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Can Bureaucrats Stimulate High-Risk High-Payoff Research?

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Can Bureaucrats Stimulate High-Risk High-Payoff Research?

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Abstract

Despite the world-highest expenditure in R&D as a percentage of GDP, there is a rising concern that Korean researchers in universities and government-funded research institutes (GRIs) are contributing neither to creating new opportunities for the economy nor to solving big societal challenges. Based on the international comparison of academic papers, patents and technology transfers, this paper shows Korea's poor performance in high-risk high-payoff research. We also point out that the root cause of such low performance in high-risk high-payoff research is a heavy-handed control over research communities by bureaucrats in ministries. This paper suggests several reform agendas for removing excessive bureaucratic controls and strengthening the autonomy of the funding and project agencies, GRIs, and research universities.

I. Introduction

In 2012, Korea's expenditure in research and development (R&D) as a percentage of GDP reached 4.3%, which was the highest in the world. Korea also has the largest number of researchers per total population among the top 10 countries in R&D expenditure (Lee et. al, 2014). In particular, Korea is home to several large conglomerate firms such as Samsung and Hyundai which are leading the world in innovative products. However, there has been a rising concern that Korean researchers in government-funded research institutes (GRIs) and universities are contributing neither to creating new opportunities for the economy nor to solving big societal challenges (Song et al., 2014).

Despite reform attempts of almost every administration since the 1990s, there still remain strong criticisms that Korea has not successfully transformed its innovation model from 'fast-follower' to 'first-mover' (Kim, 1997; Song et al., 2006; Lee, 2013). One of the main criticisms was that the Korean innovation ecosystem is lacking 'high-risk high-payoff research'. Following the Korean National Science and Technology Committee's guideline on innovative R&D projects in 2013 (NSTC and MSIP, 2013), we define high-risk high-payoff research as research that contributes significantly to academic development, improvement of public welfare, or the creation of new products, jobs, and even industries[1].

While most advanced countries[2] including the United States are creating consensus on the importance of high-risk high-payoff research in their transformation toward a more innovative economy[3], stimulating high-risk high-payoff research stands out as a daunting challenge to Korean policy makers concerning R&D for two major reasons. First, our data analysis shows very poor performance in high-risk high-payoff research in Korea despite its huge investment on R&D. Second, we argue that a heavy-handed control of bureaucrats in ministries is interrupting high-risk high-payoff research. That is why this paper is investigating the question, 'Can bureaucrats stimulate high-risk high-payoff research?'

This paper is organized as follows. Section 2 validates Korea's weakness in high-risk high-payoff research through data analysis. Section 3 examines how excessive bureaucratic control is interrupting high-risk high-payoff research in the national R&D program (NRDP). Section 4 suggests several reform agendas for removing excessive bureaucratic controls and strengthening autonomy of funding and project agencies, public research institutes, and research universities. Section 5 concludes.

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[1] DARPA defines the ambitious goal of its projects as "designed to push the boundaries of science to solve urgent real-world problems or create new opportunities" (Dugan and Gabriel, 2013, p.76). The National Academy of Sciences defines 'transformative research' as "research driven by ideas that have the potential to radically change our understanding of an important existing scientific or engineering concept or leading to the creation of a new paradigm or field of science or engineering. Such research also is characterized by its challenge to current understanding or its pathway to new frontiers" (National Science Board, 2007, p.10). The NSF's definition about transformative research leans more toward academic research, whereas the goal of DARPA research leans more toward use-inspired research. The definition of high-risk high-payoff research in this paper contains the elements both from DARPA research and the NSF's transformative research.

[2] Many countries and organizations, such as the European Union's Frontier Research, the United Kingdom's High Potential High Impact Research, and Finland's Breakthrough Research, are all putting their efforts to create an environment for high-risk high-payoff research (Cha et al., 2007).

3The National Academy of Sciences pointed out that funding agencies in the United States have a systematic problem of avoiding high-risk research, and suggested that support for high-risk high-payoff research be largely increased (National Academy of Science, National Academy of Engineering, and Institute of Medicine, 2007).

II. Poor Performance in High-Risk High-Payoff Research

This section examines whether and to what extent high-risk high-payoff research is weak in Korea, based on international comparison of major R&D outputs such as published papers, patents and technology transfers.

2.1. Academic Papers

Recently, an increasing number of countries have been evaluating university professors based on their academic papers. Corporate sectors are also putting higher values on academic papers that are published in renowned academic journals and have a high number of citations (Dosi et al., 2005). Analyzing the data provided by Thomson Reuter's Web of Science, we compare the quality of papers in Korea with that of other countries.

2.1.1. Quantitative Expansion

Before looking into the quality of papers, we first examine the quantitative expansion of papers published by Korean scholars. As illustrated in Table 1, Korea published a total of 275,000 international academic papers in the past 10 years (based on papers registered on SCI and SSCI DB), among which 105,000 papers are from 2001~2005 and 170,000 papers are from 2006~2010. This increase of 62.5% is very rapid compared with other countries. Relatively, this trend is similar to that of Taiwan's, but is quite fast when compared with western countries. But against China, Korea's increasing trend in the number of papers is only half as fast. In the early 2000s, 252,000 papers were published from China, and in the latter half of the 2000s, 551,000 papers were published, which increased by 119%. Before the 21st century, from 1993~2001, the increase rates of the number of published papers and citations were highest in Korea and China, and while Korea showed a linear growth, China was characterized by an exponential growth (Leydesdorff and Zhou, 2005). In the 21st century, the increase rate for China began to excel and it exceeded Korea by two folds.

In examining the number of papers per researcher, Korea published 0.64 papers between 2006~2010, which is higher than China (0.46) and Japan (0.58), yet it is lower than Taiwan (0.84). Even more, western countries such as the United States, Germany, and France produced twice as many papers as Korea; 2.7 times as many in the United Kingdom and Canada, and 3.6 times as many in Italy. Compared to the early years, the number of papers per researcher in Korea increased by 10.7%, yet it is still lower than the United States (13.0%), Taiwan (13.3%), the United Kingdom (14.2%), and Canada (22.8%). In the same period, China's number of papers per researcher increased by 102.4%, which is 10 times more than Korea's rate of increase. Relatively, Korea's rate of increase in the number of papers per researcher is not as fast compared to other countries.

In other words, the rapid increase in the number of published papers in Korea is mainly due to the rapid increase in number of researchers, and in contrast the increasing speed of the number of published papers per researcher is relatively slower than other countries. Considering that universities tend to produce papers more actively than the private or public sector, higher expenditure for R&D in the public sector, including GRIs, compared to the university sector from 2005~2010 could be a reason why Korea's rate of increase in the number of papers per researcher is falling behind other high performing countries.

In terms of the number of papers per thousand population (as of 2010), Korea produced 3.4 papers, which is the lowest compared to western countries, and even lower than Taiwan (4.6 papers). In 2005, Japan had produced 3.0 papers per thousand population, which had been higher than Korea (2.2 papers) and Taiwan (2.9 papers). Yet, as of 2010, Japan's number remained the same and its ranking was overtaken by Taiwan (4.6 papers) and Korea (3.4 papers). Such stagnation of academic papers in Japan might be related to its 20 years of economic recession (Hamada et al., 2011).

2.1.2. Sluggish Increase in Highly-Cited Papers

The number of citations can be an important indicator for considering whether and to what extent an academic paper is the outcome of high-risk high-payoff research. Highly-cited papers are generally defined as the papers that rank in the top 1% by citations for an academic field. As the total number of papers increases, the number of highly-cited papers would increase, yet we are now focusing on the papers that were published between 2002 and 2011. In the first five years, 2002~2006, a total of 167,189 papers were highly-cited, and in the latter five years, 2007~2011, a total of 273,516 papers were highly-cited.

As can be seen in Table 2, the number of the highly-cited papers in Korea increased from 1,620 in the first five years to 3,231 in the latter five years, and its total share increased from 1.0% to 1.2%. Compared to that, China's share rapidly increased from 2.4% to 3.9%, and Taiwan's share also increased from 0.4% to 0.7%. Moreover, the share of the highly-cited papers has been increasing for western countries such as Germany, France, the United Kingdom, Canada, and Italy. The share of the highly-cited papers for the United States decreased from 49.7% to 41.6%, but the dominance of the US still remained. In the latter five years, the number of the highly-cited papers per thousand researchers in Korea was 12.2, which was higher than China (8.8) but still lower than other countries. Compared with Korea, the United States (6.6 times), the United Kingdom (6.5 times), and Germany (4.4 times) have much higher numbers of the highly-cited papers per thousand researchers. Also, the increase rate of the highly-cited papers per thousand researchers in Korea (35.8%) is lower than other countries except Japan (27.5%) and the United States (33.4%). While Korea has been reducing the gap with other advanced countries in the number of papers and their citations (Lee et al., 2014), its share of the highly-cited papers, which is an important indicator for high-risk high-payoff research outcome, is significantly lower than western countries and that gap has yet to be reduced.

Here, we need to pay attention to China's growth. In terms of the number of papers and citations, China showed a remarkably rapid increase, two times the rate of Korea, but in terms of the highly-cited papers, its size is even three times larger than that of Korea. In particular, in the fields such as material engineering (14.1%), engineering (13.1%), chemistry (10.3%), and mathematics (10.9%), China emerges as competitive, raking 2nd in the world in the number of the highly-cited papers.

The widening gap in highly-cited papers between Korea and other high performing countries is related to the academic capacity of Korea's research universities. The Shanghai Jiao Tong University's Academic Ranking of World University (ARWU) announces the top 500 universities in the world based on quantitative measures of academic research outcomes. As observed in Figure 1, the number of Korean universities among the top 500 increased from 8 in 2004 to 10 in 2012[4] and Korea reached the 13th place in terms of the number of the included universities. On the other hand, the number of Chinese universities (including Hong Kong) started from 13 in 2004 and rapidly increased to 37 in 2012 and its ranking rose from

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[4] Korean universities included in the list were Seoul National University (101-150th place), Korea Advanced Institute of Science and Technology (KAIST), Sung Kyun Kwan University, Yonsei University, Hanyang University, Korea University, Pohang University of Science and Technology (201-300th place), Kyung Hee University, Kyungpook National University, and Pusan National University (410-500th place).

9th to 4th place. Thus, among the countries outside the United States, China has become one of the countries with the most world-ranking universities, in line with Germany and the United Kingdom. Japan displayed a contrasting change with China, as the number decreased from 36 to 21 and the ranking correspondingly went down from 4th to 9th place over the same period.

2.2. Patents and Technology Transfer

It is important for high-risk high-payoff research not to be confined to academia, but to be extended to commercialization and entrepreneurship, which will then further lead to value added results and job creation. In order to examine whether and to what extent high-risk high-payoff research is weak in Korea, we compare patents and technology transfers in Korea with those in other countries.

2.2.1. Quantitative Expansion

As can be seen in Figure 2, the number of applied or registered patents with the Korean Intellectual Property Office (KIPO) has increased rapidly. The increasing trend of patent application is outstanding after the mid-1990s, and although there were slumps during the Asian financial crisis in 1997 and the global financial crisis in 2008, the trend has been restored and shows a continuous increase. It appears that there is a 2~3 year time difference between patent application and registration, and while patent registration also shows an increasing trend, its rate of increase is relatively lower than that of patent application.

As of 2012, the share of domestic inventors and businesses was 78.4% for the number of patent application and 79.7% for the number of patent registration respectively. The share of domestic registration has been rising in recent years, which suggests that the rapid increase in the number of patents after the 2000s has mainly been facilitated by domestic inventors and businesses.

Figure 3 shows the number of PCT patent applications by country. As of 2012, Korea applied 11,846 patents and ranked 5th in the world after the United States, Japan, Germany, and China. The number of patent applications for Korea is relatively high compared to advanced countries such as France, the United Kingdom, and the Netherlands, implying that Korea’s production of patents is high for its size of the economy. Also, in terms of the number of triadic patents, Korea registered a total of 2,223.1 patents in 2010, allowing Korea to rank 5th after Japan, United States, Germany, and France (OECD, 2012). Although Korea has been successful with the quantitative expansion of patents, its ranking slightly decreases when the population size is considered: The number of triadic patent per 100 population in Korea was 45.0 cases, which is higher than the OECD average (30.35), but Korea ranks 10th among OECD countries, behind many western countries. Korea’s overall outstanding record in patent production is also visible in the US patent statistics. According to the United States Patent and Trademark Office (USPTO), as of 2011, Korea registered 246.3 patents per 100 population, which was higher than the OECD average (94.3 cases) and ranked 4th, behind Japan, United States, and Israel. This result implies Korean companies' strong presence in and targeting on the US market. .

2.2.2. Declining Role of GRIs in Patents

One of the distinct features that appear in Korea’s patent statistics is the decline of patents by GRIs. Figure 4, analyzing the applied and registered patents with KIPO by sector, shows that although the business sector is dominant in patenting, its share has been decreasing recently.

The business sector’s share in patent application decreased from 94.4% in 2000 to 79.3% in 2011, and in particular, its downturn is significant after the mid-2000s, and universities are filling this gap. The share of patent application by universities and the public sector were 1.15% and 4.47% respectively in 2000 and increased rapidly to 10.63% and 10.12% in 2011. Rise in the universities’ share of patent application suggests that universities are not only focusing on traditional functions such as education and research, but also playing an increasing role in the technology development and commercialization.

Although Korean universities already had relatively high shares in practical or development research, patents produced by universities was insignificant until the mid 2000s, where their patent production started to grow substantially. This result implies that the R&D cooperation, which had previously been led by GRIs, has moved to universities as a result of various efforts to disseminate R&D outcomes in universities by establishing R&D foundations and creating industry-academia technology holding companies as well as start-ups.

Patents by the public sector, including GRIs, did show an increasing trend during the period of 2000-2010, yet they fell short of universities. It is quite disappointing to see that the GRIs, which had played a vital role during the government-led development stage until the early 1980s, has been weakened in terms of patent production. The share of the public sector in patents was four times higher than that of universities until 2000, yet within 10 years, its share was overtaken by universities.

Observing the patent applications by institutions, the National Statistical Office (NSO) reported that, as of 2013, only four GRIs were included in the top 30 institutions, which were Electronics and Telecommunications Research Institute (ETRI, 2563 patents), Korea Institute of Machinery and Materials (KIMM, 552 patents), Korea Electronics Technology Institute (KETI, 468 patents), and Korea Institute of Science and Technology (KIST, 461 patents). On the other hand, in terms of the number of patent registration by institutions, four GRIs were included among the top 30 institutions, which were ETRI (819 patents), KIMM (471 patents), Agency for Defense Development (ADD, 401 patents), and KIST (378 patents).

It might be unfair to evaluate the performance of GRIs, solely based on the number of patents, because they have been putting more weight on basic research in recent years. However, as we will discuss in the next section, it is important to note that GRIs are currently using about 40% of government’s R&D budget and the problems involving their status and role in the innovation eco-system has been existent since the early 2000s, as their role has not been clearly distinguishable from universities.

2.2.3. Problems in Technology Transfer

High return to R&D presupposes that knowledge and technologies developed by universities and GRIs are actively transferred to the private sector. While patents may secure an exclusive right for technology innovators, technology transfers disseminate the developed technologies to a wider group of final users. Technology transfer can be divided into domestic and international technology transfer. While the number of technology transfers and the amount of royalty earnings are usually used as indicators for domestic technology transfer, technology trade statistics are used as indicators for international technology transfer.

Figure 5 shows the result of a survey on domestic technology transfers, and it appears that the number of technology transfer cases increased consistently in the period between 2007 and 2011. We can also observe that compared to public research institutes including GRIs, the technology transfer of universities has rapidly increased during this period, and the gap is widening. Also, this survey presents the ‘technology transfer rate’, which is calculated as a ratio of the number of technology transfer cases to the number of newly obtained and developed technology cases. While the technology transfer rate for public research institutes sharply declined in the 2007-2008 period, the rate for universities remained at the 15~16% level.

Although the number of technology transfer cases rose in universities and public research institutes, their royalty earnings from technology transfers remained strikingly insignificant. Figure 6 illustrates changes in royalty earnings for public research institutes and universities respectively, and though universities reported more cases of technology transfer than public research institutes, as of 2011, public research institutes made 7 times more in royalty earnings than universities. In particular, the royalty fees from the patents on wireless communication, developed by ETRI, contributed significantly to such earnings. However, we need to pay attention to the fact that the share of public research institutes in royalty earnings continuously fell from 86% in 2007 to 66% in 2011. Thus, as the quantitative expansion of technology transfers by universities led to increases in royalty earnings, the gap between universities and public research institutes on royalty earnings has decreased. The problem is that despite a total of 15,000 technology transfer cases, royalty earnings for universities and public research institutes in 2011 were only 11.7 billion KRW and 83.2 billion KRW respectively.

As shown in Figure 7, royalty earnings per technology transfer in 2011 were 10 million KRW for public research institutes and 4 million KRW for universities. Between 2007 and 2011, although there was a slight increase in universities’ royalty earnings, there was a significant decrease for public research institutes. In regards to this, Suh (2010) points out that the number of patent applications by Korean universities can be weighed against the US universities. When the royalty earnings from technology transfer are compared to the amount of research funding, however, the figure for Korea is only 0.8%, much lower than the countries such as the United States (5.3%), the United Kingdom (2.1%), and Canada (1.0%), showing that the number of patents is not paralleled with the share of "high-impact" patents.

Such weak royalty earnings of universities and public research institutes are also closely related to their lack of incentives to obtain R&D funding from the private sector. An examination of R&D financing flows shows that, as of 2011, 93.1% of public research institutes’ R&D expenditure and 88.6% of universities’ R&D expenditure came from the public sector. This result is not surprising, since public research institutes and universities are heavily relying on National R&D Program (NRDP) in Korea. However, the fact that the share of R&D funding from the private sector to universities is only 11% and to public research institutes is only 6.3% reflects the situation where R&D cooperation among the public sector, academia, and the private sector is relatively weak. Even worse, the share of R&D funding from the private sector to universities has decreased ever since 1999. Furthermore, the share of foreign funding is at an insignificant level, which exemplifies Korea’s weaknesses in terms of openness of research communities.

Technology transfers between countries take place in two forms: one is through international trade of goods and services where technologies are embodied, and the other is in disembodied form through technology trade. Usually, data on international trade, especially on import and export of intermediary goods, is used in assessing the embodied technology transfer. In contrast, data on technology export and import is used for analyzing disembodied technology transfer. Under the global economic environment, an embodied form of overseas technology transfer could be a major route for technology transfer between countries, but the outcomes of technology trade may still be useful indicators in analyzing the level of technology transfers or technology capacity of an individual country.

As observed from Figure 8[5], Korea's technology export in 2011 was around 4 billion USD while technology import was 9.9 billion USD, resulting in a deficit of 5.8 billion USD (National Science and Technology Council (NSTC) and Korea Institute for Advanced Technology (KIAT), 2012, p.21). Statistics after 1995 shows an increasing trend for both technology import and export, but technology import has increased faster, thus leading to a rise in the technology trade deficit (NSTC and KITA, 2012, p.22). The ratio of technology trade is calculated by dividing technology export by technology import, and this figure for Korea was 0.41 in 2011, with a steadily rising trend.

Figure 9 compares the ratio of technology trade among OECD countries, and Korea's export and import of technology are noticeably smaller than other technologically advanced countries. For most technologically advanced countries, the ratio of technology trade is higher than 1, while the ratio for Korea is below 0.5 (NSTC and KITA).

These results indicate that Korea's R&D results and technologies are being transferred to overseas mainly through trade in goods and services rather than real technology trade. It is clear that under the global economic circumstances, an embodied form of technology transfer may become a major route. However, Korea is still showing weaknesses in overseas technology transfers in a disembodied form compared to technologically advanced countries, despite its considerable size of R&D spending.

In summary, Korea has achieved a quantitative expansion in producing academic papers and patents, but still shows poor performance in highly-cited papers, which can be regarded an indicator of high-risk high-payoff research that is conducted mainly by research universities; the share of GRIs in patents and technology transfer is continuously decreasing; royalty earnings from technology transfer for both universities and GRIs remain insignificant; and the balance of technology trade, though improving, still shows deficit. These major findings clearly point out Korea's stagnation in high-risk high-payoff research.

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[5] Data on technology trade was collected in a manner consistent with the OECD guideline on technology balance of payments (TBP) statistics. The OECD defines technology trade as "international and commercial trade directly related to technology and technology service" (OECD, 1990). Forms of the trade include (1) patents or know-how, (2) trademarks, designs, patterns, (3) technology service, and (4) R&D commissioned to overseas (National Science and Technology Council and Korea Institute for Advanced Technology, 2012, p.8).

III. Bureaucratic Control over National R&D Program (NRDP)

The main argument of this paper is that excessive bureaucratic controls lie at the center of the stagnation in high-risk high-payoff research, as Korea has dragged its feet in transforming the role of government and empowering project and funding agencies, GRIs, and universities. Government interventions and regulations, which had worked very effectively until the early 2000s, by which Korea had been a rapid follower of advanced countries' technologies, have been interrupting high-risk and high-payoff research in a period where Korea is struggling to become a first-mover in innovation.

As an economy approaches the technology frontier, already shown in the case of Korea, R&D-based innovation becomes more important, and the cost of regulations that limit competition increases at the same time (Acemoglu et al., 2006). Then, the government should focus on the role as a public investor instead of intervening in the detailed process of R&D (Lerner, 1999; 2002), and it should promote partnership among universities, private companies, and GRIs rather than try to retain control over the commanding heights of the innovation eco-system (Song et al., 2006). Unfortunately, Korea's reform to develop autonomous capacity of project and funding agencies, GRIs, research universities has been delayed continually.

Finland, which has successfully transformed its innovation system from a fast-follower model to a first-mover one, minimized the government's market intervention by reducing direct support for industrial subsidies, which had worked to delay adaptation to market changes, and increasing indirect supports (Song et al., 2006). But in Korea, direct government supports for R&D in small and medium sized firms (SMEs) failed to strengthen their autonomous R&D capacity, and as SMEs became more reliant on such support, their productivity stagnated, even though R&D investments by SMEs have continuously increased according to administrative data (Kim, 2008).

In this section, we will first examine the NRDP that is financed by the government budget, and will discuss the different types of bureaucratic control over research in Korea.

3.1. NRDP

In accordance with the Framework Act on Science and Technology of 1999, the Korean government annually conducts surveys, analyses, and evaluations on NRDP, which include all R&D projects supported through the government's R&D budget. As the NRDP has expanded greatly, so has the control of bureaucrats in ministries over research communities.

3.1.1. Quantitative Expansion

As presented in Figure 10, Korea's investment in R&D was initially led by the government until the 1970s, and the investment by the private sector and universities began increasing rapidly later since the 1980s. As of 2012, the total volume of national R&D investment corresponds to 4.36% of GDP, which surpasses Israel (4.20%) to make Korea number one in the world. In this process, the government's R&D budget has constantly been increasing.

An annual report on survey and analysis of NRDP presents a rapid expansion of budget on NRDP (MSIP and KISTEP, 2012). Figure 11 shows that while 2.5 trillion KRW had been used for 13,715 R&D projects in 1998, the corresponding figure increased up to 15 trillion KRW (approximately 15 billion USD) for a total of 49,948 projects in 2012. In 15 years, the number of projects increased by two folds and the budget became six times as large.

As of 2012, there were 30,017 principal investigators (PIs) for national R&D projects, which is smaller than the number of projects, because a researcher could be in charge of multiple projects. Divided by their affiliated organizations, 50% of the PIs were from universities, 25% from SMEs, 10% from GRIs, and 3% from conglomerate firms, and such a composition has remained relatively unchanged. The share of PIs from universities and SMEs was higher than their respective share of funding, because the PIs in these sectors tended to carry out small-size projects. The result also reflects the tendency of university professors to participate in small-size bottom-up projects in which they choose their own research topic, while researchers from GRIs and conglomerate firms participate in large-size top-down projects where they approach projects with pre-determined objectives in specific areas.

Table 3 shows the top 50 beneficiaries of the NRDP grants in Korea in 2012, and the Agency for Defense Development (ADD) is the highest with a budget of 12,616 million KRW, followed by Electronics & Telecommunications Research Institute (ETRI), Defense Acquisition Program Administration, Korea Atomic Energy Research Institute, Seoul National University, and KAIST. Compared to the ranking for 2004, large enterprises such as the Korea Aerospace Industries, LIG Nex1, and Korea Hydro & Nuclear Power Co., Ltd., entered the top ranking in 2012.

3.1.2. Increased Support for Basic Research at GRIs

Figure 12 examines the changes in the composition of the NRDP expenditure and shows that the share of basic research has continuously increased, while the share of applied and development research has decreased. The share of basic research began to increase rapidly from 18.5% in 1998, particularly after the mid-2000s, reaching 33.8% in 2012. This expansion of basic research was actively promoted in line with Korea’s efforts to transform itself from a fast-follower to a first-mover. But what should be important is not the quantitative expansion of basic research, but how to vitalize high-risk high-payoff research in order to create new opportunities and solve important problems through convergence between basic, application, and development research.

Figure 13 shows the changes in the share of NRDP expenditure by sectors, and the share of national research institutes sharply decreased from 10.4% in 1998 to 4.8% in 2012. Universities, business conglomerate firms, and SMEs increased from 20.2% to 23.4%, 6.7% to 9.1%, and 12.1% to 13.2% respectively in the same period. What is to be noted is that the share of GRIs is sustained at the 40% level. As we described in the previous section, GRIs’ outcomes in papers, patents, and technology transfer and commercialization are relatively low compared to universities, yet supports for GRIs still continue. Of course, the NRDP expenditure data includes personnel costs for GRIs, while those costs are excluded for universities and business enterprises. However, it would pose a problem to maintain a proportional increase in support for GRIs that have not succeeded to bring out significant outcomes vis-à-vis research universities.

One factor contributing to this result is that GRIs have been controlled by bureaucrats more easily and more tightly than research universities. Under this circumstance, bureaucrats may find it in their best interests to distribute research funding to the institutions that can be easily controlled rather than to the institutions that could produce more research outcomes.

By comparing Figure 12 and Figure 13, it becomes clear that the increase in the share of basic research was not due to a larger investment into universities. In fact, the share of basic research in the R&D expenditures at universities decreased from 59% in 1998 to 48.7% in 2012, but the corresponding share for GRIs increased substantially from 9% to 36.8%. As industry-academia collaborations are emphasized in universities, they are no longer solely focusing on basic research. On the other hand, basic research in GRIs had been weak until 1998, but they were using more than one-third of their R&D expenditure for basic research in 2012, which largely contributed to the rising share of basic research in the NRDP budget. With a strong government drive for basic research, we could have expected positive changes of GRIs, especially in terms of high-risk high-payoff research, but the above-mentioned disappointing outcomes suggests that GRIs' transformation in its role and function is hardly enough to meet these expectations.

In other words, basic research and early-stage applied research of GRIs, through the strengthened support by NRDP, are designed to fuel a whole innovation eco-system (PCAST, 2012). However, much more needs to be done to enable NRDP and GRIs to help build platforms for new products, jobs, and even new industries.

3.1.3. Weak Support for High-risk High Pay-off Research

Federal agencies in the United States have been advised to have portfolios that strategically support a mix of revolutionary (or high-risk high pay-off) vs. evolutionary research; disciplinary vs. interdisciplinary work; and project-based vs. people-based awards (Azoulay et al., 2011; PCAST, 2012). Although data on NRDP in Korea does not include a direct measurement of the support for high-risk high pay-off research, it does have some information on the support for interdisciplinary and collaborative research and the people-based funding, both of which possibly encourage high-risk high pay-off research.

The trend of interdisciplinary research in Korea's NRDP can be observed through the category of 'convergence projects' in Table 4. In NRDP, a project that falls under more than two categories of national science and technology standard is classified as a convergence project. Recently, as the government has actively promoted the convergence project, its share in NRDP increased from 9.4% in 2009 to 13.2% in 2012. Divided by the discipline, fields such as materials (26.0%), chemistry (24.7%), physics (24.6%), and bioscience (20.1%) show higher numbers of convergence projects than others.

While most of the NRDP funding is project-based, the National Scientist Program is a representative case of people-based funding, which annually provides the highly renowned researchers with a grant of 1~1.5 million USD for the first five years. Following an assessment of whether the researcher has originality, the research outcome has impact, and the researcher has world-wide reputation, a decision is made on whether or not the support will be extended for five more years. This program started in 2005 with the objective of supporting high-risk high-payoff research, and until now 5 researchers have been awarded. Other examples of people-based support are the Global Ph.D. Fellowship and the Presidential Post-Doc Fellowship Program, both of which started in 2011. While the National Scientist Program supports researchers who have already earned high reputation in academia, these two programs target graduate school students or researchers who are just beginning their careers as a researcher. The Global Ph.D. Fellowship is awarded to 200 masters and doctorates each year and, once selected, they receive 30,000 USD annually, which can be renewed for three more years upon an evaluation result. Also, annually 15 fellows of the Presidential Post-Doc Fellowship Program receive 1.5 million USD for 5 years. Despite such progress, people-based funding in Korea is still only given to a relatively small number of researchers and is much weaker than the project-based funding (Lee et al., 2012).

In terms of collaboration between organizations, in 2012, government-university-industry research collaboration was 28.0%, industry-university research collaboration was 27.2%, industry-government collaboration was 13.4%, and industry-industry collaboration was 13.3%. This result suggests that businesses are the most active partner in inter-organizational collaboration and that industry-government collaboration is weaker than industry-university collaboration, which reflects GRIs' lack of collaboration with other institutions. Divided by financing ministries, the projects financed by the Ministry of Education are the smallest in size and their share in collaborative projects is only 3.3%. In contrast, more than half of the projects financed by the Ministry of Trade, Industry and Energy (MOTIE)[6] are carried through industry-university collaborations and they make up over 81.6% of the total collaborative research in the NRDP. In regards to the countries carrying out collaborative research with Korea, the US ranks first with 342 projects (39.4%), followed by Germany (60 projects, 6.9%), and Japan (58 projects, 6.7%). But the share of international collaboration is less than 1% of the NRDP.

That being said, a greater emphasis is being given to interdisciplinary and collaborative research and the people-based funding for the promotion of high-risk high-payoff research, although the overall level is still weak. Interdisciplinary research or convergence research is active in some fields, but the level of people-oriented support or international collaboration has much room for improvement. In particular, GRIs are still showing very low levels of collaborative research with both business and international counterparts.

3.2. Types of Bureaucratic Control

We will examine the problem of bureaucratic control in NRDP, dividing the financial support in three types. The first type is a top-down support where the government plans or designs the R&D projects before research teams or industry-academia-research institutes apply for them. The second type is a bottom-up support where the government invites research proposals from university professors or researchers in company R&D centers or GRIs with any possible topics and makes selections based on a peer review process. The third is a lump-sum support type where the government provides research funding for public research institutes, including GRIs, as well as universities so that they can carry out their own research agenda.

3.2.1. Bureaucratic Control in Top-Down Research Support

A direct bureaucratic control, which may interrupt high-risk high-payoff research, is more easily identifiable in this type of research funding. Top-down supports in NRDP are mostly managed through the project and funding agencies that are strongly controlled by ministries, and bureaucrats often hinder the autonomous decision-makings of Project Managers(PMs) of the project and funding agencies on an ad-hoc basis (Cho et al., 2003).

The success rate of NRDP, measured by the percentage of projects that are reported to have achieved their research objectives, is unbelievably high. The success rate of the NRDP supported by the Ministry of Trade, Industry and Energy (MOTIE) was 97% in 2010 and those supported by the Small and Medium Business Administration (SMBA) was 93% in 2008. It is highly probable that these high success rates are due to the fact that most of the research is low-risk low pay-off in nature. This argument is supported by an evidence that the commercialization rate of R&D outcomes from the NRDP remains only at 20~30%, which is extremely low compared to the United States (69%) and the United Kingdom (71%) (Song et al., 2014). Excessive bureaucratic control over project management appears to have

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[6] Preceding agency of the Ministry of Trade, Industry and Energy (MOTIE) was Ministry of Knowledge Economy (MKE).

contributed to bringing out extraordinarily high success rates due to risk aversion and promoting the production of a large number of mediocre patents, because bureaucrats tend to prefer visible outcomes in the short-run with low risks.

Table 5 shows a list of the project and funding agencies in Korea and its relevant ministries and enactments. Each of the 11 project and funding agencies is under the auspices of only one of the 10 ministries in Korea, except for the National Research Foundation (NRF), which is controlled by both the Ministry of Education and the Ministry of Science, ICT, and Future Panning. A problem of these project and funding agencies is that they have also become very bureaucratic under the excessive control by individual ministries and they have not been able to channel the R&D budget into high-risk high-payoff research. To avoid the problem of excessive bureaucratic control in top-down research support, there have been experiments to commission some big projects in certain NRDP to more autonomous project teams in the form of R&D consortium (Choi, 2013). Several flagship NRDP such as the G7 Program in the 1990s, the 21st Century Frontier Program and the Next Generation Growth Engine Program in the 2000s, and the Global Frontier Program and the New Growth Engine Industry Program in the 2010s, which were managed by autonomous project teams, have proved to be more successful in leading high-risk high-payoff research. Many studies attribute the success to the changed government behavior, allowing the projects to be run by independent entities with more autonomy over project management (Lee, 2011; Lee, 2008; Ahn, 2009a; 2009b). In the above-mentioned cases, the government tried to reduce bureaucratic control by allowing private experts to participate from the early stage of project planning and giving the project teams more autonomy after the project launch. However, considering the fact that about 1.5 billion USD of the government budget has been spent over 5 years for each flagship project since the G7 Program (Lee, 2011), compared to the annual total NRDP budget of about 15 billion USD in recent years, the lion's share of the top-down support in NRDP is still not free from excessive bureaucratic control as they are managed either directly by bureaucrats in ministries or by the project and funding agencies that have increasingly become bureaucratic.

3.2.2. Bureaucratic Control in Bottom-up Research Support

As for the bottom-up support, problems associated with the peer review process are interrupting high-risk high-payoff research. Recently, the government expanded funding for basic research from 286 billion KRW in 2007 to 650 billion KRW in 2010 and to 750 billion KRW (about 700 million USD) in 2011, and the proportion of professors who are receiving research grants in science and engineering increased from 16.4% in 2008 to 30.8% in 2011 (Lee Ju-Ho et al., 2012). The majority of the bottom-up projects, including those in basic research, are selected through peer review organized by the National Research Foundation (NRF) that has enormous influences over academic research.

The peer review process has advantages of encouraging professors to continuously produce papers while assuring their academic freedom. However, the peer review process has been criticized for a series of problems, such as professors avoiding high-risk research, preferential treatment of those who are already established, excessive time consumption on writing proposals, and overestimation of project costs beyond what is actually needed. The quality of evaluation may also decline once the peer-review system is expanded, as it gets harder to obtain high quality reviewers (Stephan, 2012).

Moreover, the peer review system tends to prefer "evolutionary" (incremental) research to "revolutionary" one, thus making it highly possible to exclude high-risk high-payoff research projects in the selection process. Furthermore, young researchers can be placed at a disadvantage in the selection process, since they have fewer research outputs than the experienced researchers. This problem of peer review does not only apply to Korea, but seems to appear around the world. Academia in the United States is continuously recommending the expansion of support for revolutionary and interdisciplinary research and people-based awards (PCAST, 2012), and the European Union is particularly focusing its efforts on strengthening international collaborations in research.

Even in bottom-up research support, bureaucratic control is still an important problem. Korea's National Research Foundation (NRF) has lower autonomy compared to its counterpart in the United States, National Science Foundation (NSF). While the budget and management of NSF is organized according to the academic fields, the NRF's budget and management is mainly project-based in order to make the bureaucratic control easier and serve the interest of bureaucrats (Lee, 2011). Consequently, despite differentiated demands by each academic field in terms of the size and duration of research funding, the NRF does not take into account such differences and applies uniform rules on the research funding. Moreover, PMs of the NRF have hardly succeeded in contributing to the autonomous development of the academia, because they are asked by bureaucrats to work on different academic fields for which they often lack training and expertise. The NRF is organized and run in line with the structure of the Ministry of Education, Science and Technology (now divided into the Ministry of Education and the Ministry of Science, ICT and Future Planning) and operated based on projects to enhance the efficiency of bureaucratic task management.

Currently, the NRF is far from becoming a trusted intermediary between the government and the academic community in order to facilitate the engagement of academic communities in setting research priorities and designing the programs (SRI and NRF, 2012). This is the reason why an excessive bureaucratic control should be lifted to provide the NRF with greater autonomy and operational authority.

3.2.3. Bureaucratic Control of GRIs

The governance structure of GRIs, which is under great influence of bureaucrats, is also hampering high-risk high-payoff research. GRIs had played a major role in the 1970s when the government had took control in building up the national R&D capacity, but the industrial sector's expansion of technological capacity since the 1980s reduced the role of GRIs in economic development. In the 1990s, R&D in universities began to expand and the problem of overlap in research areas between universities and GRIs began to rise since the 2000s (Cho et al., 2003; Civil Committee for the Development of Government-funded Science and Technology Institutes, 2010). One of the main criticisms on GRIs was the question of whether GRIs, compared with more autonomous universities, are not too excessively supported by the government through the NRDP.

The Korean government's financial support for GRIs can be divided into lump-sum support and the funding through the so-called Project Based System (PBS). The PBS was introduced in 1996 in order to address the concern of GRI research being heavily supported regardless of research outcomes. The purpose of the PBS was to increase efficiency and autonomy of research in GRIs by allocating funds for personnel and overhead costs to GRIs based on a competitive process for projects. However, when GRIs could not sufficiently secure personnel costs, it created anxiety among researchers, which led to their excessive external activities for earning projects. As a result, the government responded to these problems by reducing the size of the PBS-related budget and increasing the share of lump-sum support for GRIs from 30% in 2008 to 67.3% in 2012. Excessive bureaucratic control was one of the major reasons why the PBS has not taken root in GRIs: as individual ministries commission the PBS without sufficient coordination with other ministries, let alone with academic communities including researchers in GRIs, GRIs have failed to build long-term research capacity, particularly in high-risk high-payoff research.

Unlike the PBS, a lump-sum support for GRIs can be either used to plan research projects autonomously by GRIs or under coordination by research councils. In 1999, the governance structure of GRIs shifted from a direct control by individual ministries to an indirect control through research councils. At first, three research councils had been formed according to the fields of science and technology and they later merged into two research councils in 2008, and finally a law to unify two councils into one has been passed by the National Assembly in 2014. Despite this governance change, however, the research council in Korea is regarded as still lacking autonomy and independence, as it is highly influenced by the government and thus its capacity to respond flexibly to the changes in the external environment is limited (Arthur D. Little, 2010). The research council is often criticized as simply adding an extra layer of regulatory body instead of being an independent entity that protects the autonomy of GRIs from the bureaucrats of ministries as well as politicians. Consequently, research fields between GRIs often overlap, limiting the research council's ability in promoting "convergence research" between GRIs (Civil Committee for the Development of Government-funded Science and Technology Institutes, 2010).

Moreover, GRIs, partly financed by the public money, are under the same regulations of the Ministry of Strategy and Finance that are uniformly applied to all the public institutions concerning personnel management, execution and management of budget, and managerial evaluation. This regulation comes to the GRIs additionally on top of direct regulations from corresponding ministries and indirect regulations through the research council.

There is a rising consensus in the academic community as well as among policy makers that a change in the GRI governance is needed to strengthen the GRIs' autonomy and openness. Despite continuous efforts to improve the governance of GRIs, bureaucratic controls discouraging researchers in GRIs from conducting high-risk high-payoff research have yet to be removed. GRIs are still carrying out predominantly short-term research projects that are directly or indirectly controlled by bureaucrats, and there is hardly a continuity in research or an emphasis on convergent and collaborative research, which may contribute to the national development of technology (Lee Min Hyung et al, 2012).

There have been many attempts to reform the governance of GRIs, but none of them has led to a tangible result. While the governance reform of GRIs drifted over 10 years, the leadership capability within GRIs has been weakened. With a lowered self-esteem, outstanding researchers in the GRIs often move to positions in universities. Under these circumstances, it is difficult for the researchers in GRIs to actively engage themselves in high-risk high-payoff research. As shown above, most indicators on research outcomes of GRIs - such as the rate of increase of the number of patents, technology transfer and royalty earnings, and number of papers - have been worsening compared to those of universities.

Data on labor market mobility of researchers at the doctorate level also reveals a problem of GRIs. Turnover rate of researchers in natural sciences and engineering with PhD degrees was 13.6% in the business sector, 4.0% for those in GRIs and 2.4% for universities (MEST & KISTEP, 2011). The overall turnover rate of GRIs and universities is only a quarter of that of private companies, showing that both GRIs and universities are lacking labor market competition compared to the private sector. Moreover, a higher turnover rate in the GRIs than universities is associated with a predominantly unidirectional mobility from GRIs toward universities. Given that researchers tend to have a 'taste for science' and prefer to have discretion in choosing their research topics (Stern, 2004), a heavy-handed control over

GRIs by bureaucrats may be an important factor that has made GRI researchers to move to universities.[7]

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[7] In addition, the legal retirement age for GRI researchers is 62, lower than 65 for university professors. And public pension benefits for university professors are much better than those for GRI researchers, because separate special national pension schemes are applied to teachers and professors, government officials, and military personnel.

IV. Reform Agenda

It would be very difficult to vitalize high-risk high-payoff research in Korea without overcoming the deep-rooted problems of bureaucratic control. This would require breaking away from the convention of government intervention in Korea, for which a single reform measure would be insufficient. The role of bureaucrats in ministries should be changed, and a great amount of power should be given to PMs in the project and funding agencies and scientists in GRIs to ensure their autonomy and independence. Only a coherent reform strategy with a comprehensive package of reform measures can make positive changes in the innovation eco-system of Korea possible.

4.1 Establishing K-ARPA

The National Academy of Science and the National Academy of Engineering and Institute of Medicine (2007) in the United States argued in their report that the NSF and the National Institute of Health (NIH), unlike DARPA, had failed to support high-risk high-payoff research, and proposed that project managers in federal research agencies should have discretion to support challenging research projects, for which about 8% of their annual budget be set aside. In 2010, the Korean government also launched the Strategic R&D Planning Unit within the Ministry of Knowledge Economy (MKE) to transform the industrial NRDP from a government-led program to a market-led one. Hwang Chang-Gyu, a former vice president of Samsung Electronics, was nominated as the chief director of this ambitious experiment. However, the unit was not furnished with the legal and financial independence, and was not able to bring about any fundamental changes in the bureaucratic controls and inflexible research culture.

What Korea needs now is a new type of funding and project agency for high-risk high-payoff research, such as a type of ‘special forces’ (Dugan and Gabriel, 2013) similar to DARPA. Already in the past, Korea has often applied the special forces approach to R&D as shown in Table 6: Universities specializing in science and technology such as KAIST, GIST, DGIST, UNIST were given special support from the government via the Ministry of Science and Technology; In 2011, Institute for Basic Science (IBS) was established with much better financial support and autonomy from the government (Stone, 2013), which can be interpreted as a special forces approach to make an impact on all other GRIs. Compared to these efforts, what we are proposing here is to establish an independent project agency, "K-ARPA" (Korea Advanced Research Project Agency)[8], and to adopt the following three directions in line with the DARPA’s strategies.

First, K-ARPA should be endowed with a complete independence and autonomy to perform highly flexible and adaptive research projects. Although the DARPA is under the Department of Defense (DoD) in the United States, it seeks to meet defense needs that are going beyond the boundary of the DoD (Atta, 2008). K-ARPA should be established as the top priority project of the President to effectively overcome challenges arising from vested interests. For instance, the chief director should be appointed by the President to protect the new agency from unnecessary disputes at the initial stage. This new type of agency is expected to deliver positive shocks to the risk-aversive culture of the research community, adventuring breakthrough and disruptive approaches to the challenges of strategic importance.

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[8] We are not the first in proposing the establishment of a DARPA-like institution in Korea. Song et al. (2014) has proposed the tentative name, K-ARPA, as well as detailed roadmaps for K-ARPA. Jin (2013) has also argued that it would be high time for Korea to establish a DARPA-like institution.

To assure the autonomy of the new organization, missions of K-ARPA - such as engaging in high-risk high-payoff research for solving imminent problems related to the national security and public safety, creating new industrial opportunities in the future etc. - must be clearly stated in the legislation. Additionally, the independence and autonomy of the organization must be clearly stated in the law, which would be indispensable for accomplishing its missions amid high risks or even fear of failures. K-ARPA is also to be exempted from the "one-size-fits-all" type regulation on public institutions by the Ministry of Strategy and Finance. Through specific clauses in the law, K-ARPA should be protected from unnecessary interferences or supervisions by line ministries. Moreover, the law should entitle the project managers the discretion over project selection and management.

The new agency would not be able to attract world-class researchers without the autonomy stipulated in the law. Project managers, a core component of K-ARPA, would be PhD holders in his or her thirties or forties with about ten years of research experiences. Unlike research team leaders of the Global Frontier Program or the New Growth Engine Program who used to be at the peak of their research careers, young and promising project managers of the K-ARPA are expected to have innovative ideas and flexible ways of thinking. They should have financial and administrative discretion over their research projects so that they can take pride in their own contributions.

K-ARPA needs to be relatively small in personnel size and have a lean, non-bureaucratic structure, even without its own laboratories. Professors in universities, researchers in GRIs or private business sectors, and public officials can work as project managers for a certain time, taking official leaves from their workplace and being dispatched to K-ARPA. After three to five-year work in K-ARPA, they may either go back to their former workplace or begin start-ups, spinning off the research outcomes. K-ARPA can function as a catalyst for changes in the Korean innovation eco-system by leading high-risk-high-payoff projects and nurturing young talented innovators. K-ARPA should be an agile and flexible network organization run by project managers. Very open to new learning, K-ARPA will be able to tolerate failures and challenge daunting risks, just like the DARPA has achieved.

Second, K-ARPA should pursue a new model of an embedded network governance that has close links with research communities (Fuchs, 2010). Project managers of this new organization will work as a hub that can identify and develop networks among top domestic and global researchers in universities, research institutes including GRIs, and the private sector. They can stimulate innovation through these networks, which may be institutionalized as a new type of organization. As suggested by Fuchs (2010), an embedded network governance may be a new alternative for government support of high-risk high-payoff research, rather than being forced to choose between the extremes of free market or bureaucratic control.

The governance structures in the Global Frontier Project and the New Growth Engine Project were far from the embedded network governance, because research project teams often changed themselves into a closed unit confined by an inner circle of scientists once the teams had been organized by the government. Therefore, the project managers of K-ARPA should aggressively build open networks among top scientists in Korea as well as abroad. The affiliation of K-ARPA with the Presidential Office or the Prime Minister’s Office would be able to soften a possible backlash among relevant ministries as well as competing institutions such as other project and funding agencies or GRIs.

K-ARPA should also tackle a deep-rooted problem that Korea’s national defense R&D has so far suffered from. More than 80% of the R&D spending in national defense has been spent on pursuing armament plans, most of which were planned 10 or 15 years earlier

(Hong, 2011). In order to apply high technologies like brain and cognitive science as well as ICT to the national defense strategy and armament development frameworks, K-ARPA should help build an embedded network governance that can cover both civil and military research and translate the research outcomes from the civil sector into military applications. While leading high-risk-high-payoff projects in the areas of national security, K-ARPA can also stretch its project scope to the prevention of disasters and the promotion of public safety by including such topics as climate change, cyber terror, infectious diseases, nuclear safety, and energy.

Third, K-ARPA should explicitly put emphasis on high-risk high-payoff research like transforming basic science into emerging technologies, fostering a fundamental transformation in domains of technology application such as the Internet or GPS etc. (Atta, 2007: 2008). While the researchers in the Institute of Basic Science (IBS) are pursuing Nobel prizes, those in the K-ARPA, with a strong orientation towards practical applications, should develop technologies that help solve impending problems. K-ARPA is to be positioned in "Pasteur’s quadrant" (Stokes, 1997) with its emphasis on use-inspired research, whereas IBS is located in "Bohr’s quadrant" (Stokes, 1997) with its orientation toward curiosity-driven research.

Considering that the mission of K-ARPA is located in the Pasteur’s quadrant, research outcomes from this institution should not be eschewed from the public procurement process. The Department of Defense of the United States has purchased the new technologies from DARPA through the procurement with little sensitivity in price, which is acknowledged as the key reason how DARPA has been able to make an impact on the US innovation eco-system (Nehra, 2013). As for the public procurement system in Korea, including the way to foster the procurement of technologies developed by the new K-ARPA, we can learn some lessons from the cases of DARPA and the practices of Public Procurement of Innovation (PPI) in the European Union (Kim, 2013). Strengthening the linkage between K-ARPA and public procurement would be an effective strategy to encourage high-risk high-payoff research by sharing the risks inherent in this kind of revolutionary research.

4.2. Making Project and Funding Agencies More Autonomous and Accountable

As discussed in the previous section, project and funding agencies in Korea are strongly influenced by the bureaucratic control of ministries, which makes these agencies even more bureaucratic. One of the reasons why bureaucrats of ministries are failing to stimulate high-risk high-payoff research is their heavy-handed control over the project and funding agencies.

Therefore, establishing a totally different type of funding and project agency like K-ARPA with an autonomy and independence could be a first step to stimulate high-risk high-payoff research in Korea. After establishing K-ARPA, other project and funding agencies can follow suit to become more autonomous and more accountable. Project managers in the DARPA with their role as an embedded network agent could help re-design social networks among researchers to influence new directions of technologies (Fuchs, 2010). Program managers in the project and funding agencies in Korea, let alone those in K-ARPA, should also be able to ‘connect dots’ by building up networks among top researchers, domestic and global, in industries, universities, and GRIs, and by facilitating high-risk high-payoff research through a strong partnership with key researchers.

For greater autonomy of PMs in project and funding agencies, the government should provide PMs with a predictable budget and an authority to act as an independent decision-maker with minimal bureaucratic burden. At the same time, to hold PMs accountable, a panel of external experts, both domestic and global, should retrospectively review the PMs' decisions on a periodic basis.

Peer review process, which relies on peer scientists outside the agency evaluating research proposals, might be in favor of "evolutionary" research rather than promoting high-risk high-payoff one. However, peer review has an important merit because it enables to avoid bureaucratic control in the evaluation and selection process of research proposals. Therefore, every project and funding agency should be allowed to expand their portfolios so that they can strategically support a sound mix of disciplinary vs. interdisciplinary research, project-based vs. people-based awards, solo vs. collaborative research, and mid- and senior-career vs. early-career researchers. In order to hold the project and funding agencies accountable in high-risk and high-payoff research, the government may set up an information disclosure system for their research support portfolios, particularly for high-risk and high-payoff research, in every agency as well as create an external committee for ex-post reviews and periodic recommendations.

The NRF, which is Korea's largest funding agency that is mainly focusing on the support of bottom-up projects like the NSF in the United States, should also be given much greater autonomy and operational authority. The government can intervene in a way to set the total budget and advise its overall strategy, but the NRF should be allowed to have an operational authority in allocating the funds, designing new programs, and so forth (SRI and NRF, 2012). As pointed out earlier, the organization and budget of the NRF should be realigned based on fields rather than projects in order to involve academic communities more actively and to utilize the expertise of PMs more effectively.

4.3. Making GRIs More Autonomous and Open

In 2011, as the government announced the Special Law on Development and Support of International Science and Business Belt, the Institute for Basic Science (IBS) was established as a core research institute of the International Science and Business Belt, and a total of 517 billion KRW will be allocated for use from 2012 to 2017. The headquarter of IBS is located in the Daedeok Science Town, but unlike other GRIs, IBS also has research institutes in university campuses such as the KAIST joint campus (KAIST and GRIs in Daedeok Science Town), DUP joint campus (DGIST, UNIST, POSTECH), and GIST campus, while establishing external research networks with other research institutes and universities in Korea and overseas. By the end of 2013, 19 world-renowned scientists, including 5 scholars from abroad, have been selected as Project Directors (PDs) who are allowed to manage the research committee autonomously and are provided with research support of 10 billion KRW for 10 years. In this way, IBS is playing a leading role in challenging other GRIs for high-risk high-payoff research (Lee et al., 2012).

To vitalize high-risk high-payoff research in other GRIs, an immediate reform in the governance structure is required. While removing the government's excessive bureaucratic control and tearing down the walls between individual institutes, GRIs need to be opened up for collaborative research with universities, businesses, and overseas research institutes. Above all, the newly merged research council should be given greater autonomy and independence in recruiting chief directors and protecting them from political or bureaucratic influences. At the same time, the research council should be held accountable for strengthening partnerships not only among GRIs but also with universities, industries, and international research institutes.

It is desirable for each GRI to have more autonomy and authority in the management of projects, personnel, and finance. And the government needs to examine ways to exclude

GRIs from applying uniform regulations on public organizations set by the Ministry of Strategy and Finance. Furthermore, the governance of GRIs should be reformed to foster partnerships between GRIs and universities.

GRIs' research centers (both new and old) should be allowed to move into universities, like the way the IBS is currently experimenting, and the researchers at these centers should be able to hold professor positions while carrying out collaborative research with university professors and promoting the research participation of graduate students. This strategy can help resolve the current imbalance between universities and GRIs in terms of R&D inputs, as GRIs are relatively better equipped with research facilities and government funding while universities have abundant professors and graduate students with diverse ideas and initiatives. Moreover, both convergence between research universities and GRIs and transformation of GRIs into research universities can foster their collaboration with each other. More fundamentally, the governance of GRIs should be changed to allow the GRIs to be managed by universities under a specific government contract like the case of GOCOs (Government-Owned, Contractor-Operated) in the United States (Jaffe and Lerner, 2001; PCAST, 2012).[9]

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[9] Los Alamos National Laboratory was managed by the University of California under a government contract, and NASA's Jet Propulsion Laboratory (JPL) has recently been transformed into a new agency under the management of Caltech. All but one of the Department of Energy's national laboratories are GOCOs (PCAST, 2012). Jaffe and Lerner (2001) argue that the successful performance in patenting and technology transfer at the national laboratories in the United States is partly associated with having a university as lab manager.

V. Conclusion

Can bureaucrats stimulate high-risk high-payoff research? The Korean experience, particularly after around 2000, provides important points concerning this question.

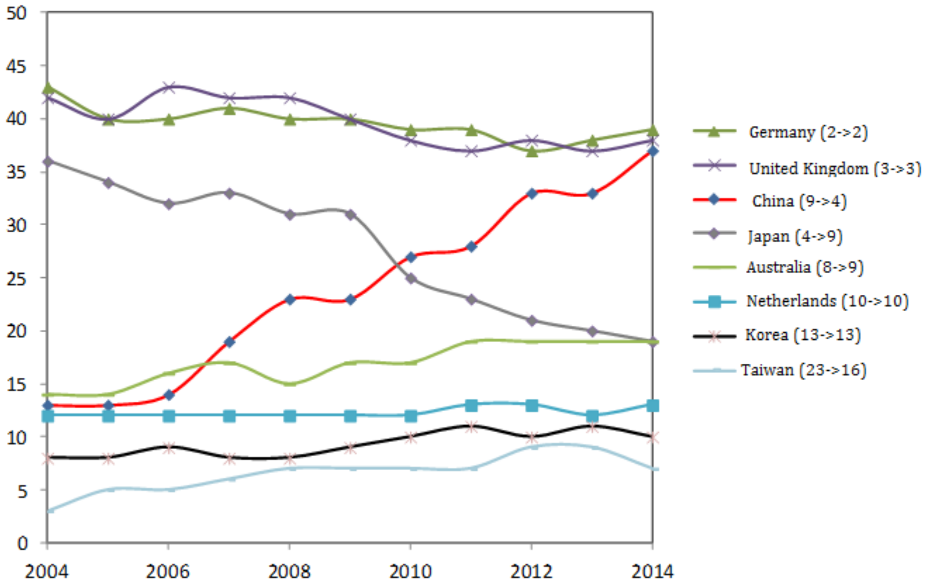
First, data shows that a rapid expansion in academic papers and patents masks a quite poor performance in terms of highly-cited papers and royalty earnings of technology transfers within or across borders that can be regarded important indicators for high-risk high-payoff research. This evidence clearly points to Korea's stagnation in high-risk high-payoff research

Second, the share of GRIs in patenting and technology transfer has continuously been decreasing despite their receiving heavy government subsidies unlike universities. This evidence points to the low effectiveness of government research support, particularly for GRIs.

Third, during the 15-year period from 1998 to 2012, the size of total NRDP budget in Korea increased by six times. However, during this period of rapid expansion of the government R&D support, a heavy-handed control by bureaucrats in ministries prevails almost everywhere regardless of the funding type; top-down, bottom-up, or institutional funding for GRIs. Government interventions and regulations, which had worked so well until the early 2000s, when Korea had been a rapid follower of advanced countries' technologies, has been interrupting high-risk and high-payoff research in a period when Korea is struggling to become a first-mover in innovation. High-risk high-payoff research in Korea cannot be vitalized without overcoming the deep-rooted problems of bureaucratic control. However, Korea has dragged its feet when it comes to transforming the role of government and empowering project and funding agencies, GRIs, and universities.

Fourth, PMs in the project and funding agencies and scientists in GRIs should be allowed to have greater autonomy and independence. This paper recommends that Korea should establish a new project agency (K-ARPA), benchmarking the DARPA in the United States, which would be a totally different type of project agency that focuses on high-risk high-payoff research with substantially greater autonomy and independence. Along with that, the existing project and funding agencies should also become more autonomous and accountable. In addition, we recommend a reform of the governance of GRIs to make them more autonomous and open, which includes concrete measures to allow GRIs to be managed by universities under a government contract.

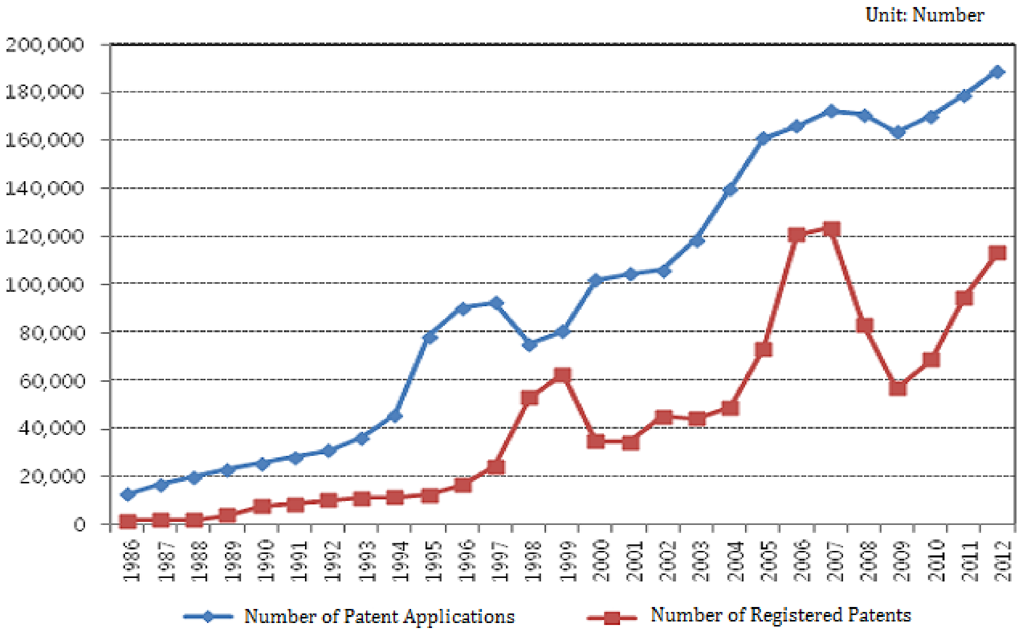
Figure 1. Number of Universities in ARWU 500 by Country (2004-2014)



Note: United States is excluded from the figure (169 universities in 2004, 246 universities in 2014). Figures for China include universities in Hong Kong. Numbers in parentheses after the country name indicate each country's ranking in 2004 and 2014.

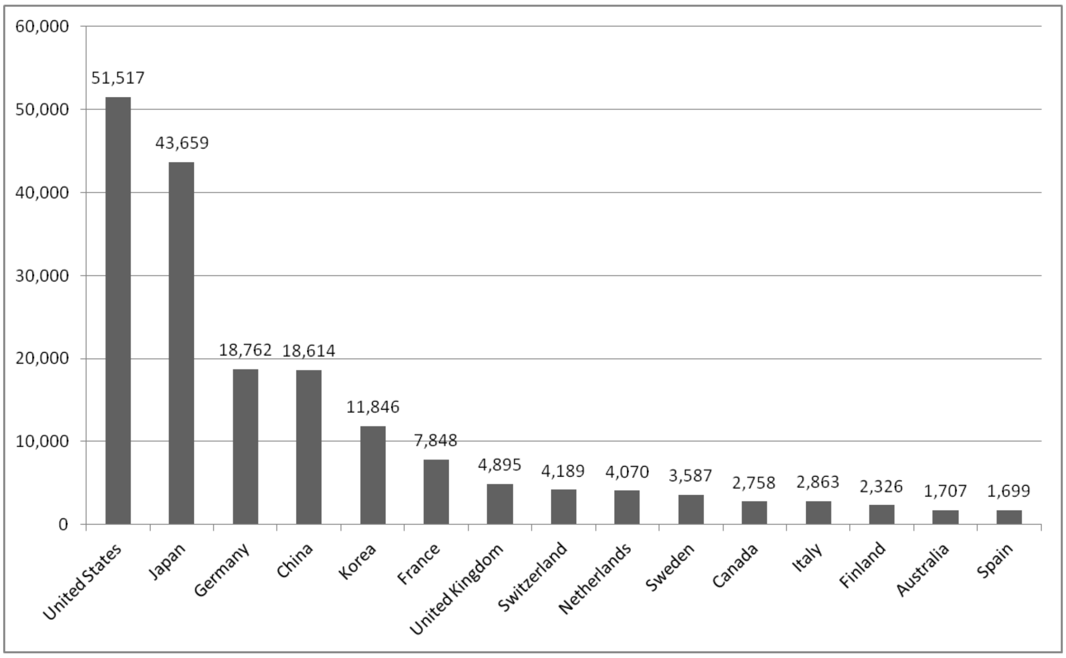
Source: Shanghai Jiao Tong University (2014). http://www.shanghairanking.com (accessed November 7, 2014)

Figure 2. Number of Patent Applications and Registrations in Korea



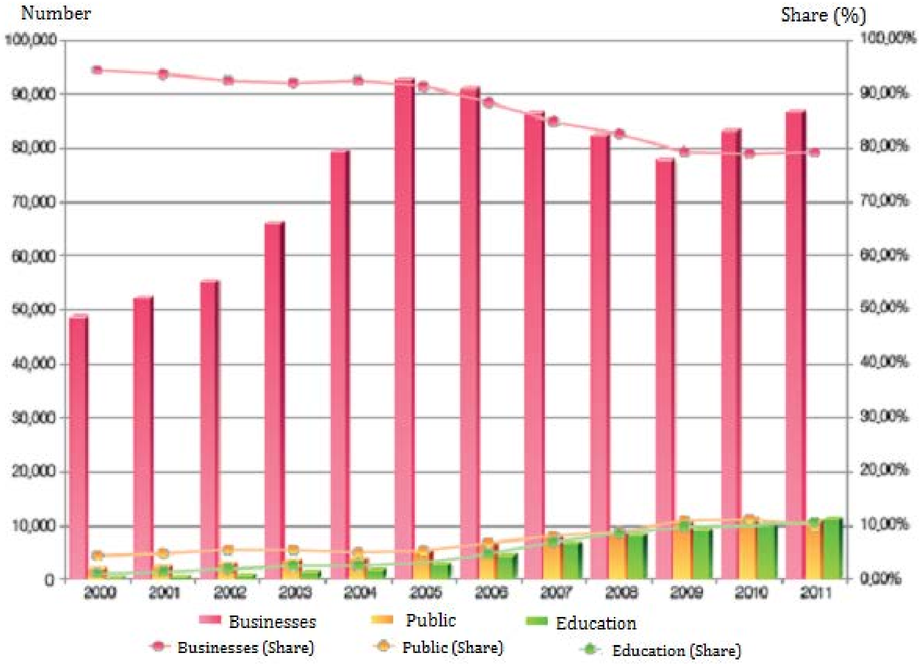
Source: Recreated by the authors based on Korean Intellectual Property Office (2013)

Figure 3.Number of PCT Patent Applications by Country (2012)



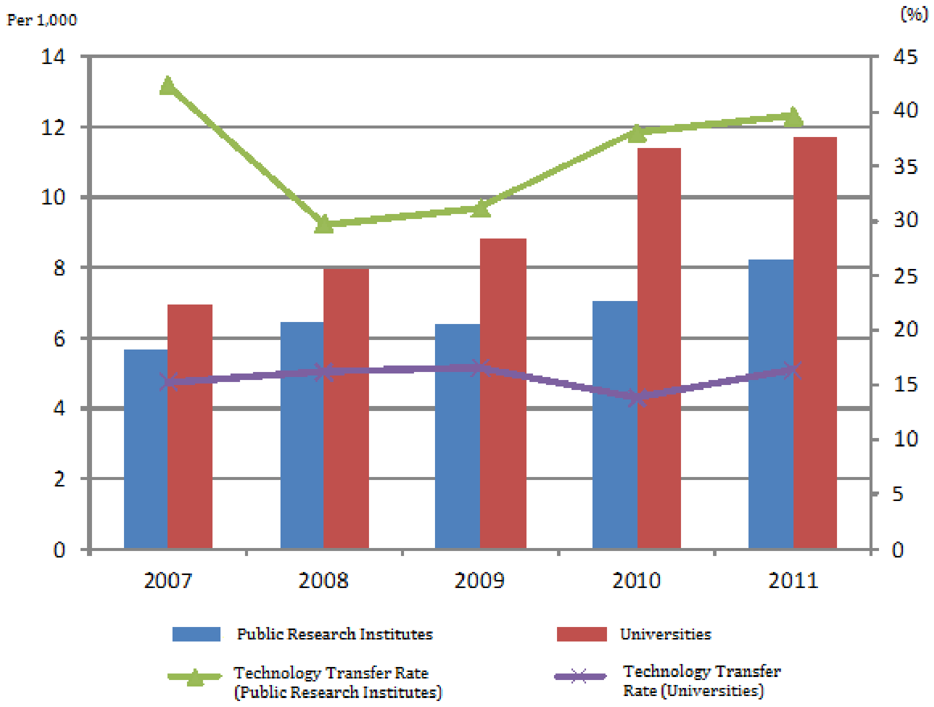
Source: Recreated by authors based on Korean Intellectual Property Office (2013). Original source comes from WIPO, PCT Monthly Statistics Report, June 2013

Figure 4. Number and Share of Patent Applications by Organization Types in Korea



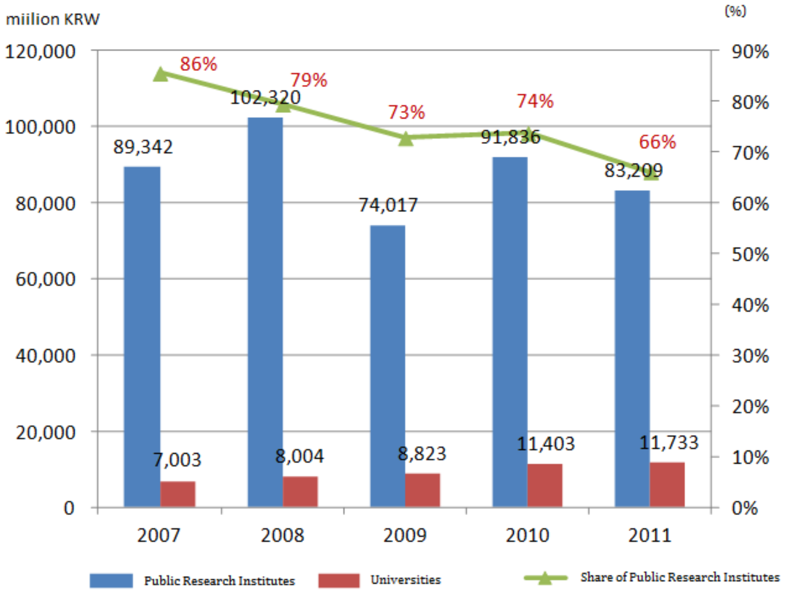
Source: Korean Intellectual Property Office’s (2013), p.23

Figure 5. Number and Rate of Technology Transfer in Public Research Institutes and Universities (2007~2011)



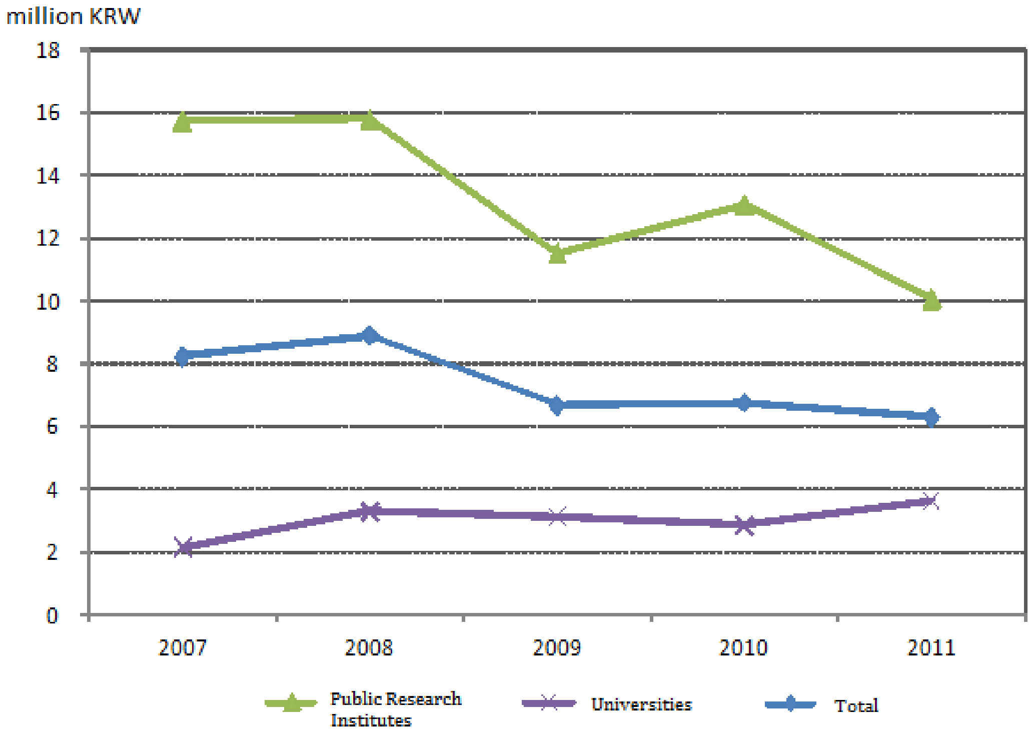
Source: Recreated by the authors based on statistics provided in KIIP and KIAT (2012)

Figure 6. Royalty Earnings of Public Research Institutes and Universities and the Share of Public Research Institutes (2007~2011)



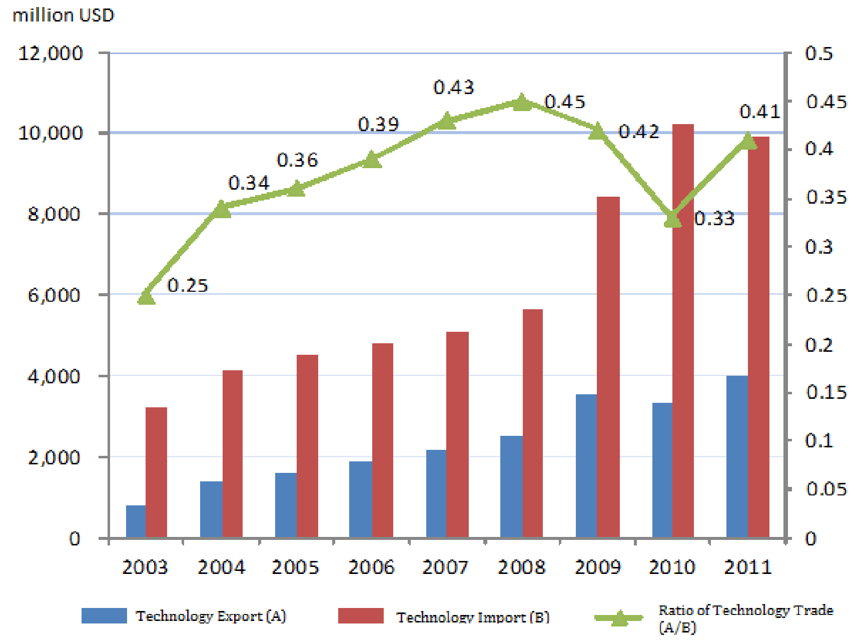
Source: Recreated by the authors based on statistics provided in KIIP and KIAT (2012)

Figure 7. Royalty Earnings per Technology Transfer (2007~2011)



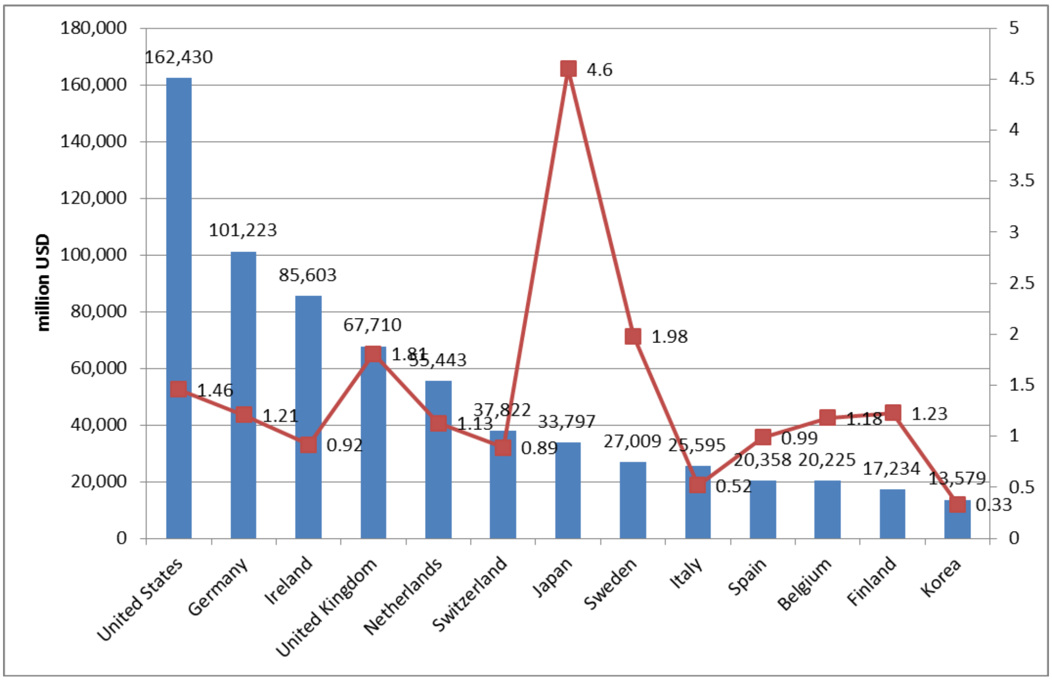
Source: Recreated by the authors based on statistics provided in KIIP and KIAT (2012)

Figure 8. Korea's Technology Export and Import (2003~2011)



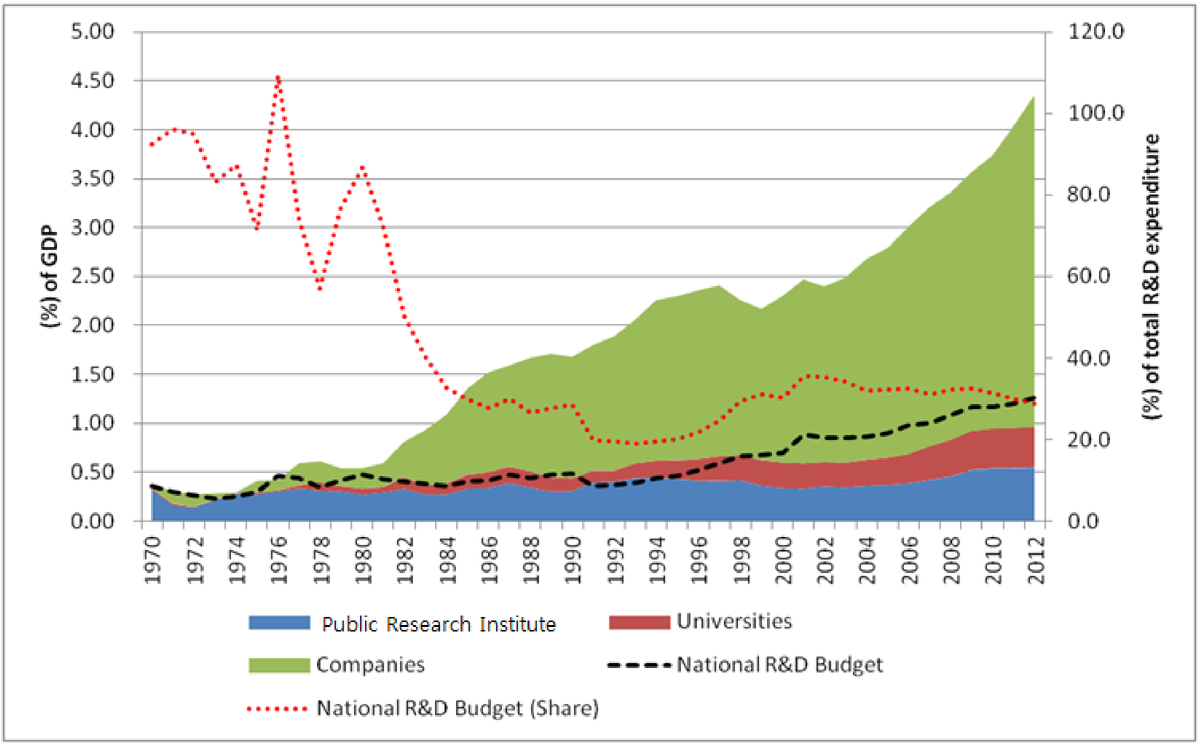
Source: Recreated by authors based on the data in
e-*Narajipyo*, http://www.index.go.kr/egams/stts/jsp/portal/stts/PO_STTS_IdxMain.jsp?idx_cd=1335 .
Original source is Ministry of Science, ICT and Future Planning, “Survey of Technology Trade.”

Figure 9. Volume and Ratio of Technology Trade in OECD Countries (2010)



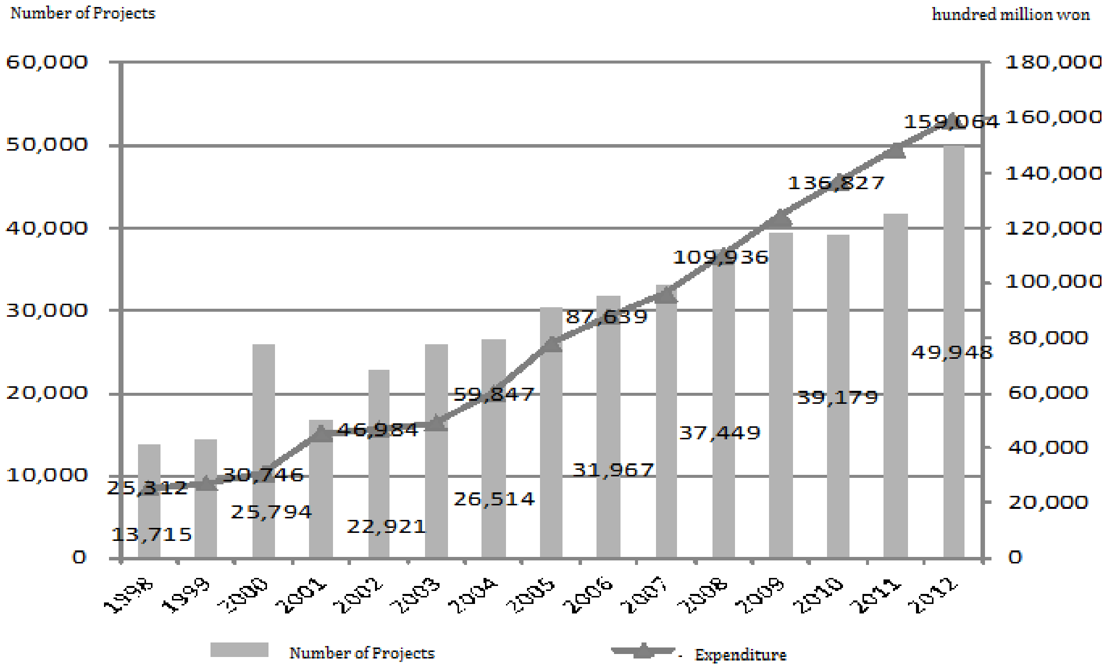
Source: OECD, Main Science and Technology Indicators 2012/1, 2012

Figure 10. R&D Expenditure as a Percentage of GDP in Korea by Sector



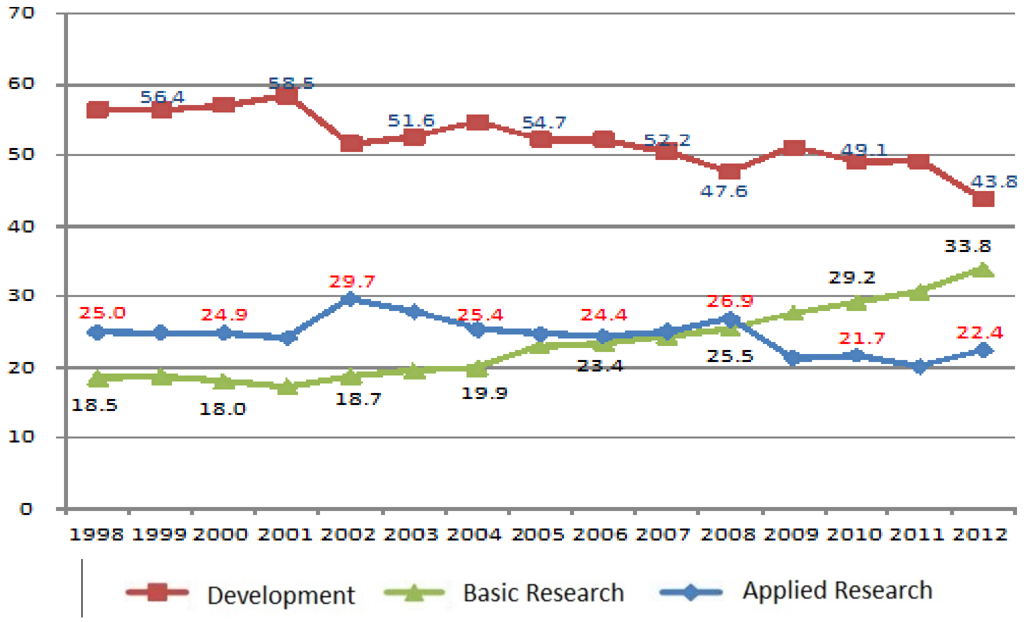
Source: Recreated by the authors based on the Figure 6 in Lee et al. (2014) p8.

Figure 11. Total Expenditure and Number of Projects in NRDP (1998-2012)



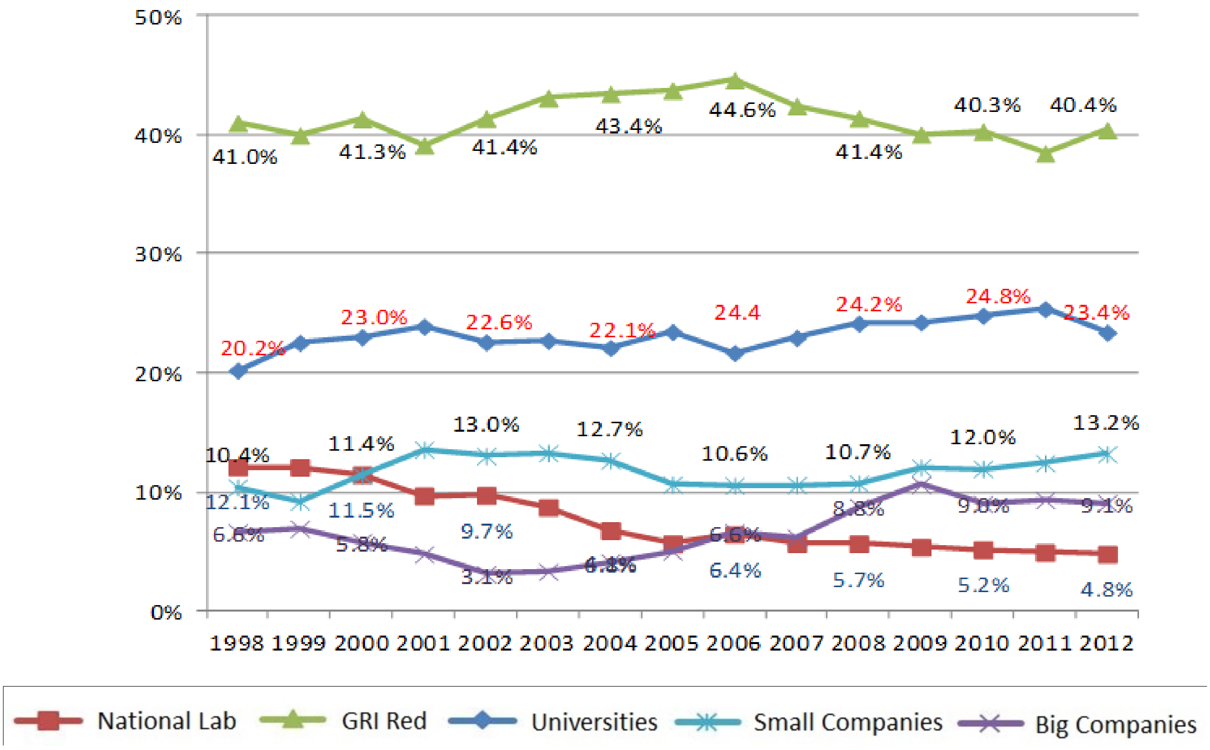
Source: Recreated by the authors based on each year’s “Survey and Analysis of National R&D Program.”

Figure 12. NRDP Budget by Research Types (1998~2012)



Source: Recreated by the authors based on each year's "Survey and Analysis of National R&D Program."

Figure 13. NRDP Budget by Performing Sector (1998~2012)



Source: Recreated by the authors based on each year's "Survey and Analysis of National R&D Program."

Table 1. Number of Papers for Major Countries

(Unit: thousand)

	Number of Papers (thousand)				Number of Papers per Researcher				Number of Papers per Population (thousand)	
	2001-2010	2001-2005	2006-2010		2005	2010			2005	2010
	a+b	a	b	(b-a)/a,%	c	d	(Korea=1)	(d-c)/c,%		
Korea	275	105	170	62.5	0.58	0.64	(1.0)	10.7	2.17	3.44
Taiwan	172	66	107	62.9	0.74	0.84	(1.3)	13.3	2.88	4.61
Japan	766	383	383	-0.1	0.56	0.58	(0.9)	3.6	3.00	2.99
China	803	252	551	119.1	0.22	0.46	(0.7)	102.4	0.19	0.41
United States	3,072	1,422	1,650	16.1	1.03	1.17	(1.8)	13.0	4.80	5.33
Germany	785	363	422	16.0	1.34	1.29	(2.0)	-3.7	4.41	5.16
France	565	260	305	17.2	1.28	1.27	(2.0)	-1.0	4.13	4.71
United Kingdom	824	378	446	17.9	1.52	1.74	(2.7)	14.2	6.27	7.16
Canada	454	194	260	33.9	1.4	1.7	(2.7)	22.8	6.02	7.61
Italy	427	186	241	29.5	2.3	2.3	(3.6)	3.3	3.18	3.99

Note: 1) Calculated 1 paper per author regardless of the number of co-authors per paper
2) In number of papers per researcher, researchers are applied with 2005 and 2010 size

Source: Number of papers are from the Web of Knowledge (Based on journals registered in SCI and SSCI DB); Number of researchers are recreated by authors based on MSTI Database

Table 2. Number of Highly Cited Papers by Country

Categories	Number of top 1% papers					Number of papers per thousand researchers				Number of papers per million population	
	2002-2011	2002-2006		2007-2011		2005	2010			2005	2010
	a+b	a	To Total (%)	b	To Total (%)	c	d	(Korea=1)	(d-c)/c (%)		
Korea	4,851	1,620	1.0	3,231	1.2	9.0	12.2	1.0	35.8	33.7	65.4
Taiwan	2,670	741	0.4	1,929	0.7	8.3	15.1	1.2	81.1	32.5	83.3
Japan	15,941	7,153	4.3	8,788	3.2	10.5	13.4	1.1	27.5	56.0	68.6
China	14,582	3,962	2.4	10,620	3.9	3.5	8.8	0.7	147.6	3.0	7.9
United States	196,847	83,054	49.7	113,793	41.6	60.4	80.6	6.6	33.4	280.6	367.3
Germany	27,459	9,921	5.9	17,538	6.4	36.5	53.5	4.4	46.7	120.3	214.5
France	19,671	7,115	4.3	12,556	4.6	35.1	52.4	4.3	49.1	113.0	193.8
United Kingdom	32,681	12,236	7.3	20,445	7.5	49.2	79.7	6.5	61.9	203.1	328.4
Canada	16,191	6,060	3.1	10,131	4.0	44.3	68.0	5.6	53.3	187.9	296.9
Italy	16,261	5,200	3.6	11,061	3.7	63.0	106.9	8.7	69.7	88.7	182.9
Russia	2,207	825	0.5	1,382	0.5	1.8	3.1	0.3	76.0	5.7	9.7

Note: 1) Calculated 1 paper per author regardless of the number of co-authors per paper
2) 360 papers omitted authors' information and most of the papers in the top 1% are the same.

Source: Information on top 1% papers are from ESI (www.webofknowledge.com) (accessed April 17, 2013).

Table 3.Top 50 Beneficiaries of the NRDP (2004 and 2012)

Categories	2004	2012
Universities	Seoul National University(1,740), KAIST(757), Yonsei University(743), POSTECH(685), Hanyang University(475), Korea University(389), Kyungpook National University(355), Sungkyungkwan University(806), Chonbuk National University(313), Chonnam National University(297), Busan National University(274), Kyung Hee University(226), Chungbuk National University(226), Kyungsang National University(222), GIST(193)	Seoul National University(3,219), KAIST(2,599), Yonsei University(1,767), POSTECH(1,691), Korea University(1,378), Hangyang University(1,130), GIST(969), Busan National University(870), Sungkyunkwan University(806), Kyungpook National University(756), Chonbuk National University(711), Kyung Hee University(638)
GRI	Electronics & Telecommunications Research Institute(3,925)	Agency for Defense Development(12,616)
	Agency for Defense Development(3,925)	Electronics & Telecommunications Research Institute(4,511)
	Korea Aerospace Research Institute(1,955)	Korea Atomic Energy Research Institute(3,693)
	Korea Atomic Energy Research Institute(1,955)	Korea Institute of Science & Technology(2,445)
	Korea Institute of Science & Technology(1,273)	Korea Aerospace Research Institute (2,325)
	Korea Institute of Industrial Technology(1,204)	Korea Institute of Ocean Science & Technology(2,276)
	National IT Industry Promotion Agency(974)	Korea Institute of Industrial Technology(2,052)
	Korea Institute of Ocean Science & Technology(956)	National Fusion Research Institute(1,955)
	Korea Institute of Machinery & Materials(879)	Institute for Basic Science(1,623)
	Korea Electric Power Research Institute(798)	Korea Research Institute of Bioscience & Biotechnology(1,341)
	Korea Institute of Science & Technology Information(776)	Korea Institute of Machinery & Materials(1,290)
	Korea Basic Science Institute(690)	Korea Institute of Geoscience & Mineral Resources(1,256)
	Korea Research Institute of Standards & Science(671)	Korea Research Institute of Chemical Technology(1,182)
	Korea Research Institute of Chemical Technology(634)	Korea Research Institute of Standards & Science(1,152)
	Korea Research Institute of Bioscience & Biotechnology(619)	Korea Institute of Science & Technology Information(1,137)
	Korea Institute of Energy Research(606)	National IT Industry Promotion Agency(1,129)
	Korea Research Fund(605)	Korea Institute of Energy Research(1,086)
	Korea Foundation for Science(570)	Defense Agency for Technology and Quality(944)
	Korea Electro Technology Research Institute(561)	National Research Foundation of Korea(833)
	Korea Electronics Technology Institute(538)	Korea Basic Science Institute(815)
	Korea Institute of Geoscience & Mineral Resources(532)	Korea Electronics Technology Institute(784)
	Korea Railroad Research Institute(494)	Korea Institute of Radiological Medical Sciences(768)
	Korea Institute of Civil Engineering & Building Technology(367)	Korea Evaluation Institute of Industrial Technology(756)
	National Software Promotion Agency(311)	Korea Institute of Civil Engineering & Building Technology(754)

	Korea institute of Radiological Medical Sciences(309) Korea Automotive Technology Institute(260)	Korea Railroad Research Institute(741) Korea Electro Technology Research Institute(727) National Security Research Institute(620)
National Research Institutes	National Institute of Agricultural Science and Technology(495) National Institute of Crop Science(471) National Fisheries Research and Development Institute(416) Korea Forest Research Institute(408) National Environmental Protection Institute(327) National Horticultural Research Institute(317) National Livestock Research Institute(265) National Institute of Agricultural Bioscience & Biotechnology(249)	National Academy of Agricultural Science(1,000) National Fisheries Research and Development Institute(934) National Institute of Horticulture & Herbal Science(869) National Institute of Crop Science(742) National Institute of Animal Science(678) Korea Forest Research Institute(584)
Big Enterprises		Korea Aerospace Industries, LTD. (1,680) LIG Nex1 (1,019) Korea Hydro & Nuclear Power Co.,Ltd. (662) Hanhwa (606)

Note: Amount granted in (   ).

Source: Recreated by the authors based on each year’s “Survey and Analysis of National R&D Program.”

Table 4. Changes in the Number of ‘Convergence Projects’ in NRDP by Sector (2009-2012)

(Unit: 100 mil KRW)

Sector	**2009**	**2010**	**2011**	**2012**
Mathematics	47(13.1)	61(13.1)	65(12.2)	50(8.7)
Physics	309(12.2)	362(13.6)	438(14.8)	810(24.6)
Chemistry	549(25.0)	614(23.0)	670(24.4)	796(24.7)
Earth Science	392(18.2)	360(11.6)	496(13.2)	490(10.4)
Bioscience	891(16.0)	1,023(16.8)	1,239(18.5)	1,439(20.1)
Food, Agriculture, Forestry, and Fisheries	380(4.9)	501(6.1)	666(7.2)	728(7.5)
Health & Medical	886(10.6)	997(9.9)	1,216(11.4)	1,357(12.3)
Machinery	1,544(10.1)	1,601(9.4)	1,934(10.2)	2,565(12.2)
Materials	734(17.1)	945(18.6)	1,145(22.1)	1,460(26.0)
Chemical Engineering	416(13.2)	557(19.2)	647(20.5)	818(22.8)
Electronics	1,008(9.2)	1,306(11.2)	2,070(14.9)	2,718(16.2)
Information Technology	919(6.7)	1,273(8.8)	1,391(9.0)	1,595(10.1)
Energy & Resources	449(6.5)	592(6.3)	1,330(13.3)	1,719(18.7)
Nuclear Energy	193(4.0)	278(4.8)	367(6.1)	476(6.9)
Environmental	389(11.0)	491(12.6)	740(17.4)	787(18.8)
Construction & Transportation	1,134(13.6)	807(10.8)	625(8.1)	758(11.3)
Science Technology & Humanities & Social Science	129(2.1)	106(1.8)	121(2.7)	192(4.7)
Others	275(3.8)	339(4.2)	463(4.4)	680(5.1)
Total	10,643(9.4)	12,212(9.8)	15,624(11.5)	19,438(13.2)

Source: Recreated by the authors based on each year’s “Survey and Analysis of National R&D Program.”

Table 5. List of Project and Funding Agencies in Korea

Funding and Project Agency	Ministry that control the Agency	R&D Project	Enactment	Established Year	Employment
National Research Foundation	Ministry of Science, ICT, and Future Planning; Ministry of Education	Basic R&D support project; R&D for Original Technology Project; Atomic Energy R&D Project	National Research Foundation of Korea Act	2009	275
Korea Institute of Planning and Evaluation for Technology in Food, Agriculture, Forestry and Fisheries	Ministry of Agriculture, Food and Rural Affairs	Agricultural Technology Development Project	Act on the Promotion of Science and Technology for Food, Agriculture, Forestry and Fisheries	2009	52
Korea Evaluation Institute of Industrial Technology	Ministry of Trade, Industry and Energy	Industrial Original Technology Development Project; Components & Materials Technology Development Project	Industrial Technology Innovation Promotion Act	2009	204
Korea Institute of Energy Technology Evaluation and Planning	Ministry of Trade, Industry and Energy	Energy Resource Technology Development Project; Electro-Atomic Energy R&D Project	Energy Act	2009	80
Korea Institute for Advancement of Technology	Ministry of Trade, Industry and Energy	Industrial Infra-technology Project; International Cooperation for Industrial Technology Project	Industrial Technology Innovation Promotion Act	2009	228
Korea Health Industry Development Institute	Ministry of Health and Welfare	Health & Medical Technology Development Project	Health and Medical Service Technology Promotion Act	1995	47
Korea Environmental Industry & Technology Institute	Ministry of Environment	Environmental Technology Development Project	Environmental Technology and Industry Support Act	2009	134

Korea Agency for Infrastructure Technology Advancement	Ministry of Land, Infrastructure, and Transport	Construction Technology Innovation Project; Project for Advancement of Plant Technology	Construction Technology Management Act	2005	78
Korea Institute of Marine Science & Technology Promotion	Ministry of Oceans and Fisheries	Utilization Technology Project for Marine Energy and Resource; Marine Biotechnology Development	Enforcement Decree of the Framework Act on Marine Fishery Development	2005	48
Defense Agency for Technology and Quality	Defense Acquisition Program Administration	Defense Technology Development; R&D Project for ADD	Defense Acquisition Program Act	2006	505
Korea Technology & Information Promotion Agency for SMEs	Small and Medium Business Administration	Supporting information on Technology Innovation in R&D	Act on the Promotion of Technology Innovation of Small and Medium Enterprises	2002	66

Source: Adapted from Suk Jun Choi (2013)

Table 6. Positioning of ‘Special Forces’ for High-Risk and High-Payoff Research

Types		Research Institute	“Special Forces”
Hub of network		Project and Funding Agency	K-ARPA
Partnership in	Research Institutes	GRI	Institute for Basic Science (IBS)
	Universities	Research University	Universities Specialized in Science and Technology(KAIST, GIST, DGIST, UNIST, POSTEC)

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