered into bilateral S&T agreements meant to strengthen policy dialogue with project-based and bottom-up co-operation (European Commission, 2022[10]; OECD, 2017[10]).

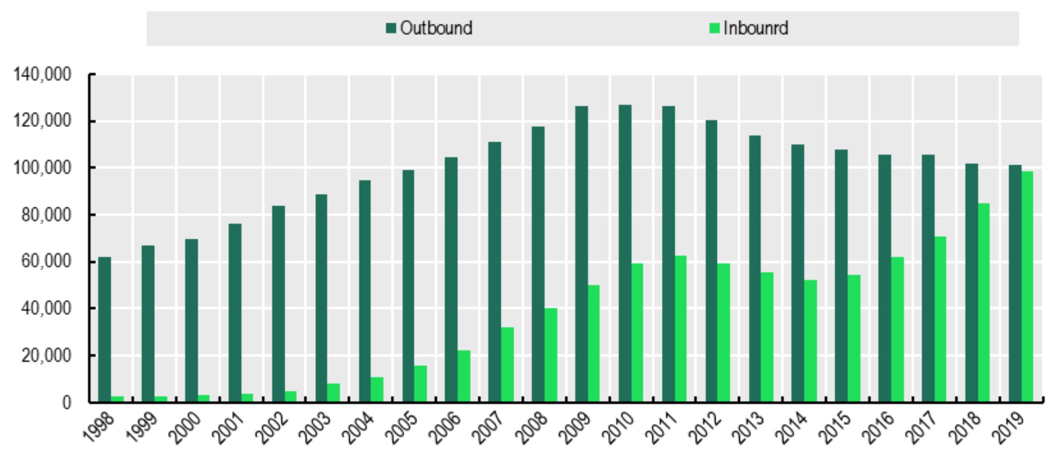
Furthermore, Macháček et al. show that Korean universities tend to recruit staff from within their institution more than in the United States, Australia, Canada, Germany, France and the Netherlands, but lower than Sweden, Japan, China, Spain or Italy. They also show that the degree of internal recruitment differs more widely among Korean institutions than in the other countries mentioned, with the exception of China, pointing to a less homogenous university system than in other countries (Macháček et al., 2021[28]). In addition, several stakeholder interviews confirmed that Korean researchers tend to be reluctant to partner with international researchers. This is because of administrative complexity, since obtaining project-based system (PBS) funding is relatively straightforward, which disincentivises taking on the additional burden of partnering with international researchers. As shown in Chapter 2, the international mobility of Korean researchers is among the lowest in the OECD.

4.1.3. International student mobility is growing, but integrating foreign students is a challenge

The number of international students at Korean universities increased more than tenfold between 2001 and 2019 and doubled between 2014 and 2019 (Jon and Yoo, 2021[29]). The increase is partially explained by the Study Korea Project (SKP) launched in 2005, which set clear goals for increasing the number of international students. Consequently, the share of international students at Korean universities has risen significantly, alongside a decline in Korean students (due to demographic changes) in the past decade. Launched in 2004, the SKP had the initial objective of 50 000 international students, which was expanded to 100 000 in 2008. This was expanded once more in the form of the Study Korea 2020 Project in 2013, which aimed to attract 200 000 students by 2020 (Green, 2015[30]). After 2015, the number of international students surged again, reaching nearly 100 000 in 2019 (Figure 4.9).[9] Nearly half of Korea's international students in 2019 came from China, followed by Viet Nam, which accounted for nearly a quarter (Jon and Yoo, 2021[29]). In 2015, the Korean Research Fellowship Programme was launched. It provides fellowships, postgraduate loans, and scholarships to outstanding overseas students to conduct research in emerging fields and thereby help them grow. While not necessarily impacting the number of foreign students coming to Korea, the programme is an important addition to attracting top talent. The ability to attract and retain foreign students is an important challenge and can be fostered by improving student satisfaction.

Figure 4.9. International student mobility in Korea, 1985-2019

Number of students



Note: Outbound students are internationally mobile tertiary students who study abroad. Inbound students are international tertiary students who leave their origin country to study in Korea.
Source: UNESCO (n.d.[31]), *UIS Statistics*, http://data.uis.unesco.org/, August 2022.

Some of the most significant factors besides academic quality that influence student satisfaction are the ability to speak the Korean language, cultural proximity to the students' origin destination and whether they receive financial support via scholarships. About one-third of students report not understanding the Korean language very well or at all, hindering their ability to communicate effectively (Alemu and Cordier, 2017[32]). This may explain why Korea tends to be a more popular choice for studying abroad among East Asian students who share cultural and historical ties and whose students are often more reliant on financial support.

While initiatives such as exchange programmes, including Campus Asia, AIMS and ASEM-DUO, have been introduced to attract international students, Moon (2016), in examining internationalisation and diversity in higher education in Korea, finds significant barriers to interaction and integration of foreign students once they are in the country related to language, social integration and cultural differences. Similarly, according to Lee and Bailey's (2020) mixed method analysis, overall interest in interacting with international students is low among Korean students. Language, mentoring, culture and social programmes to increase interaction are some measures that could help contribute to better integration of international students (Lee and Bailey, 2020[33]). Moon interprets the finding as a manifestation of a larger pattern of instrumentalisation of internationalisation and globalisation, where specific aspects of internationalisation are “cherry-picked” or appropriated to serve a national agenda. Similar mechanisms can be found to be at work in Japan and are also present in China’s policy of opening up, which seeks to attract foreign technology and talent in selected fields in order to serve the country’s catching-up agenda, with the ultimate aim of allowing China to isolate itself from the world if/when it chooses to do so. It should be pointed out that selectively pursuing certain aspects of internationalisation as a means to strengthen the nation-state can be found in many regions and countries, including Europe, Australia and North America (Moon, 2016[34]).

4.1.4. Korean university rankings could improve further

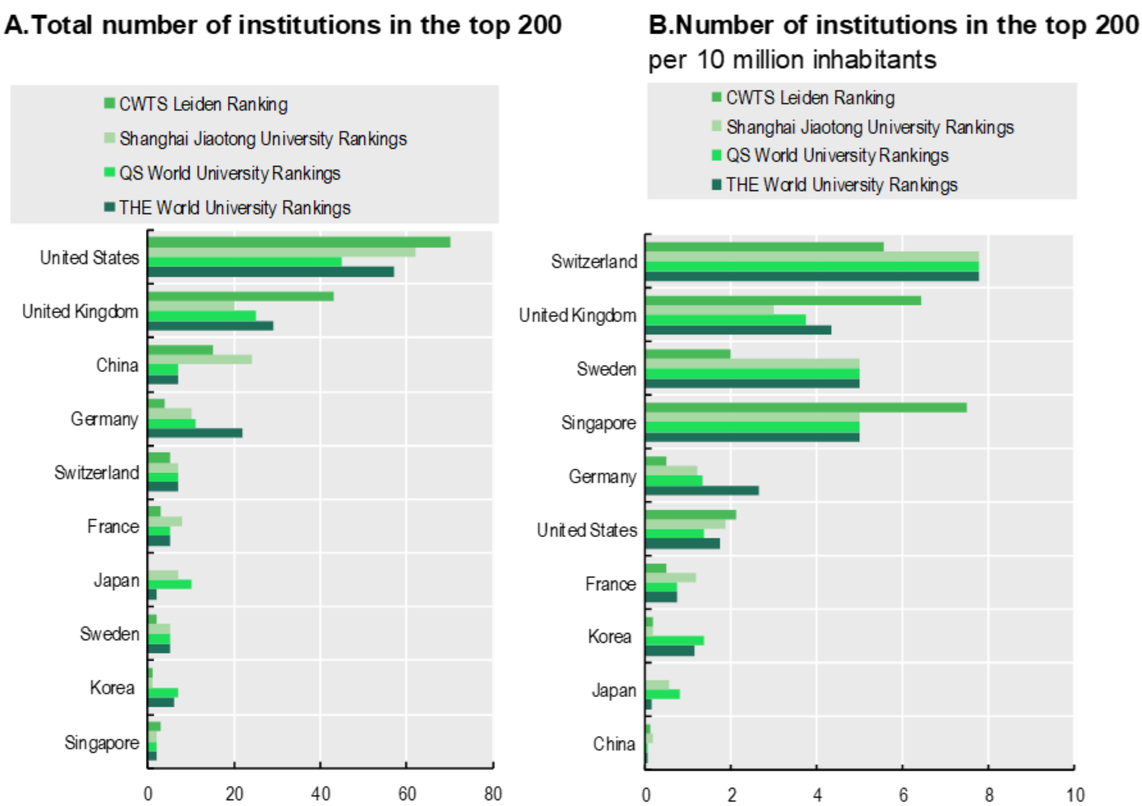
In the past decade, a handful of Korean universities have consistently been ranked among the top 200 in the world in the Times Higher Education World University Rankings and the QS World University Rankings, with SNU and KAIST quite regularly among the top 100. However, Korean universities, as a whole, score considerably lower in the Shanghai Jiaotong Ranking and the Centre for Science and Technology Studies (CWTS) Leiden Ranking, which, in comparison to the other two rankings, assign more weight to indicators for research excellence (e.g. Nobel Prizes and highly cited research in proportion to size) and less to reputation (as measured by surveys) or teaching quality (measured by surveys and student/teacher ratios) (Lim, 2018[35]). The CWTS Leiden Ranking, for example, ranks universities according to the top 10% cited publications as a percentage of total publications. According to the 2021 CWTS Leiden Ranking, only the Ulsan National Institute of Science and Technology (UNIST) ranked among the top 200 universities in the world (109th), with the next Korean universities ranked 438th (KAIST) and 439th (Pohang University of Science and Technology [POSTECH]). In comparison, Sweden had 9, France had 23, and Germany had 14 universities among the top 400 institutions, indicating a more even distribution and consistency among the latter countries’ universities in research quality. More specifically, the indicator for Nobel Prizes stands out as Korean universities have zero. In comparison, France has 65 in total, of which 36 are in “hard” sciences, including physics, chemistry and medicine.[10]

Korean universities are internationally competitive, as shown by their frequent appearance in the world’s top 200 universities of the Times Higher Education and QS World University rankings, with six and seven institutions listed, respectively (Figure 4.10, Panel A). Relative to population levels, the number of top universities is therefore comparable to the United States and about twice as high as for France for these two rankings (Figure 4.10, Panel B). However, the gap between the top institutions and the bulk of HEIs seems bigger than in Japan, Germany and Sweden, confirming the impression of an HEI landscape dominated by a handful of universities – in terms of reputation and research output. Examining the socio-economic and redistributive effects of tertiary education according to Lee and Vignoles (2021), there are indications of considerable variations in prestige, reputation and quality between a small number of top HEIs and the remainder of less well-known HEIs, many of which were established after 2000 (Lee and Vignoles, 2021[36]).

Furthermore, the more research-quality-focused Shanghai Jiaotong University and CWTS Leiden Rankings offer a different picture. Both place only one Korean institution in the world’s top 200, implying 0.19 per 10 million inhabitants, far less than many comparator countries except China (Figure 4.10, Panel B). This shows that although top Korean universities have a good reputation, attracting talented students and personnel as well as funding, the quality of the research, as measured by the share of top-cited publications, may lag behind that of HEIs in other countries at the innovation frontier.

These results should, however, be interpreted with caution due to the potential bias in university rankings in favour of western universities in terms of reputation and research quality. This may be due to historical and cultural factors. For instance, institutions in the United Kingdom benefit from long-established reputations worldwide, placing young universities in Asia at a disadvantage. Furthermore, affiliation, language and gender may constitute biases in peer reviewing since most relevant journals are western and rate articles according to their standards (Lee et al., 2013[37]). For instance, publications in English have a major advantage, benefiting institutions in the anglosphere (Jons and Hoyler, 2013[38]).

Figure 4.10. Number of top-200 universities in Korea and selected countries, 2021



Source: Times Higher Education World University Ranking, QS World University Ranking, Shanghai Jiaotong University Ranking, 2021; OECD calculations based on OECD (2022[39]), *Labour Force Statistics: Population and vital statistics*, oe.cd/il/54K, July 2022.

4.1.5. A few universities conduct most leading research in higher education institutions

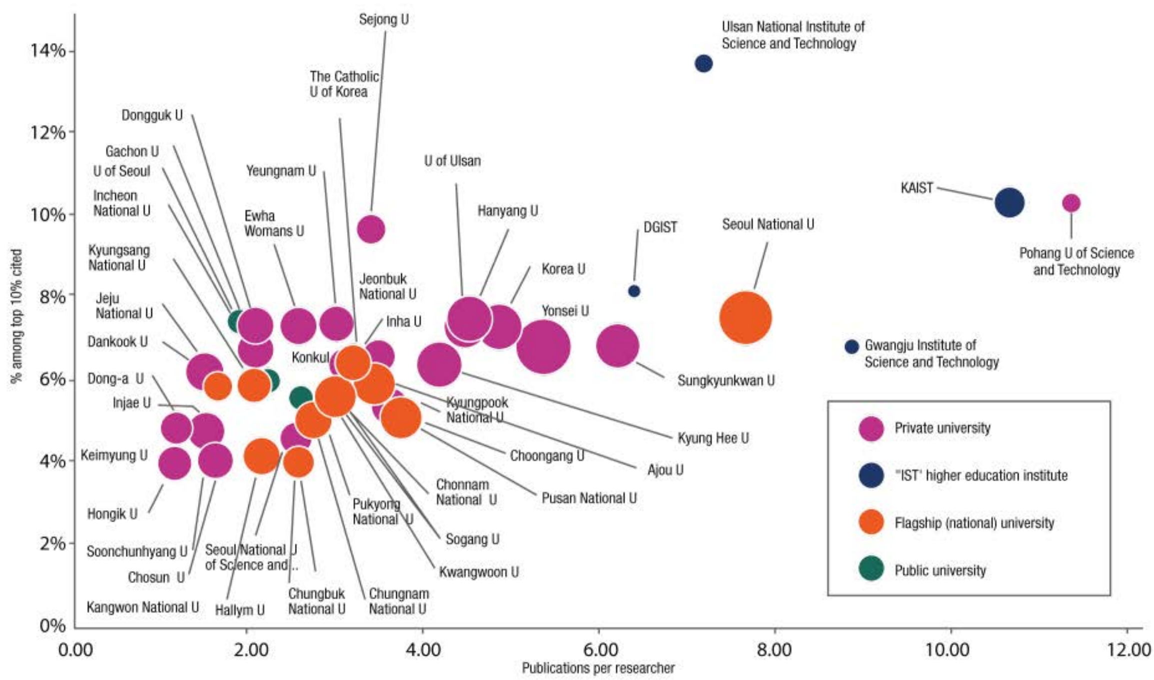
An analysis of the 45 universities listed in the CWTS Leiden Ranking makes it possible to compare the quantity and quality of research in Korean universities (Figure 4.11). A remarkable feature is that the quality and quantity of publications seem correlated to a certain extent, suggesting that universities with larger research groups and larger scientific output also produce higher quality output.

Productivity per faculty member varies widely, from about one per faculty member to more than ten for POSTECH and KAIST. This is largely linked to research funding, as discussed below, since larger funding per faculty member allows for the constitution of larger research groups and increases output per faculty member.

Concerning quality, three universities have scores above 10%, ranking them among the top 500 universities worldwide according to the Leiden ranking, including POSTECH, KAIST and UNIST. As a matter of comparison, top universities in the United States have a score above 20% (Rockefeller University, Massachusetts Institute of Technology [MIT], Princeton University, Caltech, Stanford, Harvard and University of California [UC] Berkeley), and a further 55 universities based in Europe, the United States, China, Singapore and Israel have between 15-20%.[11] The comparison within Korea shows the excellent performance of UNIST due to policies that will be discussed in more detail below. The other "IST" universities under MSIT (KAIST, Daegu Gyeongbuk Institute of Science and Technology [DGIST] and

Gwangju Institute of Science and Technology [GIST]) also perform quite well, both in quantity and quality. Regarding the flagship universities, SNU performs comparably to the IST universities. However, the other flagship universities are performing at lower levels. Some of the private universities perform quite well, in particular, POSTECH and Sejong University, and a number of others perform above average.

Figure 4.11. Quality and quantity of research in Korean higher education, 2022



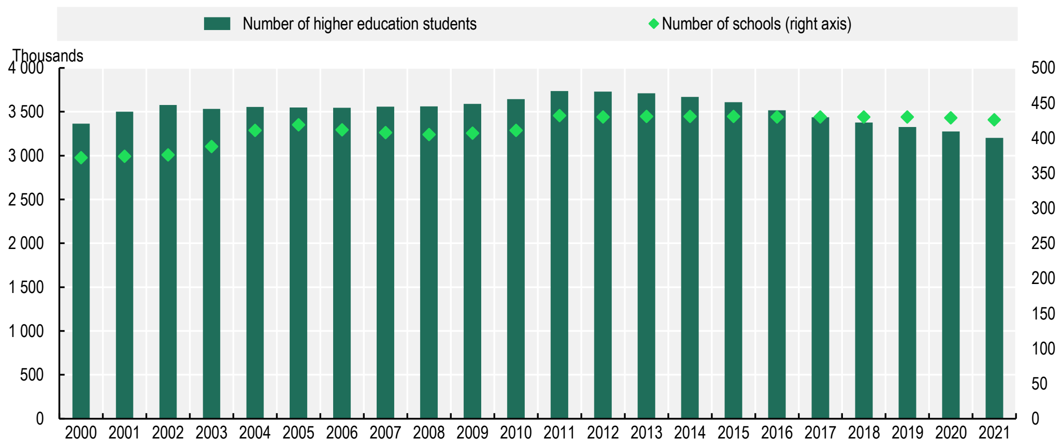
Note: On the horizontal axis, the average number of publications per faculty member is a measure of research productivity, while on the vertical axis, the percentage of publications among the top 10% cited journals is a measure of quality. The size of the symbol is proportional to the number of faculty.
Source: OECD analysis based on CWTS Leiden Data, https://www.leidenranking.com/information/data, 2022.

4.1.6. Technical skills are strong, but significant gaps persist across age groups

As of 2021, Korea had 3.2 million higher education students, about 500 000 less than in 2013, while the number of HEIs remained stagnant (Figure 4.12). The declining number of students and the ongoing tuition fee freeze have strained university finances, particularly in more regional parts of the country. This development is largely due to a steep decline in the overall population and the ongoing trend of students preferring to relocate to conglomerate areas for studies, where universities are more reputable and job prospects are better.

In 2019, Korea had the highest share of people aged 25-34 with tertiary education, close to 70% (Figure 4.13). It also had the largest difference in tertiary education between 25-34 year-olds and 55-64 year-olds, reflecting the rapid increase of tertiary educational attainment among the young and primary-age workforce in the past 30 years.

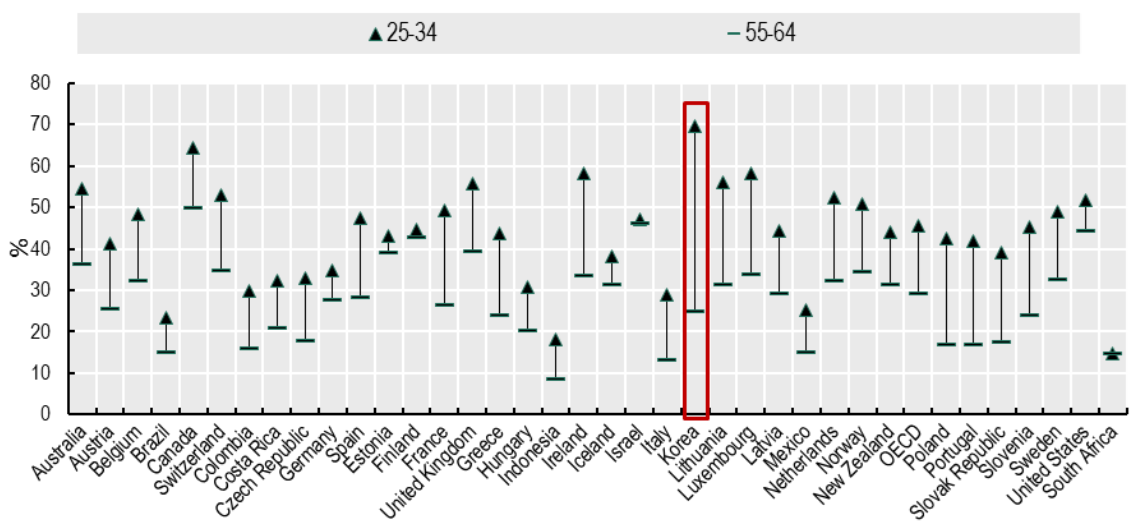
Figure 4.12. Number of higher education students and higher education institutions in Korea, 2000-21



Source: Ministry of Education Statistics, https://english.moe.go.kr/sub/infoRenewal.do?m=050101&page=050101&s=english, accessed June 2022.

Figure 4.13. Tertiary educational attainment in Korea and selected countries, 2020

Adults aged 25-34 and 55-64, Percentage



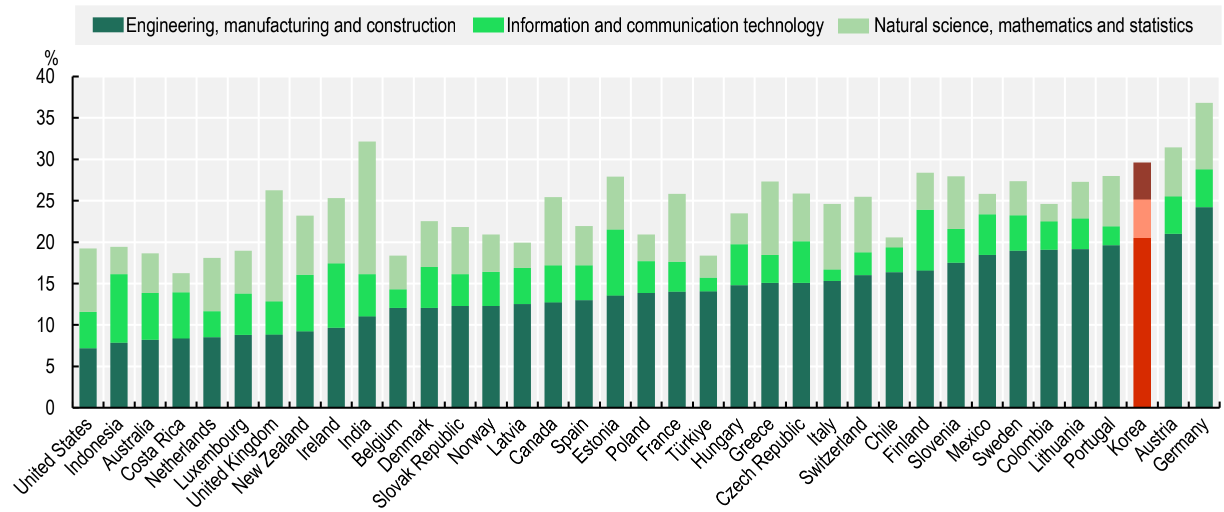
Source: OECD (2022[40]), *Education Statistics* (data), oe.cd/dp/4Fn, August 2022.

National innovation systems are highly dependent on human capital, with science, technology, engineering and mathematics (STEM) skills being of particular relevance for innovation at the technological frontier. The Korean education system outperforms most OECD economies in terms of the quantity and quality of its students. Not only does Korea have the highest share of tertiary students among its 25-34 year-old population, with close to 70%, but it also has one of the highest shares of tertiary graduates in S&T fields, with almost 30% of all tertiary graduates (Figure 4.14, Panel A). Furthermore, Korean students are among the best-performing in OECD countries according to the 2018 results from the Programme for International Student Assessment (PISA), with almost 12% of students achieving top scores in science (Figure 4.14, Panel B).

Figure 4.14. Korean students and graduates in science and technology

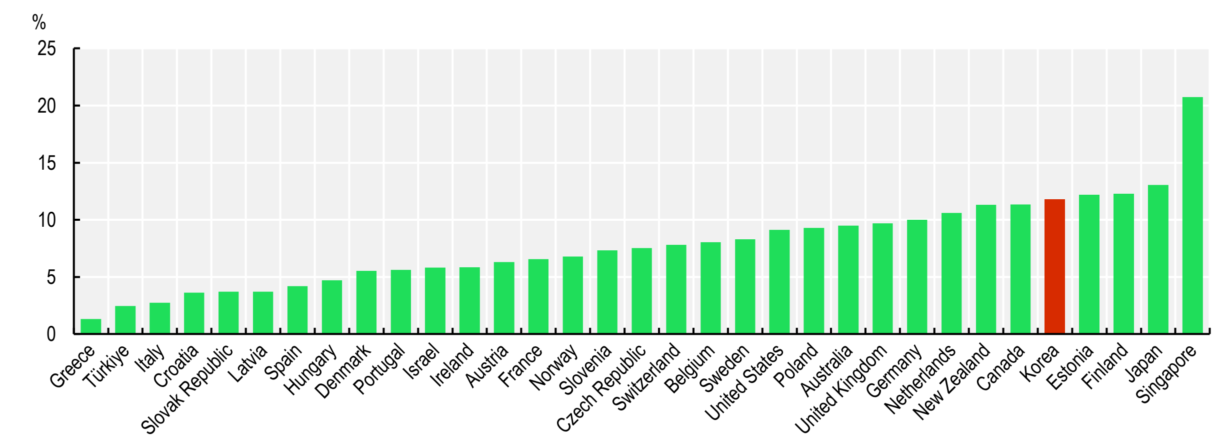
A. Share of tertiary graduates in selected sciences

Percentage of all tertiary graduates in all fields, 2019



B. Percentage of top students in all sciences

Percentage of top performers in science, based on PISA scores, 2018



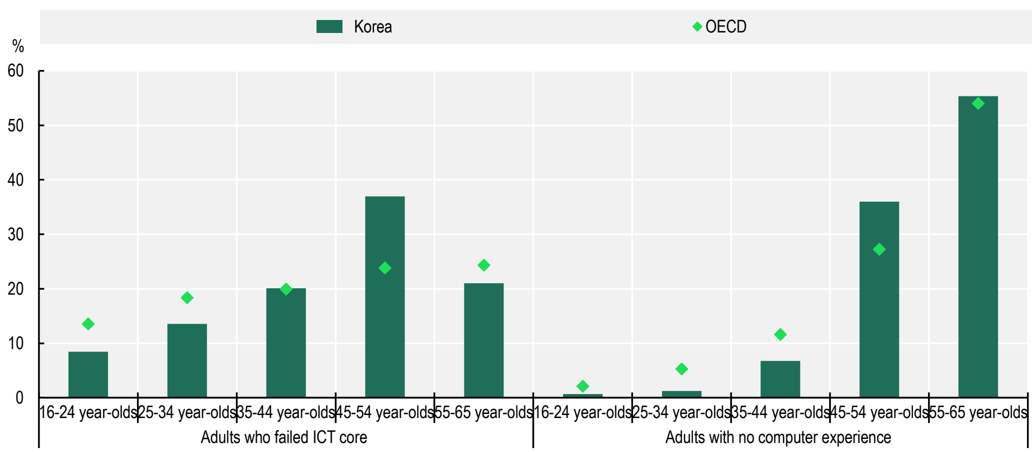
Note: With regard to Panel B, scientific performance, for PISA, measures the scientific literacy of a 15-year-old in the use of scientific knowledge to identify questions, acquire new knowledge, explain scientific phenomena, and draw evidence-based conclusions about science-related issues. It is not limited to the three fields under Panel A.

Source: OECD (2022[40]), *Education Statistics* (data), oe.cd/ds/4X0; OECD (2023[41]), "Science performance (PISA)" (indicator), https://doi.org/10.1787/91952204-en, June 2022.

However, skill levels vary significantly by age group, with middle- to old-aged workers lagging the well-educated and tech-savvy younger generation. For instance, the percentage of adults failing the information and communications technology (ICT) core test[12] in PIAAC, the OECD Survey of Adult Skills, is the second highest among OECD countries, with 9.1% in 2018. While 16-34 year-olds perform significantly better than the OECD average, almost 37% of those aged between 45 and 54 failed the ICT core test, and about the same percentage have no computer experience (Figure 4.15). Notably, 55-65 year-olds perform considerably better, which may result from training initiatives for senior citizens launched by the Korean government.

Skilled employees are among the most important resources for companies to innovate; however, there are indications that graduates' skill sets do not satisfy industry demands. First, weak ICT skills of many older workers may hinder basic operational efficiency, particularly for SMEs, which face a disproportionate challenge in attracting talented employees, as explained in Chapter 2. Second, skills shortages are commonly reported across OECD countries, although Korean SMEs are more likely to report them as a major challenge than large firms, whereas, in most OECD countries, the reverse is true (OECD, 2019[42]).

Figure 4.15. Adult ICT competencies and computer experience in Korea and OECD countries, 2018



Source: OECD (2018[43]), *Survey of Adult Skills (PIAAC)*, oe.cd/4Fk.

4.2. Classification of higher education and public research institutes

This section describes the classifications of PRIs and HEIs. The sections detail the performance, missions, funding, and governance structures of Korea's HEIs and PRIs. After this initial presentation of the various types of PRIs, the remainder of the chapter will solely focus on GRIs.

4.2.1. Public research institutes

While there is no universal understanding with regard to the role and definition of PRIs, given the rapid pace of development in Korea, there have been many adjustments and rearrangements within its national PRI system. This section presents the categorisation of diverse organisations, notably government labs, technology centres, the scientific research institutes under MSIT, institutes of S&T and the so-called GRIs. The latter have provided the main support to industrial development over the past half-century; their roles are therefore undergoing the most significant change.

Government think tanks

Government think tanks are probably the oldest category of PRIs. These are traditionally owned, funded and steered by ministries or departments of the state. Their core task is to provide the ministries with research and information needed for policy development and regulation. For example, most coastal states have marine institutes that do scientific research on aquatic life but also perform regulatory tasks, such as monitoring marine pollution and estimating fish stocks as a basis for setting limits on allowable catches, and conforming with international treaties on fishing. Government think tanks often also produce public goods, such as weather forecasts, metrology, and geological mapping – generating information important to the government and wider society.

Generally, institutes that produce public goods also sell more specialised services, such as specific weather forecasts for large agribusiness firms, certification in relation to measurement, and detailed geological maps for mining companies. Where this is the case, their service revenues reduce the proportion of income they receive from the government. Often, they participate in government-funded research programmes. Since these opportunities to get external funding vary greatly by sector, the proportion of core funding to total income also varies greatly among government labs.

Government think tanks have played a role in Korea since the 1980s (or before). By and large, the think tanks that provide policy support and advice to ministries (Table 4.2) were formerly under the control of their respective ministries but were brought together by the Ministry of the Economy and Finance in 1999 and placed under the umbrella of the National Council for Economics, Humanities and Social Sciences (NRC).

Table 4.2. Policy support and advice bodies under Korea's National Council for Economics, Humanities and Social Science

Abbreviation	Name	Date established
AURI	Architecture and Urban Research Institute	2007/20
KDI	Korea Development Institute	1971
KDI School	KDI School of Public Policy and Management	1997
KEDI	Korean Educational Development Institute	1972
KEEI	Korea Energy Economics Institute	1986
KEI	Korea Environment Institute	1992
KICCE	Korea Institute of Child Care and Education	2005
KICE	Korea Institute for Curriculum and Evaluation	1998
KICJ	Korea Institute of Criminology	1989
KIEP	Korea Institute for International Economic Policy	1989
KIET	Korea Institute for Industrial Economics and Trade	1976
KIHASA	Korea Institute for Health and Social Affairs	1972
KINU	Korea Institute for National Unification	1991
KIPA	Korea Institute for Public Administration	1991
KIPF	Korea Institute of Public Finance	1992
KISDI	Korea Information Society Development Institute	1985
KLI	Korea Labour Institute	1988
KLRI	Korea Legislation Research Institute	1990
KMI	Korea Maritime Institute	1997
KOTI	Korea Transport Institute	1987
KREI	Korea Rural Development Institute	1978
KRIHS	Korea Research Institute for Human Settlements	1978
KRIVET	Korea Research Institute for Vocational Education and Training	1997
KWDI	Korean Women's Development Institute	1983
NYPI	Korea National Youth Policy Institute	1989
STEPI	Science and Technology Policy Institute	1987

Source: NRC (2021[44]), *Affiliate research institutes*, https://www.nrc.re.kr/menu.es?mid=a20202000000.

Technology centres

Korea has several technology centres, also called "special production technology research institutions", which provide technology support (often process-related), training and some collaborative R&D to established companies and SMEs. The Ministry of Trade, Industry and Energy (MOTIE) maintains the following centres:

- Korea Electronics Technology Institute (KETI)
- Korea Automotive Technology Institute (KATECH)
- Korea Photonics Technology Institute (KOPTI)
- Korea Research Institute for Fashion Industry (KRIFI)
- Korea Institute for Convergence Textile (KICTEX)
- Korea Textile Development Institute (KTDI)
- Korea Marine Equipment Research Institute (KOMERI)
- Korea Occupational Safety Research Institute (KOSRI)
- Korea Textile Machinery Convergence Research Institute (KOTMI)
- Research Institute of Medium and Small Shipbuilding (RIMS)
- Korean Institute of Footwear and Leather Technology (KIFLT)
- Korea Institute of Robotics and Technology Convergence (KIRO)
- Dyeing and Finishing Technology Institute (DYETEC)
- Korea International Trade Research Institute (KITRI).

One of the National Research Council of Science and Technology (NST) GRIs – the Korea Institute of Industrial Technology (KITECH) – has a similar function but appears to work at higher technological levels. KITECH supports technological development in areas such as clean tech and manufacturing technology for SMEs and, therefore, has seven regional labs in addition to its headquarters. Its budget is KRW 307 billion (about USD 291 million), of which 45.4% is government direct, 39.1% is government indirect, 12.6% is private, and 2.8% is other. It employs 1 142 people, of whom 86.1% work in R&D and the remaining 13.1% in management and administration (KITECH, n.d.[45]).

Other ministries still maintain (generally branch-specific) technology centres, providing some technical and business support and training. For example, the Korea Maritime Institute,[13] one of the NRC institutes, supports the Ministry of Oceans and Fisheries. At the same time, the sector is served by the Korea Institute of Marine Science and Technology Promotion (KIMST), whose goal is to "contribute to the marine industry by cultivating marine science and technology" (KIMST, 2021[46]).

Scientific research institutes under MSIT

Scientific research institutes, such as the Max Planck institutes in Germany and the Centre national de la recherche scientifique (CNRS) in France, largely do the same kind of research as universities and receive a high proportion of their income in the form of institutional funding. In some cases, they are organised as institutes because they rely on large scientific infrastructures, which would be beyond the means of a university to fund or manage. The Max Planck Society maintains its scientific research institutes outside the university system so that it can create, develop, and even shut down its institutes at will if their research trajectory and leadership run out of steam. In the former Soviet system, science was kept in Academy of Science institutes to keep dangerous free-thinking researchers away from impressionable students, who, therefore, received their higher education in universities dedicated to teaching. Quite a few post-Soviet states have transferred the Academy of Science institutes into the universities, enabling these universities to become Humboldtian, research-based institutions, simultaneously causing the university system to grow at the expense of the institute system. Some countries choose not to have scientific research institutes and assign responsibility for all state-funded basic and applied research outside government to universities.

Under current arrangements, MSIT oversees the scientific and technological institutes, which comprise a mix of different kinds of organisations. It manages the GRIs via the NST (discussed below) and directly controls a range of other institutes (Table 4.3).

Table 4.3. Government research institutes and public research institutes that report to Korea's Ministry of Science and ICT

MSIT GRIs under the National Research Council of Science and Technology (NST)		PRIs reporting directly to MSIT	
KIST**	Korea Institute of Science and Technology	R&D-focused (scientific research institutes)	
(GTC)*	Green Technology Centre Korea	(KIAS)	Korea Institute for Advanced Study
KBSI*	Korea Basic Science Institute	IBS	Institute for Basic Science
KASI*	Korea Astronomy and Space Science Institute	(NIMS)	National Institute for Mathematical Sciences
KRIBB*	Korea Research Institute of Bioscience and Biotechnology	(KBRI)	Korea Brain Research Institute
KISTI**	Korea Institute of Science and Technology Information	KIRAMS	Korea Institute of Radiological and Medical Sciences
KIOM*	Korea Institute of Oriental Medicine	Universities	
KITECH**	Korea Institute of Industrial Technology	KAIST	Korea Advanced Institute of Science and Technology
ETRI**	Electronics and Telecommunication Research Institute	GIST	Gwangju Institute of Science and Technology
(NSR)*	National Security Research Institute	DGIST	Daegu Gyeongbuk Institute of Science and Technology
KICT**	Korea Institute of Civil Engineering and Building Technology	UNIST	Ulsan National Institute of Science and Technology
KRRI*	Korea Railroad Research Institute	UST	University of Science and Technology
KRISS**	Korea Research Institute of Standards and Science	Miscellaneous	
KFRI**	Korea Food Research Institute	(NNFC)	National NanoFab Center
(WIKIM**)	World Institute of Kimchi (under KFRI)	KANC	Korea Advanced Nano Fab Center
KIGAM**	Korea Institute of Geoscience and Mineral Resources	KISTEP	Korea Institute of S&T Evaluation and Planning
KARI**	Korea Aerospace Research Institute	COMPA	Commercialisation Promotion Agency for R&D Outcomes
KIER**	Korea Institute of Energy Research	(KIRD)	Korea Institute of Human Resources Development in Science and Technology
KERI**	Korea Electrotechnology Research Institute		
KRICT**	Korea Research Institute of Chemical Technology		
KIT*	Korea Institute of Toxicology		
KIMM	Korea Institute of Machinery and Materials		
KAERI*	Korea Atomic Energy Research Institute		
KIMS*	Korea Institute of Materials Science		
KFE**	Korea Institute of Fusion Energy		

* Formerly under the Korea Research Council of Fundamental Science.
** Formerly under the Korea Research Council for Industrial Science and Technology.
Source: National Research Council of Science & Technology (2022[47]), *Home page*, https://www.nst.re.kr/eng/index.do; individual institute websites.

MSIT currently has five scientific research institutes directly reporting to it. They make up a very small fraction of the PRIs in Korea and are, at this stage, also small compared to equivalent institutes internationally. This is consistent with the policy of focusing growth on more fundamental research in the university sector.

Three scientific institutes – namely KIAS, the IBS and the KBRI – network across the national and international research communities, aiming to strengthen basic research in Korea. They are consistent with an effort to increase the volume of basic research in Korea largely by expanding university research and networking across the universities and existing PRIs. The other two are specialist applied research centres (NIMS and KIRAMS).

The largest of the scientific research institutes is the IBS, which was established in 2011. IBS has 895 employees, of whom 56% are researchers, and the rest are administrators and technical staff. It is closely affiliated with the University of Science and Technology (UST), as manifested by the joint establishment of the IBS Campus, UST, which offers research-centred education by allowing students to participate in research. UST was also established in 2011 and provides a framework for co-operative research and higher education among leading Korean universities and research institutes. IBS specialises in comparatively long-term projects involving large groups of researchers and, in some cases, specialised scientific infrastructures, an aspect that may differentiate its research from that of the universities. It has so far built up 31 research centres, each normally set up for five years around a leading scientist, then extended for three years at a time subject to satisfactory evaluations. Its governance structure is designed partly to ensure that IBS is integrated into the global research system, and IBS emphasises the employment of researchers from abroad.

There are several other scientific research institutes that are important to mention. For example, KIAS was set up in 1996 on the model of the Institute of Advanced Study at Princeton University in the United States, working in maths, physics and computational science. It has about 150 researchers and aims to welcome visiting researchers from abroad to network with Koreans working in international research in the field. KBRI is also small and aims to act as a national hub for Korean brain research and encourage links with the international research community. NIMS (2005) works on mathematics for industry and medicine. Finally, KIRAMS dates from 1962/63, is attached to a hospital and does specialist research in medical radiology.

Institutes of science and technology

As Table 4.3 shows, there are five institutes of S&T – actually, universities, in the same sense that MIT is an "institute" of technology –that report to MSIT. They have legislative and governance bases different from national universities in the sphere of the Ministry of Education and more generous institutional funding for research.

Other MSIT institutes

Again, as Table 4.3 shows, MSIT additionally has two institutes dedicated to providing research infrastructure: an agency promoting the commercialisation of research results and a further institute working to develop human resources in S&T. The other institute shown – KISTEP – provides S&T policy formulation, co-ordination, evaluation and management of national R&D projects, as stipulated by the Framework Act on Science and Technology. The NRF and the Institute for Information and Communications Technology (IITP) act as funding agencies to MSIT.

Government research institutes

The GRI group shown in Table 4.3, which MSIT controls indirectly via the NST, comprises institutes formerly under the Korea Research Council of Fundamental Science and Technology and the Korea Research Council for Industrial Science and Technology. The set of GRIs is somewhat heterogeneous, mixing institutes that support sectors where the state is in control or a major player (atomic energy, fusion, railroads) with those dealing with more open industry structures where beneficiaries are more likely to be in the private sector. Those originating with the Korea Research Council for Industrial Science and Technology are most closely analogous to research technology organisations (RTOs).[14]

The GRI landscape is diverse and evolving

While there is an ongoing debate about the role of the GRIs, it is important to recognise that the GRIs have been and are evolving. The pattern of publications (in Scopus) Choung & Hwang suggests that while the comparatively small volume of basic research in Korea before 1990 was not very thematically focused, the growing effort from the 1980s by the PRIs and industry in response to thematically focused research programmes aimed at building industrial capacity and strength led to a focusing of the effort on the engineering-related needs of growing chaebol. By the early 2000s – when the relative share of government R&D investment started to shift from the PRIs towards the universities – the major companies had established their own basic and applied research capacity. Government-funded research across the GRIs and universities became more diversified, e.g. moving more strongly into the biological sciences. This can be seen as marking a transition from the thematically focused research pattern needed for catch-up towards the more comprehensive pattern of basic and applied research associated with a more mature economy (Choung and Hwang, 2013[48]).

The complexity of the GRI landscape can be appreciated in Figure 4.16, as presented according to scientific output, intellectual property revenue (IPR), and private-sector-financing share. Similar to the finding for universities, the quality and quantity of publications seem correlated to a certain extent, suggesting that institutes with larger scientific output also produce higher quality output.

Figure 4.16. Shares of research, intellectual property revenue and private sector financing of Korean government research institutes, 2022

Note: On the horizontal axis, the average number of publications per researcher is a measure of research productivity, while on the vertical axis, the percentage of publications among the "Excellent journal rate" measures the proportion of papers published in the top quartile according to the SCImago Journal Ranking, and is a measure of quality. The size of the symbol is proportionate to the number of staff, while the colour indicates the magnitude of IPR income as a percentage of total financing and the percentage of private financing.
Source: OECD analysis based on KIST data, 2022.

Several institutes show high productivity and high quality in scientific output, including the Korea Institute of Science and Technology (KIST), the oldest GRI, the Astronomy and Space Science Institute, the Bioscience and Biotechnology Institute, the Institute for Energy Research, the Korea Basic Science Institute, the Institute of Materials Science, the Korea Standards Research Institute, the Korea Research Institute of Chemical Technology, the Korea Institute of Geoscience and Mineral Resources, and the Korea

Institute of Oriental Medicine. Those institutes have a private sector co-financing share with less than 15% of the total and a relatively modest fraction of IPR (the highest being in the Institute of Energy with 4%, followed by the Institute of Chemical Technology at 3.4% and the Institute of Materials Science at 2.6%).

Another group of institutes has a high fraction of private sector financing (green symbols showing those with more than 9%including the National Security Research Institute, the Electrotechnology Institute and the Railroad Research Institute. It could be argued that they act as research and technology organisations. Some of these also have sizeable income from IP transfers.

The Electronics and Telecommunications Research Institute (ETRI) is a special case. Due to its extremely successful performance in raising project-based funding from the government, it does not use a large fraction of private sector funding. Rather, the project team has heard that ETRI often competes with the private sector. Nevertheless, ETRI is the absolute champion of IP transfer, as income from IP amounts to 7.8% of total financing.

The positioning of the Korea Aerospace Research Institute and the National Security Research Institute may not be directly comparable due to the confidential nature of their deliverables, which reduces the part of published results.

Several other GRIs are positioned "in-between", with modest scientific results and low engagement with the private sector. Further auditing could be useful to identify other potential reasons and bottlenecks contributing to these outcomes.

4.2.2. Higher education institutions

There were 426 HEIs in Korea in 2021, with 190 being recognised universities offering at least four-year undergraduate degrees and/or graduate education; 134 junior universities (with two-to-three-year degrees as opposed to the standard four years); 45 graduate schools; 10 universities of education (where teachers of elementary schools are educated); and 45 technical colleges and others, including cyber and corporate colleges, which are intra-firm universities established by companies to develop employee skills according to their needs (Ministry of Education, 2022[49]). This analysis focuses on the officially licensed and accredited universities, the vast majority of which are private (156) (Ministry of Education; Korean Educational Development Institute, 2019[50]).

National flagship universities

Article 3 of the Higher Education Act distinguishes two types of public universities: public universities, established and managed by the central government, and regional universities, established and managed by municipalities. Today, there are 23 public universities and only 1 regional university (the University of Seoul, which was established by the city of Seoul).

Article 10 of the Higher Education Act allows universities to establish a council to support the development of higher education. The "regional hub national university" – or "flagship university" – comprises nine public universities in different regions of Korea. These are typically the oldest and largest institutions of a region with good financing and comparatively low tuition fees. They are also often preferred by students compared to local private universities. Their historical mission has been to increase the educational quality in all Korean regions to reduce the educational gap between Seoul and the provinces and between private and public institutions. Nevertheless, today's role of national universities is more difficult to define, as stakeholders on university boards, including government and business representatives, vary in their perspectives on the institutions' goals, and their visions no longer necessarily include the specific needs of the provinces they are in (Kim and Yeom, 2017[51]).

In response to decreasing student enrolment, many public universities have now integrated into national flagship universities (Paik, 2020[52]). For example, in 2008, Sangjoo University in the North Gyeongsang province merged with Kyungpook University, now a flagship university.

Private universities

The introduction of private universities has significantly driven the expansion of higher education access in Korea (Chae and Hong, 2009[53]). Between the 1970s and the early 2000s, Korea saw the largest expansion of participation in higher education in the history of higher education (World Bank, 2002[54]), largely due to the massive rise in private institutions in the same period. While private universities are established and managed by a corporation or private person separated by the state, their establishment is approved by the Minister of Education in accordance with the establishment standards set forth in Article 10 of the Higher Education Act. Most universities in Korea are private universities that largely rely on students' tuition fees since government subsidies are relatively low. They are less regulated, e.g. in terms of enrolment caps, tuition fees or limitations in the availability of double majors, than public universities or universities established by not-for-profit educational corporations. The government retains higher control of management and operations, which are overseen by the Ministry of Education, as originally stipulated in the Private School Act of 1963 (Chae and Hong, 2009[53]). Private universities need, however, to also be certified and accredited by the Ministry of Education based on its curriculum, facilities and faculty composition requirements, among others. The accreditation process is undertaken by designated institutes, such as the Korea University Accreditation Institute (Korean Council for University Education, 2022[55]). Private universities are also concerned with the rapid decline in the number of students accompanied by severe financing challenges, risking mass closures of private HEIs. According to the Korean Educational Development Institute, the net loss of private universities was KRW 268 billion in 2018, a dramatic increase from KRW 14 billion in 2016 (Ko, 2021[56]).

Clustering

Classifying and hierarchising HEIs is a challenging task since it varies widely according to the variables used. In this attempt, an approach has been adopted to classify HEIs based on their research performance. Therefore, this should not be seen as a ranking of overall performance, as teaching aspects are not taken into account here. Clustering models have been applied to categorise Korean universities into different clusters. [15]

Four variables were introduced to conduct the analysis: 1) percentage of publications among the top 10% cited journals; 2) publications per faculty member; 3) research expenditure per faculty member; and 4) ratio of graduates to total students. For each variable, a score was computed according to the formula:

Score_i = (value_i – average) / standard deviation[16]

This makes it possible to combine the different variables in the computation.

Data provided by the NRF (2021[57]) and the Carnegie Classification of Institutions of Higher Education (2021[58]) were used. A total of 45 Korean and 104 US universities were taken into account. Table 4.4 presents the results of the cluster analysis.

Table 4.4. Korean university cluster analysis

Cluster	Korea					United States				
	Percentage of publications in top 10% cited journals	Publication/ faculty	Expenditure/ faculty (USD thousands)	Top-cited publications per faculty	Graduate ratio (%)	Percentage of publications in top 10% cited journals	Publication/ faculty	Expenditure/faculty (USD thousands)	Top-cited publications per faculty	Graduate ratio (%)
1	9.5	8.7	323	0.8	62.6	21.9	17.1	2 259	3.7	80.4
2	7.1	5.2	170	0.4	21.8	16.3	5.4	466	0.9	52.7
3	6.3	2.9	79	0.2	8.8	10.0	2.8	207	0.3	32.9
4	4.4	1.6	44	0.1	5.9	11.2	2.3	190	0.3	63.6

Note: "Top-cited" refers to the PP (top10%) of the CWTS Leiden Ranking, that is, the proportion of a university's publications that, compared with other publications in the same field and the same year, belong to the top 10% most frequently cited (CWTS Leiden Ranking, 2022[59]). "Publication/faculty" and "Expenditure/faculty" refer to the average number of articles published per faculty and the average research expenditure received per faculty, respectively. The "Top-cited" and "Publication/faculty" are multiplied to calculate "Top-cited publication per faculty", which is the average number of the top-cited articles published per faculty. For example, a faculty member from a Korean university in Cluster 1 published 0.8 articles classified as top-cited. Finally, "Graduate ratio" shows the share of graduate students as a percentage of registered students.
Source: OECD calculations based on NRF (2021[57]), *Analysis Report on University Research Performance*, https://www.nrf.re.kr/cms/board/library/view?menu_no=419&o_menu_no=&page=1&nts_no=168743&nts_cat=REPORT_L_02&search_type=NTS_TITLE&search_keyword=&nts_cat=REPORT_L_02 and The Carnegie Classification of Institutions of Higher Education (2021[58]), *Carnegie Classifications*, https://carnegieclassifications.acenet.edu/.

On average, universities in the first cluster are 1.3 standard deviations above the mean in terms of publication per faculty; they can thus be classified as "research-active" universities. Not surprisingly, the most prestigious universities – both in terms of reputation and research performance – are present. For Korea, IST universities, known for the generous amount of subsidies and grants that are given to them each year, are ranked in the first cluster, followed by the most prestigious private and flagship universities in the second cluster. The only non-IST universities classified as research-active are POSTECH and SNU. This sharply contrasts with the case of the United States, where the four research-active universities – Harvard University, California Institute of Technology, Medical University of South Carolina and Rockefeller University – are all private universities. With the exception of Harvard University, these universities are STEM-oriented, with the majority or the totality of students attending graduate-level programmes.

In Korea, the second cluster includes Sungkyunkwan University, Yonsei University, Korea University and Hanyang University. These four private universities are well known for their competitive application process and are located in Seoul. Similarly, the most prestigious universities in the United States – including the "Ivy League schools", such as Yale University or Princeton University – belong to the second cluster. For both countries, the third cluster is the largest of the four clusters. For Korea, this is also where most of the flagship universities are located. Lastly, Korea's fourth and last cluster is mostly composed of private universities in provinces. It is important to note that the last cluster in the United States includes some of the country's top-ranked universities, such as Georgetown University.

Overall, research-active universities in Korea are showing lower performance in research than US institutes. For instance, US universities in Cluster 1 are twice as productive (as measured by publication per faculty member) and 2.5 times more likely to publish an article among the top 10% cited than Korean universities of the same cluster. In Clusters 2, 3 and 4, researcher productivity is comparable between Korea and the United States, while a significant gap persists in the percentage of top-cited papers. Overall, the analysis of clusters indicates that Korean universities, even those classified as the most research-oriented, show lagging results in terms of research quality and quantity.

There are even more striking differences in research funding per faculty member. For example, US universities in Cluster 1 received around USD 2.26 million per faculty for research expenditure, whereas Korean universities received USD 0.32 million (or USD 0.43 million measured at purchasing power parity

[PPP]), which is around seven times less (or five times less at PPP). In subsequent clusters, the gap is less significant, but funding per researcher remains 3-4 times higher in the United States (2-3 times at PPP). Another apparent difference is in the ratio of graduate students. For every cluster, the average ratio of graduate students is higher in the US institutes.

Nevertheless, it is important to highlight that Korean universities seem to utilise their research funding more efficiently. For Korean research-active universities, every USD 50 000 generate a publication, whereas the number surges to USD 132 000 for the United States. When only top-cited articles are taken into account, the Korean research-active universities produce one of these high-quality publications for every USD 540 000, while top US universities need USD 610 000. The efficiency of Korean research activities is expanded further in the funding section below.

4.3. Missions of government research institutes and higher education institutions

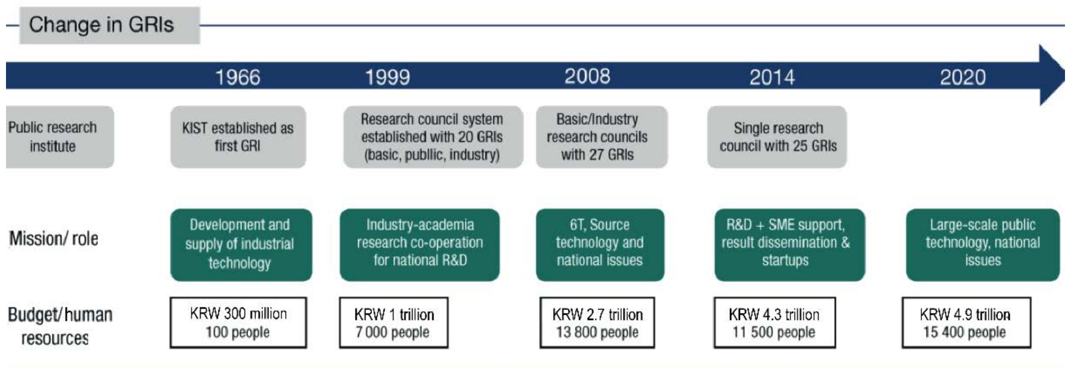
4.3.1. Government research institutes

The mission of the GRIs has changed considerably since the first institute, KIST, was founded in 1966 (Figure 4.17). Originally created to produce and provide the technology needed for Korea's industrial development and catch-up, they accounted for the bulk of the country's total R&D expenditure in the early phases of the establishment of a Korean innovation system, or 84% in 1970 (OECD, 2009[60]). In this period, the GRIs differentiated themselves according to the technology needs of respectively prioritised industries, such as shipbuilding, geoscience, electronics, telecommunications, energy, machinery and chemicals. In their heyday in the 1970s, in addition to supplying strategic industries with relevant technology, the GRIs served an important capacity-building function for industry, training a critical mass of researchers who eventually moved to corporate research centres (OECD, 2009[60]). A more detailed discussion of the GRIs' mission is found in the governance section below.

In 1999, the Act on the Establishment, Operation and Fostering of Government-funded Science and Technology Research Institutes, etc. created three research councils – basic, industrial and public – to oversee the GRIs, with each research council answering to a different ministry (Lee et al., 2012). As major industry's need for the GRIs declined, on the one hand, and as the government expanded the education and research functions of the higher education system, dependence on the GRIs declined further. After Lee Myung-Bak became president in 2008, he restructured the public council into the other two and placed the basic research council under the Ministry of Education and Science and Technology (MEST) and the industrial council under the Ministry of Knowledge Economy (MKE) (Lee, 2011[61]). In 2014, the basic and industrial research councils were consolidated into the single National Research Council of Science and Technology (NST) under the Ministry of Science, ICT and Future Planning, which became the MSIT in 2018.

Figure 4.17 shows how the mission of the GRIs has evolved in line with the pattern of development. KIST and its spin-offs aimed to secure the technologies needed to develop industry. By the turn of the millennium, industrial capabilities were sufficient for the GRIs to collaborate with industry on R&D rather than importing, adapting and developing technology. The focus moved towards specific national technology needs in the 1990s, and the GRIs' target group was extended from large companies to include SMEs.

Figure 4.17. Evolution of the mission of Korea's government research institutes



Source: STEPI (2021[62]), *Background Paper - OECD Reviews of Innovation Policy: Korea 2021*.

While recognising that the GRIs have evolved and become more diversified since the 1980s, there is still room for improvement in defining the current role of government-funded research institutes in the national innovation system. They appear to be expected to close knowledge gaps in socially and industrially important areas that private industry is unwilling or unable to pursue. With the growing importance of universities and industry to the national innovation system and Korea's transition process from catch-up to an innovation leader, the role of GRIs has further room for improvement. The government has subjected GRIs to a "roles and responsibilities" (R&R) exercise through which they define their own R&Rs. It does not intend clear distinction across GRIs, but some have a stronger basic science focus (e.g. KASI), and others behave more similar to RTOs (e.g. KITECH).

Nevertheless, there is no clear distinction, and it remains to determine if GRIs' R&Rs are sufficiently aligned with the national strategy and innovation system. The official role of GRIs is to carry out public-purpose R&D based on national missions in accordance with domestic laws and their articles of association.

Table 4.5. Major research projects based on Korea's government research institutes' roles and responsibilities

Major research projects	Major GRIs responsible
Public safety and life	KRIBB, KIST, KIMS, KOTI
DNA (Data network AI)	KIST, ETRI, KISTI, KARI
Science infrastructure and service	KIST, ETRI, GTC, KAERI, KFE, KRIBB
Sustainable society	KRICT, ETRI, KERI, KIER
Big science and society-based science	KASI, KICT, KAERI, ETRI, KIGAM
Regional development technology	KITECH, KICT, KIMM, ETRI
North-South science technology	KRIBB, KISTI, KICT, KRRI
Core future industry technology	KIST, ETRI, KIOM, KISTI

Source: Yu (2020[63]), *R&R-based research on project efficiency and linkage: Focusing on materials, parts, and equipment*, https://www.kistep.re.kr/reportDetail.es?mid=a10305040000&rpt_no=RES0220200208.

Under the administration of former President Moon, GRIs re-established their R&R per their research expertise and societal needs. Eight major research projects were defined (Table 4.5), and the funding was distributed accordingly (Yu, 2020[63]). Table 4.5 shows the major GRIs responsible for each research project. The five most funded GRIs are often the major research institutes of multiple research projects. Project team interviews suggest that perhaps half the GRIs have completed this exercise. ETRI has used it to pivot its field of activity from electronics, widely defined, to a strong focus on AI, with the intention of being the main pole enabling Korea to catch up and build capacity in AI technologies (against a background of massive investments by the United States, China, Germany and elsewhere). Table 4.6 sets out the current missions by government research institutes.

Table 4.6. Korea's government research institutes' current missions

Institute	Mission
Korea Institute of Science and Technology (KIST)	Solving national and social challenges and securing growth engines through leading and innovative research Focusing on various challenges, including population ageing, the Fourth Industrial Revolution and sustainable society by developing technologies for climate, disaster and safety
Green Technology Center	Promoting the advancement of the national climate industry and contributing to global efforts in responding to climate change
Korea Basic Science Institute (KBSI)	Conducting R&D on research facilities and equipment and analytical S&T, and joint research and support for promoting basic science
Korea Astronomy and Space Science Institute (KASI)	Developing and operating research facilities as well as public outreach for astronomy and space science/technologies related to space situational awareness Promoting collaborative R&D projects with public and private sectors
Korea Research Institute of Bioscience and Biotechnology (KRIBB)	Carrying out R&D activities and related projects in the field of bioscience and biotechnology in joint efforts with other research institutes, academia and industries to disseminate the results of scientific research and technological development in Korea and abroad Supporting the establishment of public infrastructure, government-funded think tanks, nurturing talented human resources, supporting commercialisation of SMEs
Korea Institute of Science and Technology Information (KISTI)	Taking the lead in resolving national and societal issues and innovating Korea's R&D through supercomputing and AI Securing global leadership in supercomputing and promoting an AI-driven infrastructure to address societal challenges
Korea Institute of Oriental Medicine (KIOM)	Professional and systematic R&D activities on Korean medicine theories, technologies and services and disseminating their outcomes, thereby contributing to the development of relevant industries and the improvement of public health
Korea Institute of Industrial Technology (KITECH)	Supporting the industry sector, especially SMEs, as an application-oriented research institute Focusing on three key research areas: advanced manufacturing technology, industrial technology convergence, and sustainable manufacturing system technology Strengthening field-oriented support for SMEs, running three research centres and seven regional divisions
Electronics and Telecommunications Research Institute (ETRI)	Contributing to the nation's economic and social development through R&D and distribution of industrial core technologies in the field of information, communications, electronics, broadcasting and convergence technologies Preparing for future growth by vitalising creative and challenging research
National Security Research Institute (NSRI)	Pan-national dimensional development of information security technology, including technology corresponding to national cyber security
Korea Institute of Civil Engineering and Building Technology (KICT)	Developing technology for national infrastructure facilities to address natural disasters and for eco-friendly land development R&D co-operation with governments, the private sector, multinational corporations and non-governmental organisations, as well as the implementation of government or private-sector-commissioned technology services Technology transfer related to land and construction, adaptation, commercialisation co-operation, and support for SMEs Nurturing high-skilled human resources in primary areas, the establishment of technological policies, standards and criteria for land and construction, implementation support for major national projects
Korea Railroad Research Institute (KRRI)	R&D on various railroad systems (high-speed, urban, nationwide and international), next-generation public transportation systems, railroad safety, standardisation, railroad policy and logistics technology Co-operation, support, and technology commercialisation with SMEs and other business groups in the industry Expanding public interactive research and strengthening co-operation among railway operation and construction organisations Establishing researcher-focused R&D innovative ecosystems with autonomy and responsibility
Korea Research Institute of Standards and Science (KRISS)	Establishing, maintaining and improving national measurement standards Conducting R&D in measurement S&T

Institute	Mission
	Disseminating measurement standards and technology and providing support services
Korea Food Research Institute (KFRI)	Researching longevity science, functional foods, safe distribution and food processing technology Disseminating research outcomes, providing technological support and doing research on the reinforcement of public functions for the development of industries such as food, agriculture, forestry and fisheries and for improvement in quality of life
World Institute of Kimchi (WIKIM)	Performing R&D related to kimchi to lead national technological innovation, nature and develop the kimchi industry to boost national growth
Korea Institute of Geoscience and Mineral Resources (KIGAM)	Geo-research on land and ocean, geo-exploration on deep subsurface resources and utilisation, development of new geo-technology on geo-hazards and global climate change
Korea Institute of Machinery and Materials (KIMM)	Researching humanity, the future of mechanical technology with partners from the public and private sector
Korea Aerospace Research Institute (KARI)	Contributing to the solid development of the national economy and enhancement of national life through exploration and technological advancements, development and dissemination in the field of aerospace S&T
Korea Institute of Energy Research (KIER)	Contributing to the creation of national growth engines and the development of the national economy through R&D and disseminating achievements in the energy technology area
Korea Electrotechnology Research Institute (KERI)	Conducting R&D on power technologies and power systems of renewable energy / electrical apparatus / electrical parts and materials/convergence technology based on electro-medical devices and electrical technology R&D co-operation with the government, private sector and organisations and consignment of technical services Providing support and technology commercialisation for SMEs Supporting human resources and establishing technical policies in key mission areas
Korea Research Institute of Chemical Technology (KRICT)	Reinforcing the competitiveness of chemical industries and contributing to the resolution of national and social problems by performing R&D in chemical and convergence technologies and providing public infrastructure and services
Korea Institute of Toxicology (KIT)	Contribution to public health and welfare enhancement and to the development of national industries by safety assessments of chemical and biological materials
Korea Atomic Energy Research Institute (KAERI)	Building a safe society centred on people and the environment through reliable, innovative nuclear technology Contributing to academic advancement, energy acquisition, and utilisation of nuclear energy through active R&D in related fields
Korea Institute of Materials Science (KIMS)	Comprehensive range of activities related to materials technology, including R&D, inspections, testing and evaluation, and technical support Striving for leadership in advanced material technology in Industry 4.0 and localisation of materials in response to Japanese export restrictions Mapping the scattered research capabilities in the domestic materials science field and playing a pivotal role in co-operation of industry, academia and research institutes
Korea Institute of Fusion Energy (KFE)	Promoting new research, technology support, development, demonstration and dissemination in the field of fusion energy Training nuclear fusion personnel in co-operation with industry and commercialisation of technology

Source: Individual institute websites, accessed in 2022.

In relation to the GRIs, since about 2000 – when the introduction (2003/04) of technology transfer offices (TTOs) in GRIs and universities induced a focus on patenting in GRI incentive systems, and the shift in policy towards funding research in universities put more attention on publication in the indexed scientific literature – studies of technology transfer and acquisition and the performance indicators used in evaluating projects and research-performing organisations in Korea overly relied on IP and publication indicators. These provide an incomplete picture of technology transfer and capacity building. Furthermore, the ability of patent- and publication-based performance indicators to induce perverse behaviour is well known. The temptation for analysts to use these indicators is understandable, as they appear to offer homogenous and quantifiable ways to understand performance, even though both have different meanings in different fields. The propensity to publish or patent varies among disciplines and technologies and can change over time. There are many other modes of knowledge exchange through which technological knowledge can be developed and exchanged, including education and training, personnel mobility, joint research, reverse engineering, provision of consulting or advisory services, testing and certification, among others.

Historically, based on surveying 500 manufacturing firms benefiting from technology transfer from GRIs and universities in 2004-06, Eum and Lee (2009[32]) sharply criticised the previously strong focus of GRI performance indicators on formal patents. They analysed five types of knowledge transfer: informal activities; education; R&D co-operation and technical support; patents and licensing; and business activity. Of these, business activities have little effect on company innovation. All four other modes of knowledge transfer from universities facilitate product innovation, while only IP-based transfer from PRIs strongly influences product innovation. However, Eum and Lee point out that informal activities, education, R&D co-operation and technical support from GRIs all facilitate process innovation.

ETRI provides a well-documented and useful description of contributions from university-industry collaboration to industrial innovation (Paik, Park and Kim, 2009[64]). It was central in bringing electronics technologies prioritised by the government to Korea and transferring them to the companies that went on to establish themselves among the world leaders in electronics markets. At this stage, ETRI was also heavily engaged in training various levels of the industrial workforce in the new technologies. As company capabilities rose, ETRI's role refocused towards smaller, supporting projects and new, smaller companies. ETRI was also an important source of experienced researchers for universities, industry and government (Table 4.7) (Paik, Park and Kim, 2009[64]).

Table 4.7. The changing management system at ETRI and the institute's industrial contributions

	First generation (1985-91)	Second generation (1992-97)	Third generation (1998-2000)
Mission and objectives	Technology development of large-scale national R&D through internal development and absorptions of internationally transferred technology	Development of an efficient and effective R&D management system	Value creation through cost minimisation and royalty maximisation
Scale and selection of R&D projects	Limited number of large-scale R&D projects suggested by government	Multiple and small-scale projects related to previous large R&D projects	Competitive selection of numerous projects with high marketability
Criteria of R&D performance evaluation	Technical success	The number of: - Papers - Patents - Technology licences	The number of: - Papers - Patents - Technology licences
Key technological achievements	TDX TiCOM DRAM	CDMA	Next-generation Internet

Note: TDX (time division exchange) is equipment for fixed-line telecommunication service. DRAM (dynamic random access memory) is one kind of semiconductor. TiCOM is the name of a medium-sized supercomputer for governmental administration. CDMA (code division multiple access) is a mobile telecommunication system.
Source: Paik, Park and Kim (2009[64]), *Knowledge transfer of government research institute: The case of ETRI in Korea*, https://doi.org/10.1504/IJTM.2009.024436.

Since then, in 2010, ETRI set up ETRI Holdings, an accelerator that identifies and matches start-ups with ETRI technologies. It also provides incubation and management services to the companies it invests capital and technologies in. Together with ETRI Holdings and its internal technology licensing office, it seeks to support start-ups with ETRI technologies to prepare them for their initial public offering (IPO) or mergers and acquisitions (M&A). Successful investments include firms such as Optella Inc., Syntekabio, Sugentech, Genesystem and Minds Lab (Business Wire, 2021[65]). Box 4.2 sets out ETRI's vision to become a leading institute in AI research and development.

Box 4.2. ETRI's vision to become a national AI research institute

Korea's ETRI is an example of a GRI that has successfully kept pace with industrial development and is preparing to become a leader in emerging technologies, particularly AI. Its strategic objective is to work toward a super-intelligent information society by developing key technologies in AI, robotics, autonomous vehicles and supercomputing.

It adopted a hybrid R&D strategy by combining research in core technologies and mission-driven research to support businesses and find solutions for societal challenges. Through open R&D strategies, including co-operation with the private sector and academia, more than 450 master's and PhD students work to develop technological innovation in AI and ICT. For instance, its Supercomputing Technology Research Centre seeks to leap forward significantly in high-performance computing with its Supreme-K project, which the MSIT funds. Furthermore, ETRI works with KISTI, 13 universities and 3 private companies for this purpose.

ETRI conducts approximately 600 projects a year, of which 30% are conducted jointly with the private sector. The institute is active in technology development, technology transfer (about 300 cases per year) and commercialisation and targets SMEs in particular. Furthermore, besides its domestic branches in Seoul, Daegu and Gwangju, it has international offices in the United States and China. Its budget primarily depends on project-based funding (85%), while a relatively low share comes from private funding. Of its 1 900 staff, around 400 are AI specialists. The remaining 1 500 staff receive training so as to render AI a basic skill and thereby make ETRI an AI powerhouse.

Source: Stakeholder interviews, 2021; ETRI (2022[66]), *Home page*, https://www.etri.re.kr/eng/main/main.etri.

4.3.2. Higher education institutions

In the early phases of industrialisation and catch-up, there was a clear division of labour between GRIs, which performed the bulk of research, and universities, whose primary task was education (Shin and Lee, 2015[67]); for an historical overview of Korean HEIs, see also (OECD, 2009[60])). During the 1960s to mid-1970s, there was a period of strong regulation limiting the number of students, with a focus of universities on teaching and a strong priority given to vocational education. Throughout the late 1970s and 1980s, regulation was relaxed and massive expansion occurred, notably through the emergence of new private universities. In the 1990s, the "first Korean academic revolution occurred, and research became a very important mission for universities, based on the 1989 'Basic Science Advancement Law'" (Kwon, 2015[68]).

In the late 1990s, the government began allocating investments into university research at a significant scale, with the Brain Korea Project launched in 1999 as a key pillar (OECD, 2009[60]). Thus, the modern Korean research and higher education system differs from many European countries and the United States in that initially, GRIs were the main research performers; the research university, as a concept, is a relatively recent phenomenon in Korea.

The rapid increase in the growth of HEIs in Korea can be partially attributed to changes introduced under the Kim Young-sam administration in 1996, which reduced the requirements for establishing universities (STEPI, 2021[62]). However, the emergence of a high number of HEIs and, therefore, departments dedicated to similar fields of research have consequentially created concerns about the efficiency of resource spending. This led the government to focus on a select number of research-based universities to streamline resources. Eventually, specialised IST universities were created under the MSIT, which allows them more leeway to be creative and flexible, e.g. in student admission, for instance, regarding creativity and other criteria that are not as much the case for universities under the Ministry of Education.

Korea faces a steep decline in the number of students due to decreasing birth rates, which dropped from 6.1 births per woman in 1960 to 1.57 in 1990 and 0.92 in 2019 (World Bank, 2022[69]). Korea currently has one of the lowest birth rates in the world and is the only OECD country with a birth rate below 1.0. As a result, the number of admitted students to Korean HEIs, which was 678 000 in 2000, is projected to fall to 373 000 in 2024, a decline of 45% over 20 years (Ministry of Education, 2021). Given that Korea has one of the highest levels of enrolment in higher education as a percentage of the school-age population, there is little room to increase the number of students given the shrinking school-age cohort.

Korean HEIs have been unevenly hit by the decline in the number of students, with local and regional universities and colleges hit harder than HEIs in metropolitan areas (Ministry of Education, 2021[70]). As a result, a growing number of HEIs is currently dealing with excess capacity (admitting fewer students than budgeted for), leading to serious financial problems, particularly for lower-tier institutions where tuition fees account for more than half of their total revenue (Chung, 2021[71]).

When it comes to industry-academia links, often referred to as the "third mission", a legal framework has existed since the 1963 University-Industry Co-operation Act, but the real impetus was given through its revision in 2003, whereby universities were allowed to create for-profit companies based on academics' inventions. In parallel, a Korean equivalent to the US Bayh-Dole Act, the Promotion of Technology Transfer Act, was enacted in 2000. Those initiatives led PRIs and 46 public universities to create technology licensing offices. In addition, major national R&D projects were dedicated to university-industry co-operation, including the second phase of Brain Korea, New University for regional innovation and other funds. Under these initiatives, patent filings by universities have increased 15-fold, technology transfer agreements 12-fold and royalty income 24-fold between 2003 and 2013, albeit starting from a low base (Kwon, 2015[68]).

Despite these developments, project team interviews with the private sector and university staff indicate that large firms often prefer to use their own capacities for R&D, as university research is often not considered to adequately address industry needs. Nevertheless, linkages are strong for the top-ranked research universities. For instance, a significant share of Samsung Electronics researchers graduated from KAIST, and a significant portion of their research funding comes from industry, as discussed in the following section. Similarly, Seoul National University and other universities work on problem-solving solutions with SMEs and, in the case of SNU, together with Samsung, train human resources in AI.

4.4. Funding of government research institutes and higher education institutions

4.4.1. Government research institutes

Both the financing of GRIs as well as total government expenditure on R&D (GOVERD)[1] have been increasing significantly in the last decades. However, a recent trend shows that the financing of GRIs has stagnated at about 0.15-0.16% of GDP. Furthermore, the share of GRIs in GOVERD has also decreased; while 42% of the GOVERD was directed towards GRIs in 2006, indicating that GRIs were the major recipient of the government's R&D investment, in 2020, this share shrunk to 33% in 2020 (KISTEP, 2020[72]). This contrasts with higher education expenditure on R&D (HERD), which continuously rose to 0.43% of GDP in 2020.

Funding sources for GRIs can be divided into three categories: government block funding from the central government and the municipalities; project-based funding (otherwise known as "project-based system", PBS) from public clients; and private funding. For the entire period, most of the funding came from public sources. In 2021, more than 83% of the total funding originated from the government, of which most came from government block grants. The amount of funding received from the private sector remains low, albeit gradually increasing. This indicates a rise in the number of collaborative projects between GRIs and the business sector, to be explained in detail in the following sections.

Table 4.8 shows the five most funded GRIs in 2021. The five institutes alone received almost half (47%) of the total GRI funding. ETRI is in the lead with USD 521 million. Interestingly, the share of government block funding is relatively low. The major source of funding for ETRI is PBS.

Table 4.8. Split of funding for Korea's top-five most funded government research institutes

In KRW billions

GRI	Total	Government contribution (%)	PBS (%)	Private contribution (%)
Total (25 GRIs)	5 508	4 583 (83%)	3 067 (56%)	533 (10%)
Electronics and Telecommunications Research Institute (ETRI)	674	563 (84%)	489 (73%)	23 (3%)
Korea Atomic Energy Research Institute (KAERI)	615	351 (57%)	444 (72%)	241 (39%)
Korea Aerospace Research Institute (KARI)	503	478 (95%)	382 (76%)	16 (3%)
Korea Institute of Science and Technology (KIST)	405	358 (88%)	195 (48%)	27 (7%)
Korea Institute of Industrial Technology (KITECH)	400	345 (86%)	256 (64%)	29 (7%)

Source: (Ministry of Science and ICT, 2022[73]).

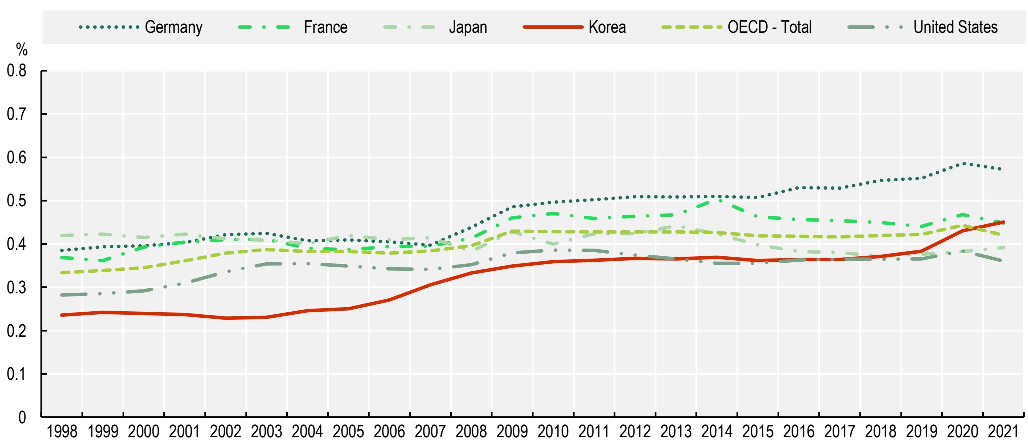
In 1996, the funding mechanism for the GRIs was reformed. The reform introduced a competitive element into GRI funding. However, it also meant that the continuity of research was no longer assured. It also changed the incentives of the GRIs, encouraging them to focus on maximising not only their income from projects but also the number of projects rather than the overall goal of development. Amid concern about duplication of R&D and worries about the efficiency of the GRIs, the autonomous, Battelle-derived model was abandoned and replaced with the PBS, in which institutional GRI research funding was awarded for the performance of specific projects negotiated between the GRI and the government. At the same time, other competitive project funding was also available from the government. This reform reduced the autonomy of the GRIs in the sense of restricting the freedom to develop long-term priorities for the purpose of competitiveness and to serve societal needs as the competitive project-based system incentivised short-term focus. The reliance on funding earmarked for projects with short-term horizons means less ability to independently shape a long-term research orientation based on basic science objectives with a long time horizon.

4.4.2. Higher education institutions

The increase in funding for universities in Korea has been one of the largest among OECD countries. However, its share is lower than that of other leading innovators in the OECD, such as Germany and Japan (Figure 4.18).

Figure 4.18. Higher education expenditure on R&D in Korea and selected countries, 1998-2021

As a percentage of GDP



Note: OECD data are estimated. Difference in methodology for the United States.
Source: OECD (2022[74]), *Main Science and Technology Indicators* (database), oe.cd/msti, May 2022.

Since 2009, the government has funded around 80% of R&D expenditure in universities, having increased from less than 50% in 1997 (OECD, 2022[75]). In 2021, ministries funded 74,745 projects with an average value of around 350 million KRW, which would be equivalent to about EUR 250,000 each (Ministry of Science and ICT and KISTEP, 2022[76]). Nevertheless, the value in terms of serving strategic priorities or promoting excellence in and impact of universities seems uncertain. . Table 4.9 shows the funding allocations to programmes and projects for selected ministries.

In 2020, research funding allocated to HEIs represented 0.43% of GDP in Korea (OECD, 2022[74]), in line with the OECD average of 0.44%, lagging countries such as Austria, Canada, Denmark, Finland, Norway and Sweden who spent more than 0.70% of GDP on HERD, but higher than the United States at 0.39%. Three-quarters of this funding originated from the central government. Another quarter came from domestic private funding. Compared to benchmarking countries within the OECD, the share of central government in the funding is over-represented. For instance, in the United States, USD 86 billion worth of research funding was allocated to HERD expenditure, where 53% originated from the federal government (National Science Foundation, 2021[77]). In France, on the other hand, USD 21 billion was spent on HERD, and 60% originated from the central government (Minister of Higher Education, 2021[78]). Table 4.10 shows the overall split of research funding and the average funding per researcher by different types of universities in Korea.

Table 4.9. Korea's university funding by ministry, 2020-21

	2020			2021		
	No. of programmes	No. of projects	Expenditure (KRW hundred millions)	No. of programmes	No. of projects	Expenditure (KRW hundred millions)
Ministry of Science and ICT	283	22 370	77 137	303	25 041	83 472
Ministry of Education	23	18 900	21 646	24	15 957	23 068
Ministry of Land, Infrastructure and Transport	49	577	5 030	71	731	5 979

Ministry of Trade, Industry and Energy	185	5 413	40 113	198	5 815	46 451
Ministry of Agriculture, Food and Rural Affairs	31	1 668	2 076	26	1 616	2 281
Rural Development Administration	57	4 600	6 869	58	4 525	7 705
Ministry of Health and Welfare	69	2 448	6 433	62	2 355	5 768
Ministry of SMEs and Startups	37	10 212	14 046	40	10 380	16 650
Defense Acquisition Program Administration	8	583	37 715	9	521	38 497

Source: (Ministry of Science and ICT and KISTEP, 2022[76]).

Table 4.10. Korea's higher education institution R&D expenditure and researchers by university type, 2021

Type	Percentage	Expenditure (USD millions)	Researcher	Expenditure per researcher (USD thousands)
IST	9.0%	499	1 465	341
Private	59.5%	3 284	54 338	60
Public	7.2%	399	7 262	55
Flagship	24.3%	1 343	11 748	114
Total	100.0%	5 525	74 813	115

Note: IST universities include DGIST, GIST, KAIST and UNIST. Expenditure refers to project-based expenditure (PBS).
Source: OECD analysis based on NRF statistics, August 2022.

In absolute terms, private universities are the biggest recipient of research expenditure, with USD 3.3 billion, accounting for almost 60% of the total research spending. A quarter of the research expenditure is directed towards flagship universities, followed by IST universities and public universities.

Expenditure per researcher – total expenditure divided by the number of researchers in the institution – is an important indicator to distinguish universities focused on research activities. This indicator is highly correlated with the university's ratio of graduate students and its ratio of STEM-related courses, with the correlation value of 0.95 and 0.7, respectively.[17] In other words, a university with relatively more graduate students and relatively more STEM-related courses is associated with higher expenditure per researcher than other universities.

In expenditure per researcher, the IST universities are the biggest recipients. This is because the IST universities were conceived as research universities at the outset and focused on STEM disciplines, requiring higher financing levels. As a result, a researcher in IST universities receives around USD 390 000, which is six times higher than the private university average. However, this does not make private universities less important in funding distribution. For instance, the top-ten private universities see 70% more expenditure per researcher than the top-ten flagship universities. This highlights the importance of private universities in Korea's R&D, particularly from the PBS.

Impact of funding on research output

Efforts are made worldwide to apply scientometric models to confirm the correlation between research funding and scientific excellence. One example is the CWTS Leiden Ranking, provided by Leiden University in the Netherlands. Along with different indicators, CWTS provides “PP(top10%)”, which is the proportion of a university’s publications that, compared with other publications in the same field and the same year, belongs to the top 10% most frequently cited.

Using the above-mentioned indicator, along with additional data on publication, regression models were built to establish a correlation between funding and scientific excellence. To find whether funding has more impact on the quantity or quality of research, three regressions were conducted with three different dependent variables: 1) PP(top10%); 2) publications per researcher; and 3) the ratio of top 10% cited per researcher. The last variable was obtained by multiplying the PP(top10%) score by the average number of publications per researcher for each institution ().

It is possible to observe an established correlation between publications per researcher and funding with an R^2 of 0.83. When it comes to the relationship between funding and the quality of research, the correlation is visible but to a lesser extent with respect to quantity. Both PP(top 10%) and the ratio of top 10% cited per researcher showed a positive correlation with expenditure per researcher. Nonetheless, Figure 4.19 shows correlation and not causation, and additional variables, such as specialisation in particular fields which differ in cost intensity, should be considered when identifying the drivers of research quality.

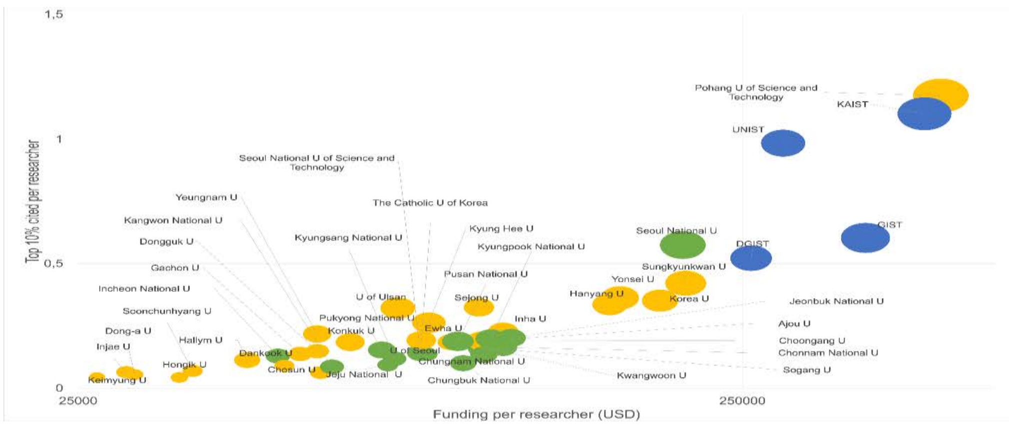
On closer view of the results, universities are in the lead with the highest funding per researcher, and their publications have the highest percentage of being classified among the top 10% cited. They also tend to excel in research quantity and have the highest average number of publications per faculty. This is not a surprising result, as IST universities have been dedicated to scientific research since their foundation, and their research activities focus entirely on STEM fields. The only non-IST universities with comparable achievements are SNU and POSTECH, with the latter being a private university. These universities belong to the “research-active” cluster, as defined by the classification previously discussed in the Clustering section.

On the other hand, flagship universities other than SNU show lower performance in research excellence, suggesting that funding directed towards flagship universities is less efficient in increasing research quality. One should also note that while private universities are mostly above the fitted line, the flagship universities are all below the fit – suggesting that those universities seem to be somewhat less effective in achieving quality output at equivalent levels of funding. One potential factor in explaining this is that the flagship universities are often located outside Seoul, which makes them less attractive to students, researchers and professors.

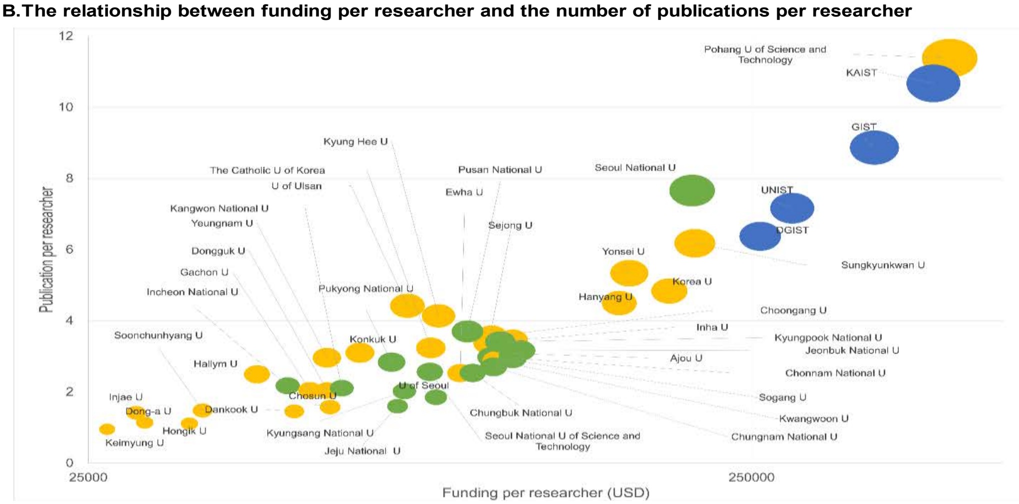
Finally, it should be noted that UNIST is an outlier, with outstanding results significantly better than even its high level of financing would warrant. This is probably due to specific internal rules that encourage top-quality publications. It became apparent from stakeholder interviews that from the outset of its establishment in 2007, UNIST has made research quality, as measured by the number of publications in the top 5%-cited journals, a criterion for the evaluation of professors, while standard practice in Korea had been to focus on the number of publications. Furthermore, great importance was placed on internationalisation, and as such, whether and the extent to which professors spoke at international events mattered for tenure at UNIST. In addition, around 11% of professors are of foreign nationality. UNIST receives around KRW 80 billion in annual block funding from the MSIT, most of which is earmarked for education, with around 5% for research, in line with government strategies. On top of this, UNIST has a long-term R&D fund, which it presides over autonomously. Around KRW 150 billion is received through project-based funding, most of which comes from the government and, to a lesser extent, from industry. Sometimes, the MSIT will grant projects to UNIST, but mostly, it is professors who are fairly autonomous in choosing their projects with the condition that they are in line with the overall government strategies. Finally, around KRW 5 billion is earmarked for internal promotion purposes.

Figure 4.19. Funding is correlated with research quantity and quality in Korean universities

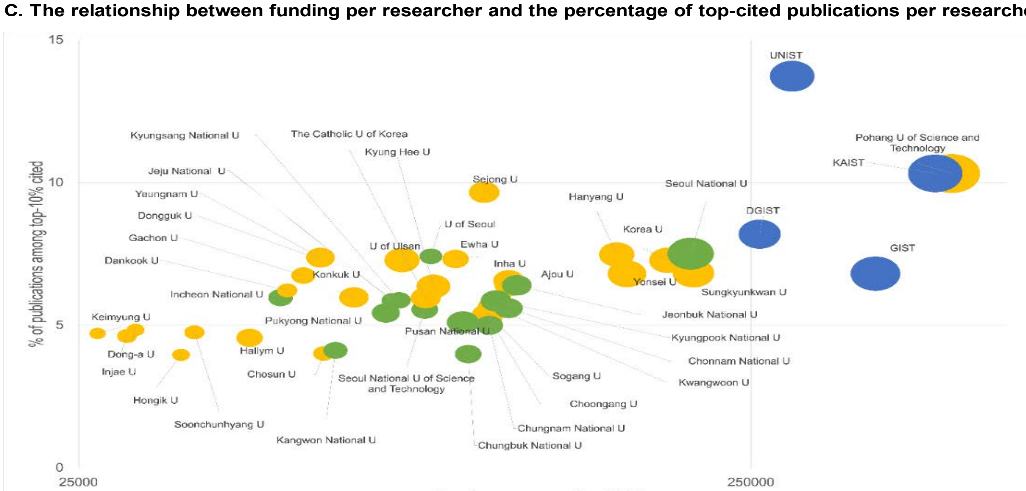
A. The relationship between funding per researcher and the percentage of top-cited publications



B.The relationship between funding per researcher and the number of publications per researcher



C. The relationship between funding per researcher and the percentage of top-cited publications per researcher



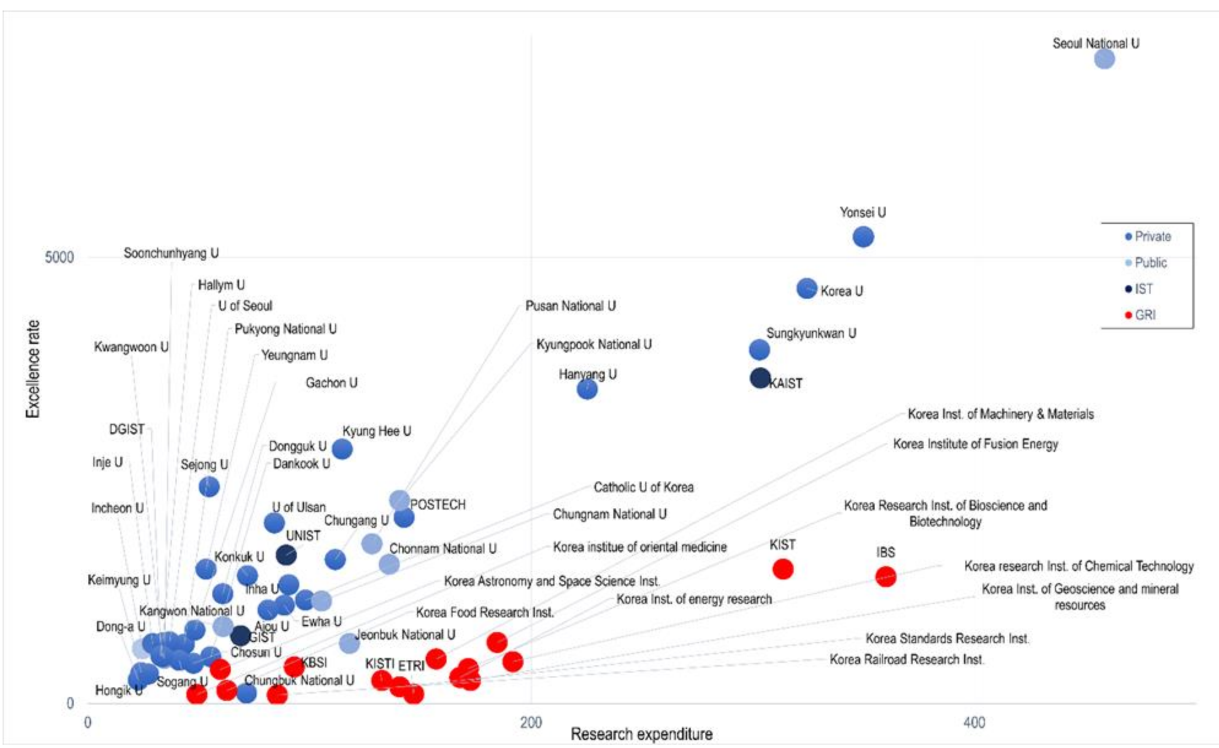
Note: The colours blue, green and yellow represent Institutes of Science and Technology, public and private universities, respectively. NRF data are based on a survey led by NRF with individual researchers, which captures all R&D funding received by researchers, including, for example, projects financed by the Ministry of Defense.
Source: OECD analysis based on NRF statistics, August 2022.

To assess and compare the effect of funding in the research activities of the HEIs and the GRIs, 58 Korean institutions ranked by their research excellence (Exc)[18] in SCImago Institutions Rankings were analysed (Figure 4.20). Of the 58 institutions, 42 were HEIs, and 16 were research institutes, of which 15 can be identified as GRIs. Similarly to the above analysis, a positive correlation between research expenditure and excellence was observed for HEIs and GRIs.

For a given level of funding, HEIs had higher research excellence than research institutes. SNU showed an outstanding number of publications that belongs to the 10% most cited, followed by prestigious private universities such as Yonsei University and Korea University. While IST universities excelled at the Leiden Ranking analysed above, they do not stand out in the SCImago Ranking. This may be due to IST universities' relatively small size and lack of humanities-related majors.

Among the research institutes, IBS and KIST had the highest excellence rate. IBS, a research institute under MSIT but not under NST, had the highest expenditure. Over 50% of the IBS budget is dedicated to the Rare Isotope Science Project, which aims to build a heavy ion accelerator and is not very conducive to a high number of publications. This helps explain why other GRIs, such as KIST or the KFE, showed greater research excellence and efficiency.

Figure 4.20. Research excellence increases with expenditure in Korean higher education institutions and research institutes

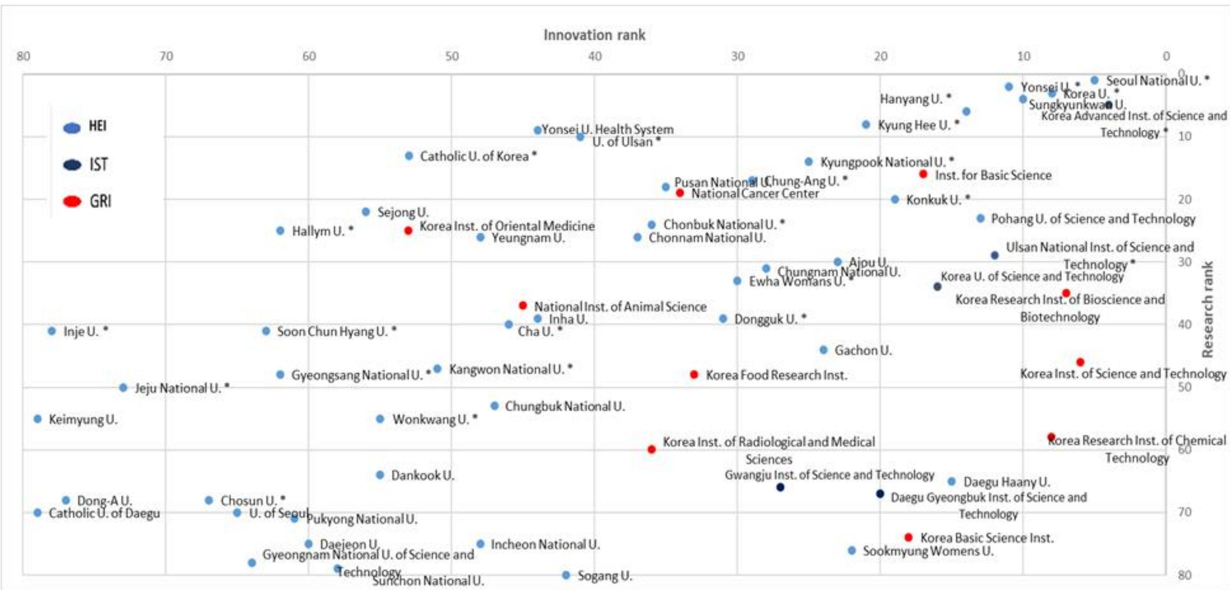


Note: On the vertical axis, research excellence is measured by "the amount of an institution's scientific output that is included in the top 10% of the most cited papers in their respective scientific fields." The horizontal axis is the research expenditure of each institution in USD millions. NRF data are based on a survey led by NRF with individual researchers, which captures all R&D funding received by researchers, including, for example, projects financed by the Ministry of Defense.

Source: OECD analysis based on NRF statistics, August 2022; SCImago Institutions Rankings (n.d.[79]), *Ranking methodology*, https://www.scimagoir.com/methodology.php; 2022 SCImago excellence rate (2017-20).

Overall, research expenditure is a statistically significant factor in explaining the research excellence for HEIs and GRIs. However, the model used here indicates that the research output of research institutes was lower than that of universities. This may suggest that research institutes are smaller in size or that their roles and responsibilities (R&Rs) do not prioritise the publication of scientific papers. Figure 4.21 shows the innovation and research performance of top HEIs and GRIs. It indicates that some GRIs rank high in terms of innovation but relatively low for research. The top universities perform best in terms of both innovation and research ranks.

Figure 4.21. Innovation and research SCImago rankings of Korean higher education institutions and research institutes, 2022



Note: See Methodology (scimagoir.com) for the criteria and methodology of the research and innovation ranking.
Source: OECD analysis based on SCImago Institutions Rankings (n.d.[79]), *Ranking methodology*, https://www.scimagoir.com/methodology.php, 2022.

4.5. Governance of government research institutes and higher education institutions

The main policy concerns with the research sector are achieving academic excellence (including in basic science) and return on investment, for instance, to foster breakthrough innovation and research which serves long-term societal needs. Accordingly, various adjustments to institutional governance have been attempted, including competitive financing of research in the form of competitive grant allocation. A notable recent development has been the introduction of the National Research and Development Innovation Act ("Innovation Act"), which proposes many positive changes in terms of research autonomy. Nevertheless, further efforts would be needed to encourage creative, long-term, high-risk and high-return research. Previously, most project evaluations were annual with very strict numerical objectives that needed to be met for evaluation and promotion purposes and left little space for developing creative, long-term "moonshot" types of basic research (Kim, 2022[80]) (Box 4.3). The Innovation Act, enacted in January 2021 with the purpose of innovating the implementation system of national R&D programmes and fostering an autonomous and responsible research environment, entails inter-ministerial joint standards for R&D and abolished project-based annual evaluations and replaced these with stage evaluations. In addition, there has been a shift from quantitative to qualitative evaluation, with the latter comprising more than 50% of metrics. Nevertheless, short-term horizons of projects can come at the cost of high-risk and high-return research: 48% of projects last three years or less.

Box 4.3. Fostering high-risk, high-impact research

The Moonshot R&D programme in Japan

The Cabinet Office launched the Japanese “Moonshot” programme to promote high-risk, high-impact R&D to find solutions to the significant challenges Japan faces, such as drastic population ageing and climate change.

In 2013, the Japanese government introduced the ImPACT programme, a five-year R&D programme aimed at encouraging S&T solutions to rising societal challenges by recruiting researchers with disruptive and ambitious research ideas. While successful, the programme, in part, brought forward projects with only limited disruptive potential. The Japanese government recognised that governments in the European Union and the United States supported high-risk, high-impact R&D on a significantly larger scale and, furthermore, were encouraged to recruit top researchers internationally to leverage global expertise.

Consequently, the Cabinet Office established the Moonshot programme in 2019, when the ImPACT programme ended. This new mission-driven programme seeks to foster revolutionary research concepts that go beyond being merely incremental extensions of already existing technologies, hence “moonshots”. The intention is to maximise Japan’s basic research capabilities to develop disruptive research projects without being held back by the possibility of failure. For this programme, the Council of Science, Technology and Innovation, which was granted more authority and a wider mandate, thus enabling it more bargaining power than ministries, formulated nine goals responding to pressing societal challenges and how S&T can augment the future of humanity. The goals are meant to be easily comprehensible and recognisable for society, such as the “realisation of a society in which human beings can be free from limitations of body, brain, space and time by 2050” and the “realisation of ultra-early disease prediction and intervention by 2050”. It was launched in 2019 with almost USD 900 million earmarked for a period of ten years from the start of the research. The duration of the projects and whether they will be continued is contingent on frequent evaluation procedures.

Evaluation criteria for high-risk, high-reward (HRHR) research

Reaching the international knowledge frontier requires the funding of science with significant risk, as many funded projects will fail while few will result in ground-breaking findings with revolutionary impact (Machado, 2021[81]). However, extensive reliance on traditional indicators for evaluating programmes and research outputs, such as Journal Impact Factors (JIFs) and H-indexes, has been proven to be a possible source of risk aversion in funding science.

Several attributes of knowledge are particularly characteristic of HRHR research, namely, basicness, which is at the core of basic research, i.e. theoretical discovery as a result of research on the foundation of a phenomenon without specified application or use; generality, which indicates the breadth of fields a scientific finding can be applied to; and novelty, i.e. a discovery highly distinguishable from the status quo.

In particular, scientific novelty is critical, as extraordinarily novel findings are associated with scientific breakthroughs and high impact. Some suggested indicators measuring novelty include new or uncommon pairwise combinations of citations in a scientific article, indicating new knowledge combinations and a higher extent of novelty. Other indicators for novelty may be given by the average age of keywords in abstracts with new or younger words suggesting higher novelty.

Machado’s (2021[81]) analysis includes the development of a novelty indicator based on new and uncommon citation pairs, implying that a pair of citations is used in an article for the first time together. He finds that several factors significantly drive novelty, including the share of top-cited publications, business expenditure on R&D, international collaborations and higher overall R&D spending. However, in a more robust statistical analysis, the latter two were not significant. It is suggested that the introduced novelty indicator may be a relevant complement to traditional indicators aiming to evaluate science funding.

Korea's Alchemist project

In 2019, the Korean government launched the Alchemist project, which seeks to foster disruptive innovation with the potential to bring about transformative change to industries in 10-20 years. A total budget of KRW 414 billion (USD 290 million) is earmarked to support the project for ten years, of which KRW 374 billion comes from the government while the rest comes from private sources. Universities, businesses and GRIs are eligible to submit proposals that are assessed based on the degree of innovativeness, industrial impact, global leadership, impact on society and human life and differentiation, i.e. the degree to which it holds independent technical value. Some of the new thematic areas of the project are reverse ageing, Hypervision metaverse and biomimetics carbon recycling.

Korea Advanced Research Programme Accelerator (KARPA)

In 2020, MSIT launched the Korea Advanced Research Programme Accelerator (KARPA) which was meant to emulate the US DARPA model to stimulate and promote breakthrough innovation. It seeks to foster inter-ministerial co-ordination and to bring solutions to national problems as well as promote innovation-leading industries. A more detailed analysis of the programme is given in Chapter 5.

Source: Japan Science and Technology Agency (2022[82]), *The basic approach for the Moonshot Research and Development Program*, https://www.jst.go.jp/moonshot/en/about.html; OECD (2022[83]), *OECD STIP Compass*, https://stip.oecd.org/moip/countries/japan; Machado (2021[81]), "Quantitative indicators for high-risk/high-reward research", https://doi.org/10.1787/675cbef6-en; KISTEP (2020[84]), *Launching of K-DARPA: Aspiring to be Korea's DARPA*, https://www.kistep.re.kr/board.es?mid=a20501000000&bid=0051&act=view&list_no=37139&tag=&nPage=5.

4.5.1. Government research institutes

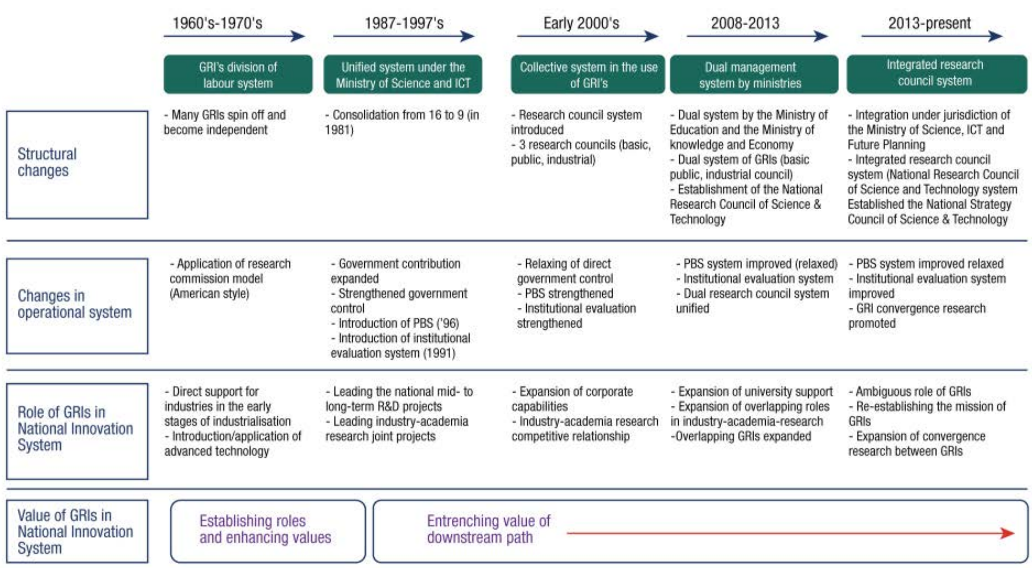
In the 1980s, in response to growing criticism of inefficiency, overlaps and failure to meet industry needs, 19 GRIs that had previously been under the authority of various ministries were consolidated into 9 under the jurisdiction of the Ministry of Science and Technology (STEPI, 2021[62]). The government also provided funding for GRIs to collaborate more closely with industry in the hope that that would increase their relevance and impact (OECD, 2009[60]). However, criticism of the GRIs' efficiency and performance continued throughout the 1980s and 1990s. Eventually, it led to the establishment of the PBS in 1996, effectively forcing GRIs to compete for funding rather than benefitting from guaranteed block funding. The Act on the Establishment, Operation, and Fostering of Government-funded Science and Technology Research Institutes enacted in 1999 led to the creation of research councils and reverted the management of GRIs back to a multi-ministry structure (Figure 4.22).

In the past two decades, the relative importance of the GRIs has continuously declined – as reflected in their share of total R&D expenditure – as the research capacity of universities and industry has grown. In its 2009 innovation review of Korea, the OECD cautioned with regard to GRIs, "[T]he main problem – stretching back perhaps 30 years – has been a lack of consensus on the role that the GRIs should play in the innovation system", though it acknowledged that this problem was not uncommon in countries with similar industrial research institute structures and that the role of GRIs becomes "less clear-cut" as an innovation system evolves and industry's own research capacities strengthen (OECD, 2009[60]).

In their early days, the GRIs' functions often focused on acquiring technologies from abroad and implanting them in Korea, partly through technical services and training. However, as government R&D funding rose, the GRIs took on increasingly R&D-focused roles. In some cases, such as metrology, R&D activities were transferred from existing government labs into the new GRIs.

By the 1980s, companies – especially the chaebol – were doing increasing amounts of intra-mural R&D, and it was less and less clear that they needed GRIs to substitute for this. As mentioned above, 19 GRIs were consolidated into 9 and placed under the then Ministry of Science and Technology as industry increasingly generated and acquired its own technologies. The GRIs continued to do large R&D projects to support national competitiveness, but the industry's capacity for research was increasing. The number of in-house corporate R&D labs rose from 46 in 1979 to 183 in 1985, so the role of the GRIs in relation to industry clearly needed to change to adapt to industrial development.

Figure 4.22. The evolution of Korea's government research institutes, 1960s-present



Source: STEPI (2021[62]), *Background Paper - OECD Reviews of Innovation Policy: Korea 2021*.

The NST was founded in 2014 when two research councils merged, so as to streamline the functions of GRIs by fostering their co-operation and evaluating their research performance. It initiated the Convergence Research Programme in 2014, which aims to streamline and accomplish large-scale research work in GRIs; contribute to finding solutions to societal challenges and technical issues faced by industry; and develop leading technologies (National Research Council of Science & Technology, 2022[85]).

4.5.2. Higher education institutions

In the first decade of the 21st century, government funding to universities increasingly focused on special purpose, project and performance-based funding allocated in competition (Han et al., 2018[86]). The Korean government has sought to promote examples of objectives or special purposes through earmarked funding, including promoting excellence, capacity building, specialisation, industry-academia collaboration, innovation and internationalisation (Han et al., 2018[86]) (STEPI, 2021[62]). Han et al. provide an overview of such programmes offered by the Ministry of Education (see below). The Ministry of Education relies strongly on quantitative (quantifiable) indicators and criteria both for assessing applications and evaluating programmes. However, these indicators say relatively little about the long-term impact, direction of change or strategic development. Furthermore, they might be counter-productive to the desired outcomes by steering behaviour towards short-term rent-seeking and designing and reporting indicators and plans to match call texts rather than long-term impact and change (Han et al., 2018[86]).

Han et al. identify several issues with government HEI programmes, which have also been confirmed in stakeholder interviews. Their traditionally rather interventionist and top-down nature appears to undermine their acceptance in the larger stakeholder community. They also disincentivise diversity and universities' ability to act strategically and differentiate themselves.[19]

> *For individual universities to win the financial support projects secured by the government, it is in the best interest of each university to plan and carry out as many programmes as possible. […] the low differentiation in terms of the purpose and content of support between the projects is also pointed out as the culprit weakening universities' bid toward specialization. (Han et al., 2018, p. 94[86])*

They also point to redundancies and overlap in policies, with new governments eager to introduce new measures, and a lack of coherence, consistency and co-ordination of HEI policies: "The goals of recent programmes have been mainly biased toward solving short-term socio-economic problems, such as low employment ratio and working on new industrial innovation, rather than enhancing the long-term standards of the system." This point echoes the analysis by Byun (2009) and was also made by the OECD (OECD, 2014[87]) which identified "policy activism" – i.e. the tendency to introduce numerous and rapidly changing programmes and policies in response to deep-rooted structural or institutional shortcomings – as a problem of Korean policies more generally. Policy activism and inconsistencies might also partially explain what observers perceive to be the passive or reactive natures of Korean universities when it comes to institutional renewal.

Table 4.11 presents an overview of programmes the government launched, the provided budget and their duration.

Table 4.11. Overview of Korea's major university-supporting programmes

Name	Purpose	Budget size KRW billions	Periods	Beneficiary
CORE	Strengthening human resources capacity and innovation in universities Establishing an infrastructure for humanities education and research, training talented human resources	60 (2016)	3 years (2016-18) (2+1)	University
PRIME	Improvement of university constitution centred on social demand (quantitative + qualitative) Strengthening student career capacity and eliminating mismatch of personnel	201.2 (2016)	3 years (2016-18)	University
CK	Characterisation of comparative advantage areas based on community demand Strengthening university competitiveness and supporting mutual growth with local communities	245.6 (2014) CK-I: 191 CK-II: 54.6	5 years (2014-18) (2+3)	Programme
SCK	Fostering professional colleges as centres of higher vocational education	269.2 (2014)	5 years (2014-18) (2+3)	Programme
BK21+	Developing world-class graduate schools and excellent researchers Enhancing the quality of education and research in domestic universities	252.6 (2013)	7 years (2013-19)	Programme
LINC+ [LINC]	Supporting the cultivation of custom-made talent reflecting industry-leading university development and social demand	238.3 (2017) [LINC 170 (2012)]	5 years (2017-21) (2+3) [5 years (2012-16) (2+3)]	University
ACE+ [ACE]	Well-taught college, fostering leading undergraduate university Creation and diffusion of leading model	73.5 (2017) [30 (2010)][23]	4 years (2017-20) (2+2) [3 years (2010-12 (2+1)]	University

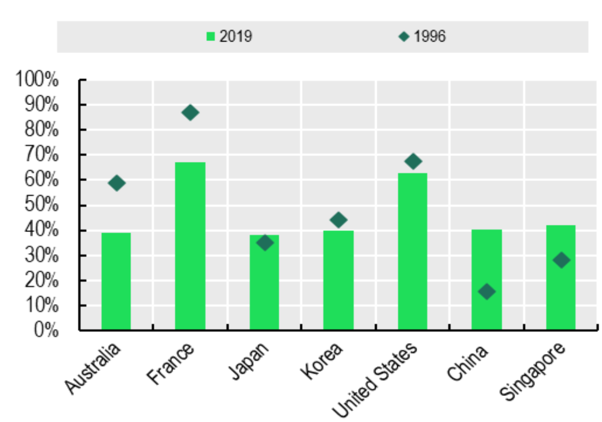
Name	Purpose	Budget size KRW billions	Periods	Beneficiary
	for advanced education in undergraduate education			
LC	Establishing an education system for lifelong learners	30 (2016)	1 year (2016)	University
PoINT	Establishing an innovation base and proprietary development model of the National University Collaboration and function restructuring, such as sharing of resources between universities and joint education curriculum	19.5	2 years (2017-18) (1+1)	University
BRIDGE+ [BRIDGE]	Enhancement of universal creative asset utilisation function Strengthening capacity utilisation of national technology, creation of technology-based new industry	12.5 (2018) [15 (2015)]	5 years (2018-2022) (2+3) [3 years (2015-17)]	University
WE-UP	Reorganisation of a female-friendly engineering education system Cultivation of female specialists who customise industrial demand	5 (2016)	3 years (2016-18)	Programme or consortium

Source: Han et al. (2018[86]), *An Analysis of Higher Education Policy: The Case of Government-Supported University Programs in South Korea*, https://doi.org/10.7545/ajip.2018.7.2.364.

Furthermore, over recent decades, governments in Asia have recognised the importance for HEIs to engage in basic research to spur disruptive innovation and have, therefore, increased funding to that effect. However, the share of R&D in basic science in Korea declined between 1996 and 2018 relative to applied research and experimental development, while it strongly increased in China and Singapore in the same period (Figure 4.23). In 2016, in response to a petition by basic scientists to the National Assembly demanding an increase in funding for basic research and a higher degree of research autonomy, the Korean government pledged the doubling of bottom-up basic research funding to USD 2.2 billion between 2017 and 2022. Although other OECD countries, such as Australia and France, have shown the same declining trend, the decrease occurred from higher initial percentages, leaving Korea as having one of the lowest shares of basic science R&D by the higher education sector as a percentage of its total R&D expenditure (OECD, 2022[88]). High national demand for applied R&D has contributed to universities participating in such research.

Figure 4.23. Expenditure on basic R&D by the higher education sector in Korea and selected countries, 1996 and 2019

As a percentage of total higher education expenditure on R&D



Note: For Australia, 2018 data are used.
Source: OECD (2022[89]), *Research and Development Statistics (RDS)* (database), oe.cd/rds, September 2022.

4.6. Research infrastructures

Korea has invested significant resources in the establishment of research infrastructures and equipment. Equally, to improve their efficiency and management, several platforms have been launched to enhance the co-ordination across the public research system.

The government has developed two roadmaps for national large research facilities (NLRFs) whose purpose is to provide a long-term oriented strategy and support system to ensure Korea's position as a leading country in S&T (Roadmap 1) and in large research facilities, to pioneer the creative economy (Roadmap 2), knowledge-based economic activities to foster creative and cultural sectors. Several characteristics of these large research facilities are the networking effects of primary scientific and technological research and their independence in terms of management and operations while being regularly evaluated by supervising bodies. Large research facilities also have their own operating and processing personnel and research staff, often engaged in co-operation beyond regional and national borders. Other typical characteristics are their mostly open accessibility to external users and national rather than ministry-level financing (Ministry of Science and ICT, 2019[90]).

The benefits of large research facilities are multi-fold (Michalowski, 2014[91]). They include increased co-operation domestically and internationally, facilitating knowledge exchange and attracting foreign talent while preventing the brain drain of highly skilled locals. Furthermore, associated research groups are often involved in pioneering research, resulting in fundamental breakthrough innovations which can possibly create new industries. As described earlier in this chapter, Korea's participation in large international infrastructures, such as CERN, ITER, EMBL, etc., indicates the government's awareness of these benefits for the research community. In addition, NLRFs contribute to economic and social development by creating jobs, training scientists and students, and fulfilling their duty to engage in research to address prevailing and arising societal challenges.

The Korean government launched its NLRF Roadmap 1 in 2010 to assist 69 facilities with establishment costs ranging from KRW 5 billion to KRW 750 billion (USD 3.5-530 million) per listing. It was established by the previous Ministry of Education, Science and Technology and focused on five core areas related to the S&T Basic Plan. The updated NLRF Roadmap 2 has a somewhat larger scope by focusing on 12 "megatechnics" areas[20] and supporting 13 major research facilities, each costing over KRW 50 billion. While the validity reviews of Roadmap 1 are based on researcher demand surveys, those of Roadmap 2 additionally entail a factual survey, performance analysis and environmental change (Ministry of Science and ICT, 2019[90], STEPI, 2021[62]).. compares major research infrastructures and shows that Korean investment is 0.18% of GDP, somewhat lower than other countries. It should be noted, however, that Korea started several years later than the European Union and the United States. Still, comparing it within Asia, Japan and China launched their respective infrastructures around the same time and allocated considerably higher investments relative to GDP.

Table 4.12. Korea's national large research facilities in comparison with selected benchmarking initiatives

Country	Initiative	Year	No. of facilities	Total investment (as % of GDP)
European Union	European Roadmap for Research Infrastructures (ESFRI)	2006	35	0.37
		2008	44	
		2010	38	
	ASTRONET Infrastructure Roadmap	2008	25	
United States	Facilities for the Future of Science	2003	28	0.28
		2007	28	
	Facility Plan	2005	25	
		2008	19	

Country	Initiative	Year	No. of facilities	Total investment (as % of GDP)
China	Large Research Infrastructure Development in China: A Roadmap to 2050	2011	34	0.33
Japan	Large Research Infrastructure Plan	2010	43	0.48
Korea	National Large Research Facilities Roadmap (NLRF) 1	2010	69	0.18 (NLRF 1)
	National Large Research Facilities Roadmap (NLRF) 2	2012	13	0.27 (NLRF 1+2)

Note: The investment calculation is based on the 2017 constant USD (PPP) for GDP in 2021. The number of facilities refers to those supported in the respective year (not the total).

Source: OECD calculations based on Ministry of Science and ICT (2019[90]), *National Large Research Facilities Roadmap*, https://publicadministration.un.org/unpsa/Portals/0/UNPSA_Submitted_Docs/2019/d4164970-f5aa-4c09-9588-23c3fa89f0ca/2020%20UNPSA_ZEUS_National_Roadmap_26112019_093032_de461911-3adc-461a-9e2f-53e310d84ca3.pdf.

In addition to the establishment of research equipment facilities, the sharing of such also has wide-reaching benefits for the research community. In the past, the co-utilisation of research equipment in research projects in Korea has been low because it has focused R&D investment capabilities on securing research institutes' capabilities. However, after the policy shift to utilisation-oriented rather than input-led investments in 2008, the overall demand for shared research equipment access in Korea increased, and the government launched digital platforms to that effect. The Zone for Equipment Utilisation Service (ZEUS) platform allows researchers to find and reserve R&D facilities and equipment nationwide. It is operated by the National Research Facilities and Equipment Centre (NFEC) in the KBSI and interconnects equipment and facilities funded by the government while providing researchers from the private and public sectors with the possibility to reserve these. Around 5 300 reservations are undertaken daily, and the platform enables researchers to exchange experiences and feedback regarding the equipment and facilities. In addition to the core platform, four complementary sites fulfil different objectives, such as strategic investment, training of engineers, international collaboration, and research and infrastructure linkage.

Due to these policies, the number of joint use of research institutes has significantly increased (from 2 008 cases in 2013 to 128 112 cases in 2021), and the number of joint utilisation facilities that serve those underprivileged in R&D is increasing (from 52 cases in 2011 to 438 cases in 2021). Reasons for low co-utilisation are multi-fold and notably include the lack of awareness of the role and function of public goods, as well as legal ownership and responsibility of the research site. Furthermore, some noted that policies have been developed top-down and have not adequately considered the researchers' perspectives and incentives to use or share equipment. Professors at universities, for instance, have placed little emphasis and importance on the co-utilisation of research equipment, partly due to low recognition and low awareness of the need to make it available to others, resulting in protective ownership. Other factors impede the co-utilisation of equipment, such as a lack of plans to systematically organise the use of equipment or difficulties in accounting separately for joint use in the budget (Yi, 2016[92]). Promoting various policy activities for the joint use of equipment, such as completing the equipment management operating system for joint use, education to improve awareness, and budget support at the national level, could help in this regard.

4.7. Knowledge flows between higher education, government research institutes and business

4.7.1. An overview of international knowledge flows

Organising knowledge flows between academia and business is key to realising the full value to society of the knowledge created by scientific research to leverage it in high-value-added products and services. This is becoming even more important in the context of leveraging STI as a contribution to the resolution of societal challenges, where civil society organisations are also important stakeholders (please refer to Chapters 2 and 5 for a more comprehensive discussion of societal challenges).

The facilitation of such knowledge flows is one of the large challenges faced by many OECD countries and other advanced economies. Whether in PRIs or HEIs, academics often focus on addressing fundamental scientific issues, and their main objective is to advance the knowledge frontier and publish the results of their research in prestigious scientific journals. The diffusion and application of knowledge in the economy is rarely an objective that academics would spontaneously pursue unless significant incentives are created. Similarly, the business sector would rarely reach out to academia to help resolve some issues and satisfy the needs of their customers.

Large legacy barriers exist between the different communities, with different educational backgrounds, value systems, time horizons and social circles. For example, while business people will typically have degrees in business, economics or engineering and be driven by business metrics, such as economic profit and short-term results, academia will have educational backgrounds in scientific disciplines and be driven by academic recognition, based on publications and conferences, typically on a medium- to long-term horizon.

Yet, by joining the complementary strengths of business and academia, valuable contributions can be made to the economy and society. Business people can add value by identifying market opportunities for innovative products and services, while academics can provide adequate scientific and technical solutions to enable such innovations – the combination of both makes it possible to unleash the full potential of the national innovation system. The cross-country variation in the adoption of technologies accounts for at least 25% of per capita income differences (Comin and Hobijn, 2010[93]). Furthermore, changes in the pattern of technology diffusion account for 80% of the income divergence between rich and poor countries since 1820 (Comin and Ferrer, 2013[94]).

Etzkowitz (2002) identifies various models of government intervention in favour of academia-business linkages, including the statist model, whereby the state takes a leading role in establishing partnerships with a relatively weak academic and private sector, such as was in place in the Soviet Union, France and Latin American countries during the second half of the 20th century. This contrasts with the "laissez-faire" model applied in the United States throughout most of the 20th century, where the role of government is limited to correcting market failures, leaving an open ground to academia in charge of knowledge production and business responsible for knowledge absorption. However, the relationship between the actors and the policy-making process is not always static, as described above. In both models, there is a pull to increase the independence of university and industry from the government and increase interdependence among the three partners. To better describe these dynamic partnerships, Etzkowitz proposes an alternative model: the Triple Helix interactive model, where academia, business and government are interdependent and relatively equally important stakeholders (Etzkowitz, 2002[95]).

Nowadays, policy makers reason in terms of knowledge co-creation, as joint production of innovation by industry, research, and potentially also civil society, which facilitates the transfer of tacit knowledge between participants. They exist in different forms, including projects, joint laboratories or industry-led ecosystems, and may use digital technologies that enable collaboration at a distance. They may include hackathons to generate ideas, expert networks and ad hoc teams (Kreiling and Paunov, 2021[96]).

Overall, fostering university-industry collaboration is a challenging policy issue, as the development of such collaboration relies on a very complex set of good practices (Awasthy et al., 2020[97]).

4.7.2. An historical overview of knowledge flows in Korea

A legal framework for university-industry co-operation has existed in Korea since the 1963 University-Industry Co-operation Act. However, until around 2000, there were limited knowledge flows from universities and GRIs to the business sector in Korea. Universities were mainly focusing on teaching, with sparse resources for research. GRIs have been rigidly managed, and their interaction with industry is limited.

Following the initial policies aimed at developing indigenous S&T capacity in GRIs and universities (described in the previous sections), there was a series of restructuring during the liberalisation period of the 1980s, including the merger and de-merger of KIST and KAIST, and the establishment of dominant governmental agencies between 1993 and 1997. The Brain Korea Project, which started in 1999 to increase the research capacity of universities through large central government subsidies, became a potential factor that undermined the culture of co-operation (Park and Leydesdorff, 2010[98]).

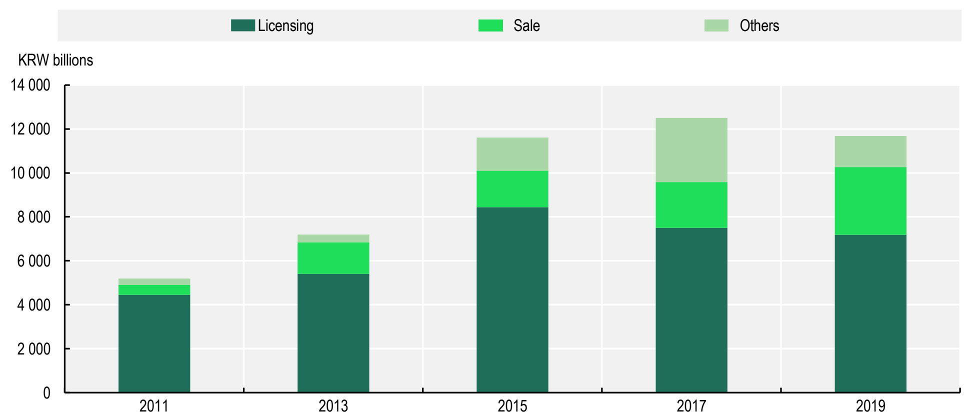
While the relative weight of R&D spending by the higher education sector has declined due to the steep increase of R&D spending by companies, some universities have become research universities with greatly increased funding for conducting cutting-edge research (Shin and Lee, 2015[67]).

Knowledge flows, for instance, technology transfer, from higher education and GRIs, have greatly increased since the turn of the millennium, the real impetus being given by the 2003 revision of the University-Industry Co-operation Act, whereby universities were allowed to create for-profit companies based on academics' inventions. In parallel, as mentioned above, a Korean equivalent to the US Bayh-Dole Act, the Promotion of Technology Transfer Act, was enacted in 2000 (Kwon, 2015[68]). Those initiatives led PRIs and most public universities to create technology licensing offices (TLOs) and industry-university co-operation foundations (IUCFs). As of 2019, 354 among 416 universities in Korea (including technical colleges and vocational schools) had IUCFs (Ministry of Education and NRF, 2021[44]). Although TLOs and IUCFs are formally separate organisations, they work closely together and are often headed by the same person. Organised under these organisations, IP rights related to research outcomes of university staff now belong to universities, not individual faculty (Eom and Lee, 2010[99]).

In terms of budget, the share of ministries' programmes and projects on commercialisation jumped from 0.7% of the total government R&D budget in 2007 to 7.1% in 2020 (STEPI, 2021[62]). This reflects the reorientation of governmental support for knowledge diffusion where multiple government bodies, notably MSIT, MOTIE and the Ministry of Education (MOE), began to form a mutual understanding of the need for integrated support rather than dividing the labour. The targets for support varied across the stages of the innovation cycle. MOE expanded programmes around existing research and business development (R&BD) foundations within universities, MSIT around the science and technology parks (STPs) and MOTIE through its agency, KIAT. Regarding legislative initiatives, the Technology Transfer and Commercialisation Promotion Plan, which is an implementation plan based on the provision of the Technology Transfer Promotion Law, is renewed every three years. The recent 6th and 7th Plans covering the period of 2017-22 increasingly focused on forming the ecosystem for open innovation and bringing in market perspectives to divert the excessive focus on technology centrism. In addition, major national R&D projects were dedicated to university-industry co-operation, including the second phase of Brain Korea, New University for regional innovation and other funds, as mentioned above.

GRIs have been reorganised and subjected to stronger performance pressure by transitioning major parts of their financing from block funding towards competitive bidding for research grants. The patenting rate of GRIs is high in international comparison, according to a 2020 report by the Korean Intellectual Property Office, which compares the number of patents per unit of financing and finds such an efficiency to be several times higher in Korea than in leading US or Japanese universities and institutions (KIPO, 2020[100]). This indicates a high potential for knowledge transfer from GRIs to industry, even though the commercialisation is less successful. While IP revenues vary across GRIs, most only have a small income from intellectual property transfer. Technology transfer from GRIs and universities to companies has markedly increased in Korea. The number of technology transfer cases from GRIs and universities to industry more than doubled between 2011 and 2019, from 5 193 to 11 676, and they were almost evenly split in 2019 between GRIs with 6 077 cases and universities with 5 599 cases (MOTIE, KIIP and KIAT, 2021[103]). A majority of transfer cases are based on licensing. However, the relative importance of technology sales and other methods, which include free licensing or transfer, coaching and equipment transfer, is increasing (Figure 4.24). The technology transfer income of GRIs and universities has also increased, from KRW 125.8 billion in 2011 to KRW 227.3 billion in 2019. GRI transfer income is higher than that of universities (Figure 4.25).

Figure 4.24. Number of technology transfer cases from Korean government research institutes and universities to industry, 2011-19

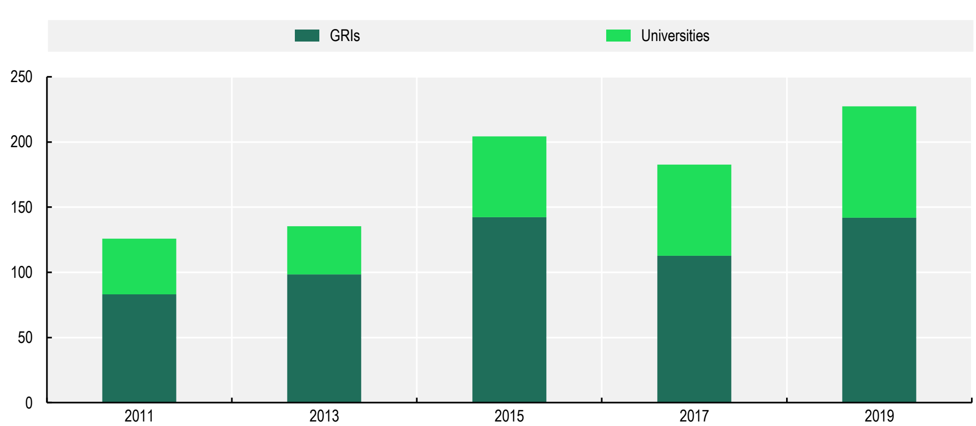


Source: MOTIE, KIIP and KIAT (2021[103]), *2020 Report on the Technology Transfer and Commercialization Survey, based on the 2019 Outcomes of Public Sector Research Institutes*, https://www.ntb.kr/marketTrend/selectStatsReferView.do?bbs_seq=24#file.

Finally, Korean industry has multiplied its R&D spending. Many companies have reached the technological frontier and, therefore, need to acquire more scientific knowledge to innovate successfully (Lee, 2011[101]). Technology transfer from GRIs to the private sector is promoted as well. GRIs run their own specific knowledge transfer programmes to external organisations, with a particular emphasis on knowledge transfer to SMEs (National Research Council of Science & Technology, 2022[102]).

Figure 4.25. Technology transfer income of Korean government research institutes and universities, 2011-19

In KRW billions



Source: MOTIE, KIIP and KIAT (2021[103]), *2020 Report on the Technology Transfer and Commercialization Survey, based on the 2019 Outcomes of Public Sector Research Institutes*, https://www.ntb.kr/marketTrend/selectStatsReferView.do?bbs_seq=24#file.

4.7.3. The current state of academia-industry linkages in Korea and a way forward

As is evident from the above, much effort has gone into enhancing the academia-industry linkage, particularly since the turn of the millennium, which has fuelled some of Korea's technological development. This section takes stock of the current state and tries to draw some learnings for the future.

Three Korean universities – SNU, KAIST and POSTECH – rank 1, 2 and 3, respectively, in Reuters' 2019 ranking of Asia Pacific's most innovative universities, which is based on patent statistics and counts of research citations in patents,[21] followed by prestigious Tsinghua and Tokyo universities at ranks 4 and 5. Overall, 19 Korean universities are among the top 75 in this ranking, on par with Japan and second only to China, with 25 institutions. SNU posted 907 patent families between 2012 and 2017, reaching a commercial impact score of 38.7, while KAIST filed 695 patents and reached an exceptional commercial impact score of 57.8. POSTECH filed 349 patents with a commercial impact score of 48.8. Nevertheless, the ranking would be reversed if measured per staff member since SNU is much larger, and thus patenting per staff member is much higher in KAIST and POSTECH (Table 4.13).

Table 4.13. Reuters' 2019 ranking of Asia Pacific's most innovative universities

Top 20 universities

University	Country	Staff	Total patent families filed, 2012-17	Success rate	Commercial impact score
SNU	Korea	2 099	907	78.2%	38.7
KAIST	Korea	895	695	79.4%	57.8
POSTECH	Korea	446	349	79.7%	48.8
Tsinghua University	China	3 416	834	62.7%	34.8
University of Tokyo	Japan	3 801	971	52.6%	32.5
Osaka University	Japan	3 225	618	52.1%	33.6
Kyoto University	Japan	2 578	703	48.5%	29.0
National University of Singapore	Singapore	1 803	439	33.5%	41.3
Sungkyunkwan University	Korea	2 904	252	77.0%	30.9
Peking University	China	4 735	469	54.8%	27.5
Hanyang University	Korea	1 428	506	77.9%	33.2
Kyushu University	Japan	2 473	551	52.8%	25.4
Tohoku University	Japan	3 195	649	59.8%	25.8
Yonsei University	Korea	1 951	561	78.6%	24.4
Nanyang Technological University	Singapore	1 561	472	40.0%	43.5
Korea University	Korea	1 474	502	85.7%	24.2
Zheijang Universiy	China	3 562	243	62.6%	27.4
Tokyo Institute of Technology	Japan	1 311	341	54.5%	23.8
Kyung Hee University	Korea	1 365	264	79.9%	28.6
Fudan University	China	2 721	130	56.9%	29.6

Note: Total patent families measures the number of basic patents filed by the institution between 2012 and 2017. Success rate is the ratio of patents filed by the institution between 2012 and 2017 that were subsequently granted by patent offices. Commercial impact score is an indicator of how often basic research originating at an institution has influenced commercial R&D activity, as measured by academic papers cited in patent filings. Higher scores are better.
Source: Ewalt (2019[104]), *Asia Pacific's Most Innovative Universities 2019*, https://graphics.reuters.com/ASIA-UNIVERSITY-INNOVATION/0100B02G03Z/index.html#:~:text=KAIST%20falls%20from%20first%20place,of%20projecting%20dynamic%203D%20images.

Among SNU’s inventions, the new “lipid nano tablet”, resembling the membranes of living cells, could represent a breakthrough leading to the development of ultrasmall biologically based computers, whereby computing is performed by nanoparticles bonded to pieces of DNA, while KAIST has invented ultrathin holographic displays capable of projecting dynamic 3D images. In addition, POSTECH invented artificial corneas that are 3D-printed out of tissue-derived “bio-inks”, making them transparent, robust and better to transplant in human eyes. Sungkyunkwan University, Hanyang University, Yonsei, Korea University and Kyung Hee University are also within the top 20 in this ranking (Ewalt, 2019[104]). All these examples are a good indication of the innovation that fostered industry-academic collaboration can induce. Promoting partnerships and joint research can help real-world applications of research findings.

Nevertheless, these metrics are most relevant for the linear model of technology transfer, whereby knowledge is generated at universities and then “pushed” into commercialisation. This has made Korea successful in the catch-up mode, but there is room for improvement at the technology frontier. Hameed, von Staden and Kwon (2018) suggest that Korea should now adopt a different model. For this to happen, the shared mental model in university-industry interactions needs to move towards demand-oriented technology transfer practices rather than supply push. At the same time, policy orientation should evolve from institutional and top-down mode towards more participatory and bottom-up (Hameed, Staden and Kwon, 2018[105]). In this respect, Korea may want to follow some of the good practices of co-creation between academia and industry, including projects, joint laboratories, industry-led ecosystems, hackathons to generate ideas, expert networks and ad hoc teams (Kreiling and Paunov, 2021[96]).

Technology from GRIs and universities is predominantly transferred to SMEs, the technology recipients in 90.8% of all transfer agreement cases in 2019. In contrast, only 2.0% of all technologies were transferred to large firms and 2.4% to mid-sized companies. Most technologies are transferred via patents, which 69.3% of all technology transfer cases from GRIs and universities have been based on in 2019. Technology transfer from GRIs and universities is occurring almost exclusively in a domestic context. Only 0.3% of all transfers in 2019 were made to overseas organisations (MOTIE, KIIP and KIAT, 2021[103]).

Universities and large companies often find it difficult to establish common ground in Korea, not least due to their strong separation of tasks and limited interaction in the past. Recently, the Ministry of SMEs and Startups has dedicated a budget of about USD 46 million for the issuance of innovation vouchers for SMEs with a high growth potential of up to USD 37 000, which can be used relatively flexibly for seeking technology consultations from university researchers (Korean Ministry for SMEs and Startups, 2022[106]). Chapter 3 elaborates on government support for business innovation in-depth. Beyond introducing such financial instruments with lower entrance barriers than competitive grants for university-industry research collaborations (UIRCs), another potentially effective way to strengthen knowledge transfer from GRIs and universities to companies is programmes that focus on networking. Person-to-person networks are highly important for effective inter-organisational collaboration in Korea’s relationship-oriented culture (Hemmert and Kim, 2020[107]).

Based on desk reviews and interviews, there are some indications that the investment environment and culture around entrepreneurship at universities is changing, incentivising more professors to establish their own start-ups rather than licensing technology to companies, which had previously been the preferred approach. More specifically, some of the conditions around personal risk are being eased so that professors do not need to invest their own assets into starting a business, as, increasingly, universities assist in providing equity that they can use to start a business without being liable with their own funds. KAIST, for instance, while not providing its own seed funding, engages in efforts to link venture capitalists among its alumni network (as well as external ones) with start-ups at the university. From spring 2021 onwards, KAIST has additionally started its own holding company through which it takes shares in the newly founded companies and brokers' relationships with other investors. Finally, professors across Korean universities can start their businesses parallel to their academic careers, for instance, by reducing teaching hours instead.

According to interviews held by the project team, student entrepreneurship has largely increased due to start-up programmes, such as the Tech Incubator Program for Start-up (TIPS) (see Box 4.4). In the case of KAIST, a specific entrepreneurship education curriculum encourages students to engage in start-up creation and has been quite successful. For instance, as part of the "K-School" dual major programme, students enrol in a business major besides their tech-oriented field. Furthermore, there are initiatives in place that also intend to spur start-up activities among university professors, which are traditionally low at around 7-8% of professors embarking on starting their own businesses. For example, professors at some Korean universities can start their businesses parallel to their academic careers, i.e. with the option to reduce teaching hours instead. Still, at the top universities, in particular, professors tend not to take the risk of starting a business. In smaller universities, there is often higher pressure for professors to find jobs for their students; in such cases, co-operation with the private sector is particularly important.

Box 4.4. Tech Incubator Program for Start-up (TIPS)

The TIPS policy programme was introduced by the Korean government under President Park Geun-Hye in 2013 and was largely inspired by the Israeli Technology Incubator programme. Due to its significant success, the succeeding Moon Jae-in administration maintained and expanded the TIPS programme.

The procedure involves private companies that initially angel invest around USD 0.1-02. million in the most promising start-ups, which are then recommended to and complemented by the government with R&D, commercialisation and marketing funding. The objective is to incubate these companies with no more than USD 0.5 million within two to three years before they become globally operating companies and support them with mentoring, education, and funding. In July 2018, the post-TIPS policy was established, which entails further follow-up support amounting to an additional (maximum) USD 0.5 million. Between 2013 and 2019, around USD 450 million was allocated to TIPS by the government, of which USD 308 million was for R&D, USD 54 million for commercialisation, USD 29 million for marketing and USD 21 million for post-TIPS support.

The main success factors of TIPS are the selection by highly experienced private sector companies, business angels and venture capitalists who then support the early-stage companies with valuable mentoring and educational support. Moreover, the programme has managed to involve many professionals and highly educated students, with about 60% of founding team members having a postgraduate degree and thus being a crucial driver of entrepreneurship at universities. By the end of 2018, job creation through TIPS was, on average, 5.5 employees per firm or about 3 690 staff in total. By 2022, more than 1 300 start-ups had been supported, 90% of which had registered IP. The overall government support amounts to KRW 700 billion, while KRW 4.7 trillion comes from the private sector. Only around 20 of the 1 300 firms failed and had to exit the market, a success rate of 98%. This contrasts with the low success rate achieved before the TIPS programme when the government directly supported start-ups. The TIPS programme has been so effective and successful because it circumvents the so-called "death valley" in Korea, the fact that venture capitalists are often reluctant to finance in the initial phases to start production, and there are few super angel investors. The objective is to increase the annual number of supported early-stage firms by 500 annually to 3 500 by 2030.

Source: Han (2019[108]), "Promotion of Technology-based Start-ups: TIPS Policy of Korea"; TIPS Korea (2018[109]), *Meet Our Extra-ordinary Start-ups*, http://www.jointips.or.kr/bbs/board.php?bo_table=eng_startup; OECD stakeholder interviews, 2021.

Kim and Cho (2022) provide a literature review of commercialisation success factors for technology transfer and commercialisation, including R&D capability, management ability and technology diffusion capability for the technology provider, as well as technology absorption capacity, commercialisation willingness and capability on the recipient side and technology characteristics, IP rights and environmental conditions, such as government support and co-operation partnerships. They study commercialisation practices in the case of ETRI and introduce the concept of technology commercialisation proactiveness (TCP) for both SMEs and GRIs. TCP for SMEs is measured based on technology transfer expenditure and frequency, while the GRI TCP is measured according to the degree and type of GRI researchers' support. Both TCPs are found to have a positive effect on technology commercialisation success (Kim and Cho, 2022[110]).

Min, Vonortas and Kim (2019) studied the commercialisation of technologies from universities and GRIs in 669 cases. They found that the post-transfer partnership of the company with universities and GRIs positively affects the successful commercialisation of transferred technologies. In contrast, the recipient company's absorptive capacity does not significantly impact the successful commercialisation of technologies sourced from universities and GRIs. They also found that market competition intensity negatively affects the success of commercialisation (Min, Vonortas and Kim, 2019[111]).

In addition to building infrastructure for knowledge transfer from GRIs and universities, the Korean government has also introduced support policies for the technology collaboration of GRIs and universities with companies, focusing on knowledge transfer to SMEs. An online platform has been created that allows SMEs to search for specific technologies developed by universities and GRIs (Korea Technology Finance Corporation, 2022[112]). Another recently promoted knowledge transfer channel is contract research given by SMEs to universities and GRIs (Ministry of SMEs and Startups, 2019[113]). Recent statistics on collaborative research projects by GRIs show that approximately two-thirds of all projects involving the private sector are contract research projects (National Research Council of Science & Technology, 2022[102]). The number of collaborative projects of GRIs with universities is approximately half that of projects with the private sector, indicating that there is also some collaborative research activity between GRIs and universities.

In the case of UIRCs, collaboration partners can apply for government subsidies offered by various programmes by different government agencies, which typically cover approximately 60-70% of all project expenses. A major UIRC support platform in recent years has been the Leaders in Industry-University Co-operation (LINC) programme, which had a total budget of KRW 390 billion in 2021 (LINC, 2021[114]). Overall, there appear to be relatively few UIRCs that do not rely on government subsidies. Most UIRCs are short-term and small-scale; however, some are developed to an advanced level and big scale in which technology transfer could be conducted (Hemmert, 2017[115]). The project duration is rarely longer than three years and often only one year or shorter. Projects tend to have modest budgets of KRW 100 million or less. University partners are mostly not leading research universities but smaller universities that are often located outside the capital agglomeration of Seoul.

A reason for faculty's low UIRC participation rate in research universities is faculty evaluation policies, which emphasise publication in leading academic journals over industry collaboration projects (Park and Leydesdorff, 2010[98]). Faculty at leading research universities with the largest R&D budgets are incentivised to focus purely on academic work and are often inactive in UIRCs. Another partial obstacle to collaboration and knowledge transfer between universities and industry is a limitation on faculty at national universities from receiving income from work in the private sector. [22]

On the industry side, large Korean companies tend to work with foreign universities when developing fundamental technologies, as they perceive that foreign universities are most advanced in basic research. Conversely, UIRCs with universities within Korea tend to focus on developing applied technologies. UIRCs have become more frequent and vibrant at leading research universities. As some researchers at these universities are now recognised as internationally leading in their scientific fields, more and more companies are eager to work with them, as they assume that collaborating with them may enhance their technological competitiveness.

While UIRCs overall have become more frequent in Korea than in the past, the quality of knowledge being created and transferred often appears modest. This is because most UIRCs are conducted between relatively small non-research universities and SMEs, which are often located in geographic proximity to their university partners. As UIRCs also tend to be small-scale and short-term, the content of these collaborations tends to focus on incremental new product or process innovations.

Policies towards strengthening linkages between academia and industry in Korea have focused on financial instruments, such as supporting the establishment of TLOs and IUCFs and grants for UIRCs. Regulatory instruments have also been used, such as assigning IP to universities instead of individual researchers. In contrast, there is little emphasis on soft instruments such as awareness raising, networking and training programmes, which constitute an important part of the policy mix to support knowledge transfer from academia to industry (Guimón and Paunov, 2019[116]).

Korean policy support for university-industry collaboration is seen as weak in an international comparison of environmental, technical and managerial dimensions. In contrast to Israel and Singapore, which are seen as having highly developed policies across the board, Korea's policies are "developing" at best. Korea's policies are particularly underdeveloped in the area of broader research policies that establish a favourable environment for collaboration, information sources for collaborations, intellectual policies and practices conducive to fostering and sustaining collaboration, and the extent to which collaboration is emphasised in institutional leadership priorities and incentives (Dollinger, Lodge and Coates, 2018[117]). Box 4.5 sets out government-led initiatives to support university-industry collaboration.

One policy instrument that appears to have been effective in stimulating knowledge transfer from universities to industry is the provision of financial support for company facilities, such as innovation parks, on university campuses. Companies are incentivised to move into these facilities, as their usage cost is lower than for normal office premises due to government subsidies. Once companies are located on campus, collaboration with university researchers becomes more vibrant due to high geographic proximity.

Box 4.5. Government-led action in favour of university-industry collaboration in Innopolis and Innotowns

Korea has 5 Innopolis in Daedeok, Gwangju, Daegu, Busan and Jeonbuk and 12 Innotowns that aim to promote technology commercialisation in PRIs based on regional needs, as well as 19 science and technoparks focused on fostering local industries and the creative economy innovation centres (CCEI) on start-ups. This is concurrent with the development in many OECD countries where they systematically create comprehensive infrastructure providing office and laboratory space to foster the creation of "deep tech" start-ups with adequate services, such as dust-free labs, supercomputing platforms and/or services such as strategy, marketing, IP, legal, human resources and other consulting (e.g. the EPFL1 Innovation Park in Switzerland) as well as competence or excellence centres for public-private co-operation on projects and programmes (e.g. the Austrian COMET programme).

In Korea, the original objective in the 1970s was to establish "science towns", such as the Deadok Science Town, created as clusters combining GRIs and universities, adding private R&D and venture firms to the cluster in the 1990s, technology commercialisation and a hub-and-spoke system linking its unique research capacity with advanced industries across the country as of 2005.

Daedok is situated one hour from Seoul, Daegu, and Gwangju. Started as a greenfield operation in 1973, it comprises 30 government-funded institutions, 5 universities, over 400 corporate R&D centres and more than 1 200 high-technology SMEs as of 2012. As of 2010, Daedok Innopolis employed 11% of all PhDs in Korea (Oh and Yeom, 2012[118]). This is a typical example of the "statist triple helix model", as defined by Etzkowitz. While the government has successfully provided human capital, infrastructure, technology and competitive research institutes, the more tacit elements, such as inter-firm interaction, shared know-how and spillover of expertise, have been less successful. The development of linkages has been less successful than, for example, in the San Diego biotechnology cluster, due to insufficient networking activities (Kim and An, 2012[119]).

The original Innopolis were considered too big (more than 40 organisations per cluster) to generate significant synergies, and this is why much smaller Innotowns were created in 2019, designed to be "small but robust R&D zones", run by the regional government and focusing on stakeholders from universities, GRIs and businesses with high innovation potential in a limited zone to prevent excessive geographical spread.

Source: Kim and An (2012[119]), "A comparison of Daedeok Innopolis cluster with the San Diego biotechnology cluster", https://doi.org/10.7165/wtr2012.1.2.118; Oh and Yeom (2012[118]), "Daedeok Innopolis in Korea: From science park to innovation cluster park to innovation cluster", https://doi.org/10.7165/wtr2012.1.2.141.

Overall, much has been achieved in academia-industry collaboration, in particular as a support to the SME sector, giving rise to increasing numbers of patents and technology transfer cases. However, this support remains strongly driven by "supply push" rather than company demand driven. In addition, collaboration occurs primarily with SMEs, while the chaebols' innovation ecosystems are relatively disconnected from academia, even though Samsung collaborates significantly with top academic institutions. Therefore, specific incentives should be envisaged for academics who collaborate with industry, particularly large companies (chaebols). Namely, such collaborations can be especially challenging due to the high standards required by results-oriented conglomerates, which can prove to be more competitive than regular work on project-based research work. Evaluation criteria also need to evolve from purely quantitative ones (counting patents and technology transfer cases) towards more qualitative evaluations looking at breakthrough innovations created for the markets, as well as for addressing societal challenges.

4.8. Synthesis

Table 4.14sets out the main achievements and challenges of the Korean research system, focusing on GRIs and HEIs.

Table 4.14. Korea's main achievements and challenges related to its research system

Achievements	Challenges
Research and innovation performance • Korea has the highest government expenditure on R&D in the OECD. • The share of the business sector's higher education expenditure on R&D is the highest in the OECD. • Korea has a very strong start-up support ecosystem, see, e.g. TIPS programme. • Korea has among the highest shares of graduates in science and technology fields and top-performing students in these fields.	Research and innovation performance • Despite significantly higher expenditure on R&D, research outputs in terms of quantity and quality are just on par with the OECD average. • Revenues from intellectual property are lower than in other OECD innovation leaders and remain stagnant. • Compared to other OECD innovation leaders, academic-industry co-publications are low and declining. • Korea is seeing strong skill discrepancies across age groups, with low ICT skills in the old-age population.

Achievements	Challenges
Government research institutes • Korean GRIs show, in part, successful adaptation in their role and contribution to research and innovation. • Some GRIs lead the innovation frontier and are active in highly innovative technology development and commercialisation.	Government research institutes • The rise in PBS funding may incentivise focusing on short-term priorities set by the government rather than impact. • GRIs are largely reliant on PBS, causing concern about the possibility of providing a long-term research orientation and profiling. • Despite the R&R exercise, it is unclear if R&Rs align with the national strategy or innovation system.
Higher education institutions • Higher education expenditure on R&D has strongly increased. • Korea has seen a strong performance of its IST universities and some flagship universities, including Seoul National University. • The role of HEIs has changed drastically since the 1990s and has pivoted towards assuming a key function in research and the national innovation system.	Higher education institutions • Tuition fee freezes, and sharply declining numbers of students exert pressure on HEIs, notably in rural areas. • Korean universities perform poorly in research quality-focused international university rankings, and there is a strong discrepancy between IST universities, SNU and other universities.
Knowledge flows between academia and industry • Korea has seen strong growth in patenting and technology transfer cases in the past two decades. • Korea sees a high number of industry-academia co-publications, above the OECD average (but declining). • According to Reuters, three Korean universities are seen as the top three innovative universities in the Asia Pacific based on patenting and the citation of basic research in patent applications.	Knowledge flows between academia and industry • Most collaboration occurs between academia and SMEs, driven by strong government subsidies, while collaboration with chaebols is less widespread. • There are insufficient incentives for top academics to engage in academia-industry collaboration. • There is a continued prevalence of supply push rather than demand-driven collaboration.

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Notes

1. GOVERD represents the component of GERD incurred by units belonging to the government sector. It is the measure of expenditures on intramural R&D within the government sector, including all units of central, regional or municipal government, including social security funds, and all non-market non-profit institutions that are controlled by government and that are not part of the higher education sector.

2. This ranges from 0.6-0.7% in emerging countries such as Islamic Republic of Iran and Indonesia, to 6.5% in Germany and 8.3% in Sweden.

3. It should, however, be noted that Sungkyunkwan University is owned by Samsung and therefore does not constitute a representative case for Korean universities.

4. The historic acronym stands for Conseil Européen de Recherche Nucléaire (European Council for Nuclear Research), reflecting the original focus on nuclear physics at its establishment in 1950. However, today the laboratory exclusively performs research in particle physics.

5. As of 1 August 2022, Albania, Armenia, Bosnia and Herzegovina, the Faroe Islands, Georgia, Iceland, Israel, Kosovo, Moldova, Montenegro, North Macedonia, Norway, Serbia, Tunisia, Türkiye and Ukraine have applicable association agreements in place. Discussions at various stages are in progress with Canada, Japan, Korea, Morocco and New Zealand. For more information, see https://research-and-innovation.ec.europa.eu/news/all-research-and-innovation-news/updates-association-third-countries-horizon-europe-2021-12-21_en and https://research-and-innovation.ec.europa.eu/strategy/strategy-2020-2024/europe-world/international-cooperation/korea_en.

6. For more information, see https://www.embl.org/partnerships/remote/australia; there is also a bioinformatics resource hosted at the University of Melbourne.

7. For more information, see https://www.nrf.re.kr/eng/page/31752ceb-b028-4721-a493-1d46d43b2285.

8. This is GT Online; see https://www.gtonline.or.kr/ for more information.

9. 2019 as the reference year; as in 2020, student mobility has subsided drastically due to the COVID-19 pandemic.

10. For more information, see http://nobelprize.org (2022).

11. For more information, see https://www.leidenranking.com/ranking/2021/list.

12. The ICT core test assesses the basic ICT skills needed to take the computer-based assessment, such as the capacity to use a mouse or scroll through a web page. For further information, see http://www.oecd.org/site/piaac/.

13. For more information, see https://www.kmi.re.kr/eng/main/main.do?rbsIdx=1.

14. RTOs are research institutes with a mission to support innovation in industry. They aim to have technological capabilities at least "a step beyond" those of many companies in industry. They generally work using a three-part "innovation model", in which the state provides core funding to allow the RTO to develop or acquire the needed technological capabilities. In a second stage, they tend to co-operate with more advanced users, who pay the project costs involved (but who are often in turn subsidised to do so via government innovation or R&D support programmes). This deepens the RTOs' technological capabilities, helps them understand how to apply them in industry and standardise or systematise them. In a third stage, the RTOs sell technical services such as measurement, testing, consulting, design, or certification, allowing them to support not only the more but also the less advanced companies. Thus, RTOs aim to offer advanced support to advanced users and less advanced support to those with lower levels of technological capability overall. A recent report from OECD on RTOs (including Korean GRIs) shows that these organisations play an increasing and changing role to support policies that tackle societal challenges.

15. Cluster analysis – or hierarchical cluster analysis (HCA) – is a method in data mining and statistics that seeks to build a hierarchy of clusters. Inspired by Shin (2009[30]), an agglomerative hierarchical clustering method called the Ward's method was applied. Ward's method performs clustering to minimise variance between different clusters, measured by the sum of squares index (E). A similar approach was applied to the top US universities for benchmarking purposes.

16. Such a score thus gives a normalised value of each variable, in that a positive score of *x* signifies a value which is above the average by *x* standard deviations; a score of zero gives a value that is within the average; a negative score of -*y* is a value below the average by *y* standard deviations.

17. Correlation value here refers to the linear correlation coefficient and is obtained by dividing the covariance by the product of the two variables' standard deviations. The range of values for correlation coefficient is -1.0 to 1.0, where -1.0 means perfect negative correlation and 1.0 means perfect positive correlation. Finally, a correlation coefficient of 0 indicates no relationship between the two variables.

18. Excellence indicates the amount of an institution's scientific output that is included in the top 10% of the most cited papers in their respective scientific fields.

19. See also STEPI (2021[62]).

20. These are: Space, Astronomy, Meteorology, Oceanography, Arcticology, Life, Nuclear Energy, Nuclear Fusion, Accelerator, IT, Mechanics, Construction and Transport.

21. The indicator measures the number of citations in patent filings of basic research originating at the university.

22. Educational Officials Act, Article 19-2 (Special Cases concerning Prohibition of Profit-Making Activities and Concurrent Offices). The Article may allow (associate/assistant) professors to serve as an outside director of a private company after obtaining permission from the head of the school, given that this activity does not interfere with the education of his/her students and academic studies.

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