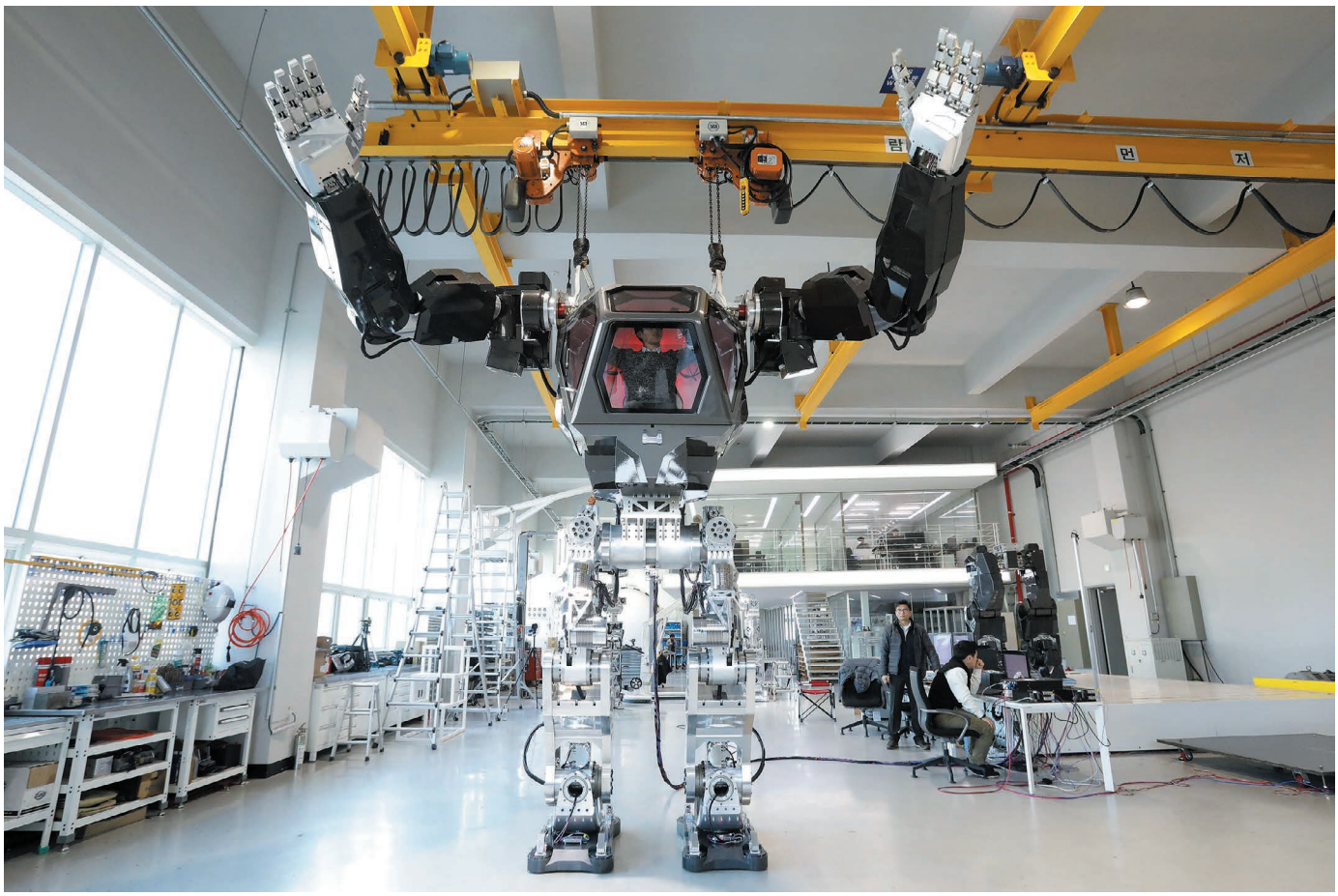
COMMENT



CHUNG SUNG-JUN/GETTY

A piloted walking robot developed by robotics company Korea Future Technology in Gunpo.

Restructure science in South Korea

To build on the success of its centralized research agenda, the nation must switch to projects led by independent principal investigators, urges **Han Woong Yeom**.

South Korean science is both flourishing and floundering. In some ways, things could not be better. National spending on research and development (R&D) by industry and government was 4.24% of gross domestic product (GDP) in 2016 — the second-highest percentage for any country worldwide (Israel was first, with 4.25%). For three decades, the government has invested billions of dollars each year in high-tech industry, turning South Korean electronics companies such as Samsung, LG and SK Hynix into world leaders.

Academic research is booming, in terms of the numbers of papers published and citations: in 2016, the nation ranked 12th and 13th, respectively (see go.nature.com/2jwxzcc). Institutes and facilities are being built. In 2011, the government ▶

HUBS OF ASIAN SCIENCE
A *Nature* collection
nature.com/collections/asianhubs

set up the Institute for Basic Science, a national network of research centres mimicking Germany's Max Planck Society. In 2017, it launched a world-class X-ray free-electron laser facility in Pohang[1], and in 2021, it will open a heavy-ion accelerator in Daejeon.

Yet many researchers are dissatisfied. In 2017, biologist Won-Kyung Ho at Seoul National University initiated a nationwide movement calling for more funding for projects proposed by individuals. In 2017, just 6% of the national research budget went to projects led by small research groups. The rest went to big, government-directed 'top-down' projects in strategic areas such as information technology, robotics, materials and biotechnology. This imbalance was arguably the biggest scientific issue discussed during the presidential election campaign last year.

Something is wrong with the South Korean R&D system, and everyone knows it. The country invests a lot but gets less and less back. Scientists feel disenfranchised by the government's opaque system for funding. The public is not seeing solutions to pressing problems, such as air pollution. Even government ministers and economists complain that all those highly cited papers are not generating enough new technologies.

But that is not so surprising. An approach that gets a nation from science infancy to adolescence might not be the best to take it to maturity. Now that South Korea's high-tech industry is world-leading, it no longer needs to be directed by the state.

The country's R&D is at a turning point. It needs a new strategy. South Korean industry must change from fast follower to first mover. Government R&D must pave the way. But I think that backing certain industries and technologies is no longer the best way to do it. A better bet is long-term support of basic science, investment in infrastructure and human capital, and addressing public issues.

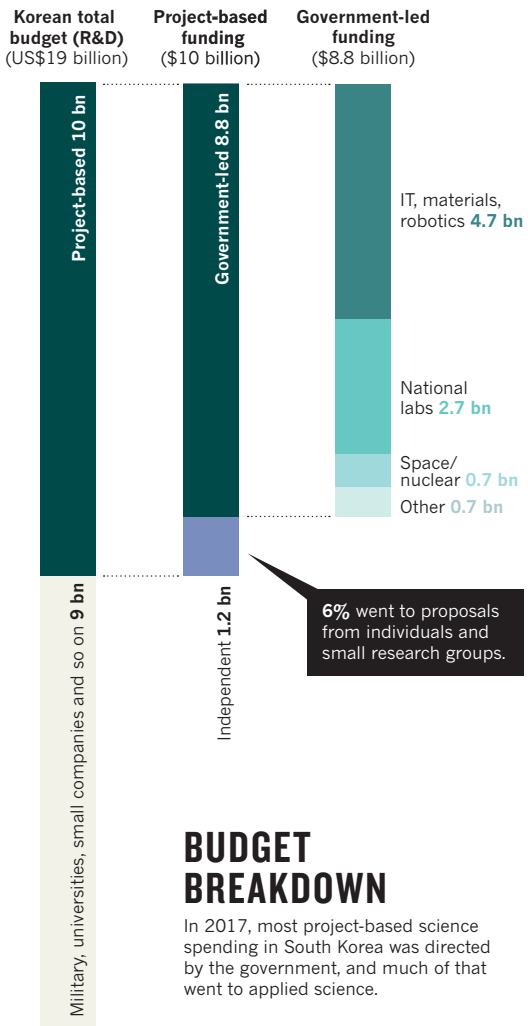
As vice-chair of South Korea's Presidential Advisory Council on Science and Technology, here I outline the three main challenges and some steps taken in response. I call for urgent discussions among scientists, industrialists and policymakers to forge a more effective path.

THREE PROBLEMS

Bottom-up basic research is underfunded. In 2017, only US$1.2 billion of South Korea's $18 billion of government research funding went to bottom-up (independent) basic research projects by individual investigators and small groups (see 'Budget breakdown'). Eighty per cent of these projects received less than $50,000 per year, which is insufficient to fund a globally competitive study. Just 11% of grants proposed by mid-career researchers were accepted last year. This is much less than the roughly 30% acceptance rate that is standard in the United States, the European Union and Japan.

This is mainly the result of previous governments' policies, which focused on strategic areas and the development of emerging technologies, industries and markets to fuel economic growth. For example, between 1999 and 2013, $1.4 billion went to 16 projects in the 21st Century Frontier R&D Program. These ranged from nanomaterials and nanodevices to proteomics and hydrogen fuel. Over the 2010–23 period, ten projects in the Global Frontier Program run by the Ministry of Science and ICT will consume similar budgets. Topics range from flexible electronics to biomedical technology.

This approach has produced a two-tier R&D system. Little has been spent on research infrastructure in universities, and young researchers find it hard to obtain start-up grants. By contrast, some leading Chinese universities offer start-up grants of $20 million to promising researchers in areas such as condensed-matter physics — ten times more than a South Korean scientist might expect. Unsurprisingly, many talented young physicists from South Korea now work in China.



SOURCE: SOUTH KOREAN GOVERNMENT

R&D is inefficient. South Korea produces many patents, but few innovations. For example, in 2016, South Korea ranked third in the world for the number of patents it filed, after the United States and Japan[2]. Yet the Netherlands, which ranked sixth and has one-quarter of South Korea's R&D budget, earned five times more in technology payments. South Korea scores low in terms of its 'innovation potential' (its ability to create and use innovations), which includes factors such as the quality of its research institutes, workforce and collaborations between universities and industry. The World Economic Forum's *Global Competitiveness Report 2017–18* lists South Korea as 26th in the world, behind New Zealand (13th), Taiwan (15th), Malaysia (23rd; see page 514) and Ireland (24th)[3].

Part of the problem is poor government leadership of R&D projects. Government-driven projects are often badly designed and can have unclear goals that fall below the standards used in industry. For example, the country's next-generation superconducting technology project began in 2001 without a clear idea of market needs, and ended up without any serious research output. None of the test products developed by the 21st Century Frontier R&D projects had a substantial market impact by 2013, when the initiative ended.

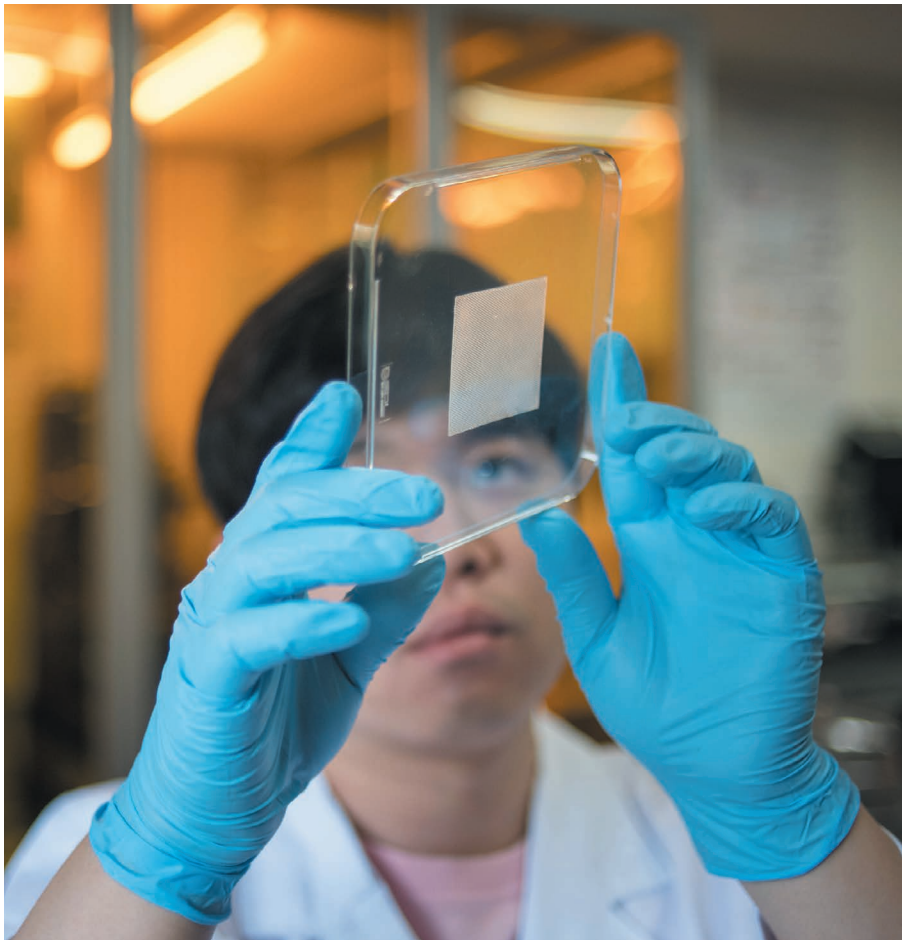
Unsurprisingly, industrialists, policymakers and the public are dissatisfied with the outcomes. Academics feel that mega-projects produce fewer papers and citations than would all the small, independent projects that could have been funded. International collaborations and the infrastructure needs of the science community are being neglected.

Public concerns are not being met. South Korea's citizens feel that they are paying for science that is not addressing their problems. Severe air pollution is the main example. South Korea's air has the highest concentration of fine particulates (PM_{10} and $PM_{2.5}$) out of the 34 countries in the Organisation for Economic Co-operation and Development: triple that of the United States and twice that of Japan. Neither the government nor the scientific community collects proper data on air quality or health impacts.

In South Korea, the proportion of people aged over 65 is increasing at the highest rate in the world. Conditions such as Alzheimer's disease have become a major social issue. Yet there is no clear national R&D strategy for this.

Several crises have further undermined

ED JONES/AFP/GETTY



An engineering student at Sung Kyun Kwan University near Seoul inspects a wet-tolerant adhesive patch inspired by the suckers found on octopus tentacles.

the public's trust in the science system. One was the magnitude-5.4 earthquake in my home city of Pohang in November 2017, which was possibly caused by a geothermal power plant injecting water into a fault zone[4]. Another was the deaths of more than 100 people — including children and their mothers — which were linked in 2011 to inhalation of toxic disinfectants that had been sold for use in home humidifiers since 2001. In both cases, scientists and the government were criticized for dodging their responsibilities.

POLICY DRIVES

The current government acknowledges all of these problems. Within two months of winning the election in May 2017, it proposed policy changes in three areas over the next five years. These are welcome, but leave many issues unaddressed.

First, the government will double the budget for bottom-up research proposals, reaching $2.2 billion in 2021. This is a good start. But universities and national labs need improvements to infrastructures, core facilities, technical capacities and research administrations. Students and postdoctoral researchers need more financial support. Addressing all of these areas could require as much funding again.

Second, more government initiatives will focus on societal issues, such as air pollution, earthquakes, chemical hazards, infection, climate change, Alzheimer's disease and renewable energy. However, this doesn't solve the inefficiency problem with government-led programmes. I am already seeing poorly designed and badly directed projects being set up, such as those on environmental issues and emerging technology. Late last year, South Korea's president, Moon Jae-in, called for improvements to the planning and organization of R&D projects, but these have yet to take effect.

"Something is wrong with the South Korean R&D system, and everyone knows it."

Third, industrial support needs reform. It is unclear which directions will most benefit the economy and where top-down involvement will be most effective. The current government is betting on the 'fourth industrial revolution' to generate commercial opportunities and quality jobs in artificial intelligence, data science, ultrafast mobile communication, the Internet of Things, smart cities, bioinformatics and so on. But artificial intelligence could take away as many jobs as it creates, for example. In my view, the concept of the fourth industrial revolution is too vague to pin taxpayers money on.

Furthermore, these three policy drives will squeeze budgets in other research areas. There is no clear idea which areas those should be.

OPEN DIALOGUE

I don't have all the answers. But the first thing that needs to happen is a frank and honest debate. Whatever policy we want to make or whichever problem we want to solve, openness and rigour will reduce the possibility of major errors.

I would like to see more scientists getting involved in policymaking in South Korea. I will seek to establish a culture that makes it routine for the government and the scientific community to hold regular, transparent, evidence-based discussions. As a first step, the Presidential Advisory Council on Science and Technology will look at South Korean R&D directions and at ways to strengthen its research institutes.

The roles of government and industry need to be reset in light of the rapidly changing global economy. Sweden, for example, has come under fire in the past for its high R&D spending and low output[5]. The rate of innovation is slowing worldwide[6], and each advance is becoming more expensive. For example, with silicon technology approaching its fundamental limit, the cost of creating computer chips that are ever smaller has exploded.

South Korean science has come a long way in the past 30 years. The challenges it faces present a great opportunity: it is time for South Korea to reposition itself to deliver the best science, innovations and solutions for its people. ■

Han Woong Yeom *is professor of physics at Pohang University of Science and Technology and director of the Center for Artificial Low Dimensional Electronic Systems at the Institute for Basic Science, Pohang, South Korea. He is vice-chair of South Korea's Presidential Advisory Council on Science and Technology.*
e-mail: yeom@postech.ac.kr

1. Kang, H.-S. *et al. Nature Photon.* **11**, 708–713 (2017).
2. Organisation for Economic Co-operation and Development. Patents Database (OECD, 2016); available at https://stats.oecd.org
3. Schwab, K. (ed.) *The Global Competitiveness Report 2017–2018* (World Economic Forum, 2018).
4. Kim, K.-H. *et al. Science* **360**, 1007–1009 (2018).
5. Bitard, P., Edquist, C. & Rickne, A. in *Small Country Innovation Systems: Globalisation, Change and Policy in Asia and Europe: Theory and Comparative Framework* (eds Edquist, C. & Hommen, L.) Ch. 7 (Edward Elgar, 2008).
6. Youn, H., Strumsky, D., Bettencourt, L. M. A. & Lobo, J. *J. R. Soc. Interface* **12**, 20150272 (2015).