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The Impact of Korean Government's Industrial R&D Expenditure on Technological Competitiveness

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Summary

In Korea, the total amount of R&D executed by the Korean government in 2019 was $16 billion. The Compound Annual Growth Rate of Korean government R&D budget is 5.04% (2010~2019). This paper studies whether the Korean government's R&D expenditure effectively achieves its purpose. Assuming the purpose of government R&D expenditure is set as science and technology competitiveness based on related laws and the indicator is identified as the technology balance of payments (TBP), this study estimates the statistical correlation between government R&D expenditure and TBP. Since the characteristic of government R&D expenditure is different for each field, the correlation by field is analyzed by dividing it into nine fields (Chemicals, Earth, Material, Health and medical, Environment, Energy, Construction and transportation, Electrical and mechanic, and Food and agriculture). Basic science fields that are less related to economic performance are excluded from the analysis. According to previous studies, the total amount of government and private expenditures and exchange rate are factors that affect the performance of science and technology R&D. All data required for analysis are administrative data and are available online. As a result of multiple regression analysis, it is estimated that the correlation between government R&D expenditure and TBP is statistically significant only in the energy sector. As the correlation between government R&D expenditure and TBP is estimated to be statistically insignificant in most fields except energy, overall review and innovation of government R&D expenditure strategies in each sector are required. Combining all industries in one regression with controls for the size of the industry, greater the statistical power, results in the finding that private R&D statistically significantly raises TBP. Government R&D has no statistically significant effect, so further research is needed to improve the performance of government's industrial technology R&D.

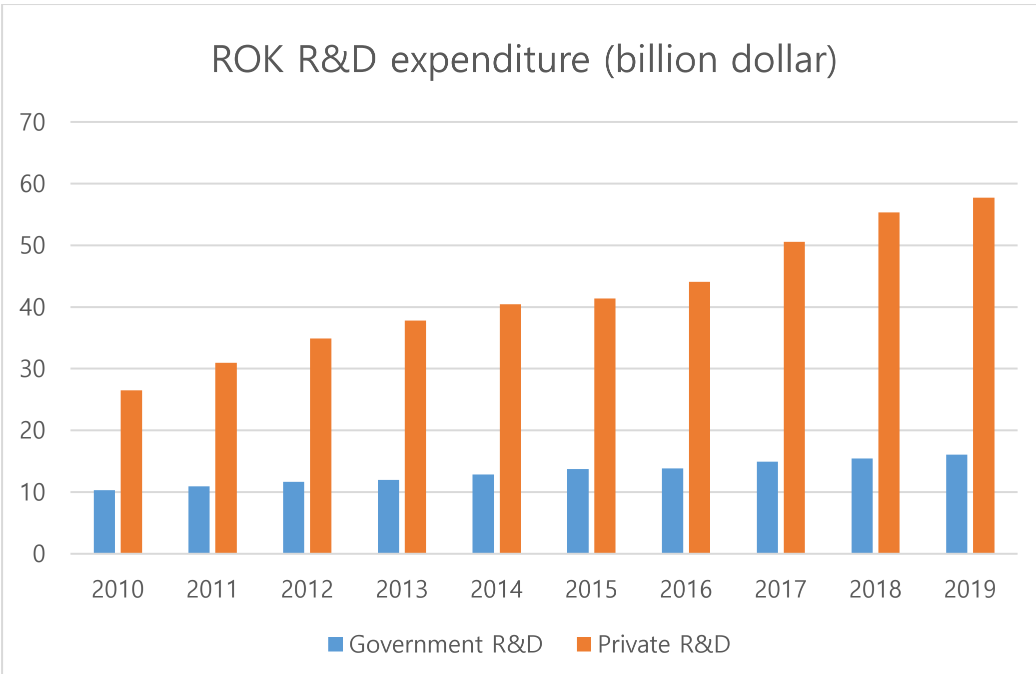
Discussion of the Issue and Problem Statement

In Korea, government R&D expenditure continues to increase, and the ratio of total R&D spending to GDP in 2019 is second in the world. The total amount of R&D executed by the Korean government in 2019 was $16 billion, and it increased 4.0% from $15.5 billion in 2018. The Compound Annual Growth Rate (CAGR, 2010~2019) of Korean government R&D budget is 5.04%.

Table 1 R&D expenditure in Korea (Unit: million dollar)

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Government R&D	10332.76	10950.06	11639.57	11992.97	12863.09	13720.77	13818.90	14936.44	15463.49	16080.30
Private R&D	26517.41	30968.49	34894.76	37792.77	40427.77	41406.06	44080.46	50580.14	55328.30	57702.01

Figure 1 Government and private R&D expenditure in Korea



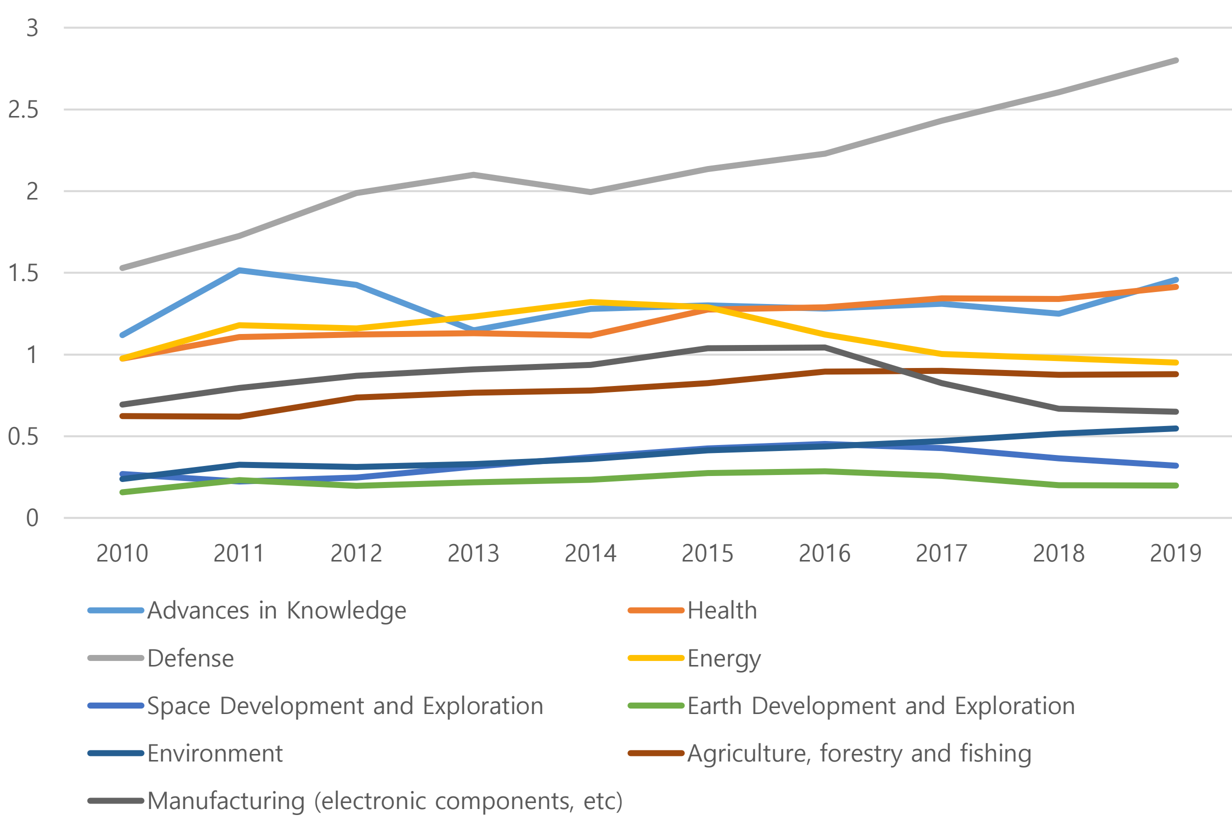
As the amount of government R&D expenditure increases, the need to evaluate effectiveness of expenditure increases. In other words, it is necessary to identify whether the Korean government's R&D expenditure effectively achieves its purpose. In Korea, the Framework Act on Science and Technology, which specifies basic matters related to science and technology, was enacted in January 2001. According to this law, it is stipulated that the government should establish and promote comprehensive policies for economic and social development through science and technology innovation.

Fagerberg, J. (1987) said that the outcome of R&D expenditure related to economic development has competitiveness, income, and job creation ability. Technological leads and lags are major determinants of the relative efficiencies, competitiveness, and incomes of firms and countries. According to R. Asplund (2020), the economic outcome of R&D expenditure is evaluated in merely two, but highly relevant dimensions: in relation to firms' productivity, on the one hand, and their job creation capacity, on the other.

Among the various factors that can be considered as the economic performance of government R&D expenditure, this study selects competitiveness. This is because income, job creation ability, and productivity are significantly affected by domestic and foreign economic issues, exchange rates, and domestic and foreign regulations. Therefore, I would like to evaluate the outcome of the Korean government's R&D expenditure based on the competitiveness of science and technology.

Most of the government budgets in Korea are set in a way that increases or cuts a certain percentage year-on-year if there are no special issues, i.e. incremental budgeting. The same goes for the R&D budget, and the Ministry of Strategy and Finance decides the total amount of the entire R&D budget and the Ministry of Science and ICT decides the budget for each detailed field. Because each field of science and technology has a wide variety of characteristics, the Ministry of Science and ICT adjusts the budget for each detailed field.

Figure2. Government R&D expenditure by fields (billion dollar)



For example, government support is urgently needed in environmental and agricultural sectors, and private companies are actively investing in R&D in the information and electronics sectors. In Finland, the rapid growth in resources spent on production of knowledge has made investments in knowledge even more important than investments in machinery and equipment (Asplund, 2020). In addition, technological leads and lags emerge largely as a result of differences in cumulative and firm-specific investments in technological activities including design, R&D, production engineering and learning by doing, the relative mix of which varies between sectors. R&D expenditures and patenting activities are therefore proxy measures of firms' and countries' commitments to technological activities rather than ends in themselves (Patel and K. Pavitt, 1987).

Therefore, when determining the budget for R&D in science and technology details, it is necessary to reflect the characteristics of each field, performance, and recent issues rather than the year-on-year adjustment method. Table 2 below shows the amount of R&D expenditure by year by each field in detail.

■ **Table 2 Korean government R&D budget by each field (unit: million dollar)**

Field	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Advances in Knowledge (Non-Purpose Research)	1,148	1,118	1,515	1,426	1,148	1,278	1,300	1,281	1,311	1,251	1,457
Health	912	975	1,106	1,123	1,130	1,116	1,276	1,288	1,344	1,341	1,414
Defense	1,376	1,529	1,726	1,987	2,099	1,994	2,135	2,228	2,430	2,605	2,800
Social Structure and Relationships	233	121	56	74	94	81	82	86	95	120	120
Energy	962	975	1,180	1,160	1,233	1,321	1,289	1,123	1,003	978	951
Space Development and Exploration	268	269	223	247	314	372	425	452	427	365	319
Earth Development and Exploration	154	157	232	196	218	233	274	285	256	200	198
Transportation/ Information/ Other infrastructure	82	76	113	82	123	116	132	139	304	476	552
Environment	233	238	325	313	330	361	414	437	470	516	547
Social Security	30	42	89	83	86	93	105	113	144	182	205
Culture, leisure, religion and mass media	49	78	73	66	71	70	73	76	76	86	81
Other public purposes	1,370	1,789	1,383	1,896	1,842	1,929	2,048	2,021	1,948	2,071	2,297
Agriculture, forestry and fishing	646	624	620	736	765	780	824	895	900	876	880
Manufacturing (food and tobacco)	43	50	64	46	49	57	60	67	52	51	50
Manufacturing (fiber, clothing and leather products)	83	86	101	106	100	118	119	114	99	89	93
Manufacturing (wood, paper and printing)	29	23	12	10	6	7	7	8	9	8	9
Manufacturing (Chemicals and Chemicals)	152	249	281	332	314	334	360	347	333	315	312
Manufacturing (Medical Materials and Drugs)	87	104	138	145	153	187	211	220	236	220	199

Manufacturing (non-metallic minerals and metallic products)	136	133	140	151	139	153	166	189	194	181	171
Manufacturing (electronic components, computers, video, sound and communication equipment)	663	693	795	870	909	937	1,037	1,043	825	667	650
Manufacturing (medical, precise, optical equipment and watches)	122	157	193	210	239	265	304	306	292	291	280
Manufacturing (Electrical and Mechanical Equipment)	321	475	461	429	474	532	619	606	555	521	531
Manufacturing (Automotive and Transport Equipment)	451	480	510	478	467	486	532	571	565	532	516
Electricity, gas, steam and water	16	22	24	16	23	26	25	25	34	49	62
Sewage, waste disposal, raw material regeneration and environmental restoration;	77	80	71	54	60	66	73	66	58	48	43
construction	83	102	148	179	176	200	223	233	235	226	220
Publishing, video, broadcasting and telecommunications and information services	95	91	183	248	209	204	200	202	206	203	185
Professional, scientific and technical services	137	183	196	220	209	192	212	202	235	251	299
Education service	44	183	70	49	44	48	46	46	40	39	32
Health and social welfare services	17	18	29	33	35	37	34	37	66	116	131
Arts, sports and leisure-related services	5	8	20	25	26	25	27	28	30	31	32
Other industries	431	392	429	407	417	427	422	388	607	795	920
Training and staffing	0	0	0	0	739	806	841	880	950	956	813
Total	10,454	11,522	12,508	13,395	14,243	14,854	15,894	16,004	16,331	16,653	17,369

In Table 1, the total amount of government R&D expenditures is steadily increasing year by year, but in each of the fields in Table 2, there is a larger percentage change in increase or decrease. In other words, the overall government R&D budget tends to be determined by a certain ratio adjustment method compared to the previous year, but it can be inferred that different factors in each detailed field are considered important. Therefore, when evaluating the performance of government R&D expenditure, it can be seen that the analysis results for each field are more meaningful.

In conclusion, the problem statement of this study is: Did Korea's government R&D expenditure by fields contribute to the improvement of science and technology competitiveness?

Literature Review and Hypothesis

Research on R&D investment performance can be divided into research to confirm performance and research to analyze factors affecting performance. According to Chang (2010), the larger the total amount of R&D projects, the greater the performance. In addition, the larger the amount of private investment in R&D projects, the greater the performance. In the study, R&D performance was evaluated by the number of papers and patents generated in the project, and these indicators are judged to have limitations in measuring the performance of R&D projects as quantitative indicators.

In addition, according to Hwang (2009), the higher the proportion of private investment participating in national R&D projects, the higher the efficiency of R&D projects. In the study, the number of papers, patents, sales growth, and job creation were considered as output variables on efficiency.

Since the above studies measured project-level performance, the scope of research is different from my study to confirm investment performance by fields, but it is worth noting that the amount of investment and the investment entity affect the performance of R&D projects.

As mentioned earlier, science and technology policymakers input their budgets to effectively improve the technology competitiveness of each field. The technology competitiveness can be identified by various indicators.

Hwang (2009) classified R&D performance into direct performance and economic performance. Direct performance is the primary performance produced through R&D, and can be quantified by the number of papers or patents. Economic performance is economic profit generated through the commercialization process and includes increased sales and technology fee income.

In this study, the use of the following indicators is considered because the results of R&D investment at the national level by technology field are analyzed from a competitiveness perspective.

The first is the technology balance of payments (TBP). This indicator can be obtained by subtracting technology imports from technology exports. Effective R&D investment leads to improved technological competitiveness, which increases technology exports and reduces technology imports. In other words, as the R&D investment effect increases, the TBP also increases. The second indicator is the result of technology level evaluation. In Korea, technology levels in the field are evaluated every two years through Delphi surveys of experts in related fields. Technology level is represented by percentage compared to the country with the best technology.

Among these two indicators, I will use the TBP as a dependent variable. The TBP index is related to the purpose of R&D investment and measured objectively according to the OECD manual. The results are announced every year. Therefore, it is appropriate to use this indicator in consideration of relevance, reliability, and ease of analysis.

TBP is an indicator of the trade balance, so the exchange rate is an influencing factor. However, existing studies on the effect of the exchange rate on the trade balance have presented conflicting results.

Chang (2009) analyzed that the elasticity of the real effective exchange rate was much greater than that of domestic or foreign real income in his study using the panel data approach, indicating that the real effective exchange rate is the most important factor on the trade balance. However, Lee (2011) argued that the impact of the exchange rate on the trade balance is limited, so it is important to manage demand-side factors and secure the unique competitiveness of Korean export goods rather than the exchange rate.

Therefore, I will estimate whether there is a significant correlation between TBP and the exchange rate, including the exchange rate as an independent variable.

In summary, independent variables include government R&D expenditure, private R&D investment, and the exchange rate. To explain further, all research equipment and facilities and personnel expense are included in the expenditure and investment.

Therefore, through this study, it is intended to confirm whether the Korean government's R&D investment in each science and technology field has a statistically significant correlation with the technological competitiveness (TBP) of the field.

Data Plan

For my project, I will use administrative data.

First, TBP data can be obtained from the Korean Statistical Information Service (KOSIS). TBP data registered in KOSIS are managed by the Ministry of Science and ICT, and TBP data for each technical field are available on this site are shown in the following table.

Table 3 TBP by technical field by year (Unit: million dollar)

Field	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Total	-6889.37	-5868.40	-5741.26	-5192.70	-5775.41	-6001.13	-4154.56	-4678.21	-3862.19	-4120.88
Math	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
physics	0.00	0.00	-0.37	-0.30	0.00	0.00	-4.74	-6.80	-5.02	-6.99
chemistry	18.66	62.62	0.86	-1.30	-78.04	-71.42	-90.50	-39.24	-32.65	-33.86
biology	0.58	0.84	-3.77	36.70	-63.19	-52.93	-27.52	-57.17	-88.05	-76.31
earth science	-0.22	-1.45	-35.60	-30.50	-3.06	-2.33	-0.95	-0.95	-7.81	-4.82
Mechanic	-435.25	-141.98	-151.17	608.80	-540.23	-614.12	-457.59	-185.15	-213.68	0.03
Material	-704.67	-696.18	-123.02	-219.20	-276.02	-247.65	-37.02	-24.63	-38.07	-0.92
Chemical Engineering	-718.17	-700.41	-195.36	-238.90	-366.60	-183.98	-408.22	-404.79	-360.85	-755.32
electrical electronics	-1899.45	-3452.78	-5304.71	-6045.00	-4367.79	-4544.37	-2275.95	-2769.98	-2325.95	-1543.28
Info-communications	0.00	0.00	0.00	0.00	648.54	61.20	-887.59	-778.82	-291.99	-1488.20
Information	-3358.72	-461.34	-475.86	-620.20	0.00	0.00	0.00	0.00	0.00	0.00
Communications	750.52	523.18	957.48	2051.00	0.00	0.00	0.00	0.00	0.00	0.00
Food, Agriculture, Forestry and Fish	-157.69	-203.73	-99.91	-79.10	-183.79	-213.81	-190.38	-260.59	-252.97	-329.29
health and medical	-66.19	-94.20	-184.73	165.40	44.30	250.00	377.73	-201.58	-181.07	-3.27
environment	-0.73	-0.40	-5.06	-4.80	-5.80	-5.08	0.86	5.21	-2.58	-3.49
energy resources	0.09	-45.50	-197.03	-181.90	-47.83	-42.31	-13.89	-6.13	-35.56	-14.88
nuclear power	1.81	-19.23	-27.73	-38.30	-42.62	-32.96	-38.52	-22.42	1.91	58.41
construction and transportation	-186.98	-211.29	677.37	-169.00	-56.15	46.75	171.88	243.31	124.38	132.84
Astronautics, Astronomy and Ocean	-41.74	-54.18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
humanities and social	-2.99	-5.26	9.62	0.50	5.20	-2.71	0.00	0.00	-6.95	-18.70
etc	-88.23	-367.09	-582.27	-426.70	-442.32	-345.41	-272.14	-168.47	-145.28	-32.84

Data about R&D expenditure can be obtained from the Korean National Science and Technology Information Service (NTIS). This information portal integrates and provides information, including programs, projects, human resources, and outcomes of national R&D programs. Based on the law, Framework Act on Science and Technology, data on this portal is collected by the Ministry of Science and ICT from the following organizations; Related central administrative agencies, Local governments, Businesses, educational institutions, Research institutions, institutions and organizations related to science and technology.

In the case of exchange rates, time series data can be obtained from www.index.go.kr, and the dollar value against the won from 2012 to 2020 is shown in the following table.

Table 4. Exchange rate (2012 ~2020, unit: dollar/won)

2012	2013	2014	2015	2016	2017	2018	2019	2020
1,070.6	1,055.4	1,099.3	1,172.5	1,207.7	1,070.5	1,115.7	1,156.4	1,086.3

Research Design

I will use regression for my research. This is because my study estimates the relationship among variables and suggests an improvement strategy based on the analysis results. In my regression analysis, the dependent variable is technology competitiveness, TBP and the independent variables are the factors that influence TBP.

Independent variables include government R&D expenditure, private R&D investment, and the exchange rate. All research equipment and facilities are included in the investment.

The R&D process takes time, and the R&D currently being conducted does not affect the increase in efficiency until a certain period of time, so it is necessary to assume a time lag structure (gestation period). Gestation period appears differently for each country, company, and technology field, and even in the same field, it appears differently for each R&D stage and research task. In addition, differences in technology level and strategy can affect gestation period in various ways. Since it is difficult to obtain accurate information on the distribution of gestation period, the average period is widely used to estimate the actual R&D gestation period (Hong et al., 1991).

According to KISTEP (2018), the average gestation period of Korea's national R&D projects was analyzed to be two years. Therefore, in this study, the amount of R&D investment is applied as a value two years before TBP.

Therefore, the equation for regression analysis is as follows.

$$TBP_{ij} = \alpha + \beta_1 Gov\_exp_{ij-2} + \beta_2 Pri\_exp_{ij-2} + \beta_3 Exc\_rate_j + \varepsilon$$

TBP_{ij}: Technology Balance of Payments in sector i and year j
Gov_exp_{ij-2}: Government R&D expenditure in sector i and year j-2
Pri_exp_{ij-2}: Private R&D investment in sector i and year j-2
Exc_rate_{ij}: Exchange rate in year j

In addition to the data presented above, the data that requires additional acquisition are the amount of private R&D investment by technology and year. The amount of private R&D investment by technology and year cannot be obtained directly from NTIS. However, since data on total R&D investment amount by technology and year are available from NTIS, I will obtain private R&D investment amount by technology and year by subtracting government R&D expenditure data from the total.

The key to the use of above variables, R&D expenditure and TBP, is that the categories of each technology field are different. There are 33 categories of technology classification used for Korean government R&D expenditure, and 20 categories of technology classification used for TBP.

Therefore, the categories of R&D expenditure and TBP need to be integrated for analysis. The criteria for integration depend on similarity. In addition, items with low similarity are excluded for accuracy of analysis by field. In addition, since TBP is used as an indicator of science and technology competitiveness, basic science fields that are less related to economic performance are excluded from the analysis. Accordingly, the table below shows the integration of R&D expenditure and TBP categories.

Table 5. Category integration

TBP	**R&D expenditure**	**Integration**
chemistry	Manufacturing (Chemicals)	Chemicals
	Manufacturing (fiber, clothing and leather products)	
Chemical Engineering	Manufacturing (wood, paper and printing)	
earth science	Earth Development and Exploration	earth
Material	Manufacturing (non-metallic minerals and metallic products)	Material

health and medical	Health	health and medical
	Manufacturing (Medical Materials and Drugs)	
environment	Environment	Environment
	Sewage, waste disposal, raw material regeneration and environmental restoration	
energy resources	Energy	Energy
nuclear power	Electricity, gas, steam and water	
Construction and transportation	construction	Construction and transportation
	Transportation/ Information/ Other infrastructure	
	Manufacturing (Automotive and Transport Equipment)	
electrical electronics	Manufacturing (electronic components, computers, video, sound and communication equipment)	Electrical and Mechanic
Mechanic	Manufacturing (Electrical and Mechanical Equipment)	
Food, Agriculture, Forestry and Fisheries	Agriculture, forestry and fishing	Food, Agriculture, Forestry and Fisheries
	Manufacturing (food and tobacco)	

Government R&D expenditure, private R&D investment, and TBP applying the integrated categories are shown in the table below.

Table 6. Government R&D expenditure by fields (unit: million dollar)

Field	2012	2013	2014	2015	2016	2017	2018	2019
Chemicals	447.16	420.29	457.85	485.81	469.30	440.76	411.53	413.89
Earth	196.29	218.44	233.26	274.19	285.30	256.25	200.00	198.48
Material	150.65	138.61	153.09	166.06	189.22	194.44	180.63	170.53
health and medical	1,333.13	1,369.00	1,381.55	1,580.20	1,593.76	1,635.61	1,631.48	1,693.29
Environment	366.99	389.81	427.37	486.57	503.32	528.08	563.62	590.65
Energy	1,176.67	1,256.41	1,346.77	1,313.84	1,147.36	1,037.13	1,026.52	1,013.05
Construction and transportation	738.44	765.55	802.77	886.90	943.49	1,103.82	1,234.27	1,287.15
Electrical and mechanic	1,298.77	1,383.07	1,469.13	1,656.16	1,648.75	1,379.78	1,188.12	1,181.21
Food, agriculture, forestry and fisheries	781.89	813.81	837.13	884.12	961.93	952.33	926.90	929.59

Table 7. Private R&D investment by fields (unit: million dollar)

Fields	2012	2013	2014	2015	2016	2017	2018	2019
Chemicals	3,649.75	4,143.28	4,034.81	4,923.34	4,834.76	5,558.34	6,282.66	6,181.58
Earth	279.21	291.75	240.92	312.07	265.03	254.26	184.14	196.19
Material	2,829.69	2,495.82	2,653.89	2,937.54	3,003.81	2,974.92	2,959.75	3,535.93
health and medical	537.06	692.38	772.65	915.35	1,063.34	1,329.21	1,408.04	1,755.81
Environment	500.22	425.95	401.68	270.55	452.90	322.11	307.80	332.97
Energy	686.25	652.16	734.92	813.48	977.25	1,496.36	1,751.44	1,437.81
Construction and transportation	662.03	574.96	673.33	391.42	214.99	2,753.62	2,931.00	3,005.35
Electrical and mechanic	26,983.76	29,496.22	32,452.99	31,934.28	34,305.42	38,226.98	42,393.87	43,928.01
Food, agriculture, forestry and fisheries	265.89	262.23	397.85	676.00	250.56	423.95	477.47	627.00

Table 8. TBP by fields (unit: million dollar)

Fields	2012	2013	2014	2015	2016	2017	2018	2019
Chemicals	-194.51	-240.20	-444.64	-255.40	-498.72	-444.04	-393.50	-789.18
Earth	-35.60	-30.50	-3.06	-2.33	-0.95	-0.95	-7.81	-4.82
Material	-123.02	-219.20	-276.02	-247.65	-37.02	-24.63	-38.07	-0.92
health and medical	-184.73	165.40	44.30	250.00	377.73	-201.58	-181.07	-3.27
Environment	-5.06	-4.80	-5.80	-5.08	0.86	5.21	-2.58	-3.49
Energy	-224.76	-220.20	-90.45	-75.27	-52.41	-28.55	-33.66	43.53
Construction and transportation	677.37	-169.00	-56.15	46.75	171.88	243.31	124.38	132.84
Electrical and mechanic	-5,455.89	-5,436.20	-4,908.01	-5,158.49	-2,733.54	-2,955.12	-2,539.64	-1,543.25
Food, agriculture, forestry and fisheries	-99.91	-79.10	-183.79	-213.81	-190.38	-260.59	-252.97	-329.29

Results

The results of regression analysis in nine fields by applying the above data are as follows. All regressions are robust to heteroscedasticity.

First, in the case of chemicals, the correlation between each independent variable and dependent variable is not statistically significant because the p-value significantly exceeds 0.05 confidence level in both government R&D expenditure, private R&D investment, and exchange rate.

Table 9. Regression result (Chemicals)

Dependent variable: Chemicals

F test of the regression: F(3,2) = 0.50, p=0.72, R-squared=0.43

	Coefficient	s.e.	t	p
Constant	1276.121	4333.630	0.294	0.796
Gov_exp	-0.229	5.158	-0.044	0.969
Pri_exp	-0.163	0.139	-1.177	0.360
Exc_rate	-0.796	2.271	-0.351	0.759

Second, in the case of Earth, the correlation between each independent variable and dependent variable is not statistically significant because the p-value significantly exceeds 0.05 confidence level in both government R&D expenditure, private R&D investment, and exchange rate.

Table 10. Regression result (Earth)

Dependent variable: Earth

F test of the regression: F(3,2) = 0.49, p = 0.72, R-squared = 0.42

	Coefficient	s.e.	t	p
Constant	-49.640	69.641	-0.713	0.550
Gov_exp	-0.024	0.045	-0.527	0.651
Pri_exp	0.071	0.079	0.899	0.464
Exc_rate	0.029	0.042	0.683	0.565

Third, in the case of Material, the correlation between each independent variable and dependent variable is not statistically significant because the p-value significantly exceeds 0.05 confidence level in both government R&D expenditure, private R&D investment, and exchange rate.

Table 11. Regression result (Material)

Dependent variable: Material

F test of the regression: F(3,2) = 1.03, p = 0.525, R-squared = 0.61

	Coefficient	s.e.	t	p
Constant	-2748.01	4766.602	-0.57651	0.622506
Gov_exp	1.91379	8.736258	0.219063	0.846925
Pri_exp	0.35165	1.212403	0.290044	0.79909
Exc_rate	1.176139	2.478684	0.474502	0.681904

Fourth, in the case of Health and Medical, the correlation between each independent variable and dependent variable is not statistically significant because the p-value significantly exceeds 0.05 confidence level in both government R&D expenditure, private R&D investment, and exchange rate. However, in the correlation between all independent variables and dependent variables, it is statistically significant because the F-value is 23.84 and the P-value is 0.0405.

Table 12. Regression result (Health and Medical)

Dependent variable: Health and medical
F test of the regression: F(3,2) = 23.84, p = 0.04, R-squared = 0.97

	Coefficient	s.e.	t	p
Constant	-2593.79	2667.616	-0.97233	0.43345
Gov_exp	-0.72742	1.213467	-0.59946	0.609733
Pri_exp	-0.05391	0.544362	-0.09903	0.930144
Exc_rate	3.313386	1.238865	2.674534	0.115978

Fifth, in the case of Environment, the correlation between each independent variable and dependent variable is not statistically significant because the p-value significantly exceeds 0.05 confidence level in both government R&D expenditure, private R&D investment, and exchange rate.

Table 13. Regression result (Environment)

Dependent variable: Environment
F test of the regression: F(3,2) = 0.88, p = 0.57, R-squared = 0.57

	Coefficient	s.e.	t	p
Constant	30.94035	51.9632	0.595428	0.61196
Gov_exp	-0.00826	0.038865	-0.21254	0.851377
Pri_exp	-0.03888	0.029752	-1.30693	0.321299
Exc_rate	-0.01201	0.03857	-0.3113	0.785025

Sixth, in the case of Energy, in the correlation between all independent variables and dependent variables, it is statistically significant because the F-value is 96.52 and the P-value is 0.0103. And in the case of government R&D expenditure, the p-value is 0.035, less than 0.05, so the correlation with the dependent variable TBP is statistically significant. In the case of private R&D investment, the p-value is 0.005, so the correlation with TBP is statistically significant.

Table 14. Regression result (Energy)

Dependent variable: Energy
F test of the regression: F(3,2) = 96.52, p = 0.01, R-squared = 0.99

	Coefficient	s.e.	t	p
Constant	-389.479	75.19319	-5.17971	0.03531
Gov_exp	0.207156	0.039964	5.183584	0.03526
Pri_exp	0.200548	0.014428	13.90008	0.005136
Exc_rate	-0.07075	0.056099	-1.2612	0.334422

Seventh, in the case of Construction and Transportation, the correlation between each independent variable and dependent variable is not statistically significant because the p-value significantly exceeds 0.05 confidence level in both government R&D expenditure, private R&D investment, and exchange rate.

Table 15. Regression result (Construction and Transportation)

Dependent variable: Construction and transportation
F test of the regression: F(3,2) = 0.58, p = 0.68, R-squared = 0.46

	Coefficient	s.e.	t	p
Constant	-1103.281	1563.279	-0.706	0.553
Gov_exp	0.795	0.604	1.317	0.318
Pri_exp	-0.088	0.092	-0.964	0.437
Exc_rate	0.525	1.180	0.444	0.700

Eighth, in the case of Electrical and Mechanics, the correlation between each independent variable and dependent variable is not statistically significant because the p-value exceeds 0.05 confidence level in both government R&D expenditure, private R&D investment, and exchange rate.

Table 16. Regression result (Electrical and Mechanics)

Dependent variable: Electonical and mechanic
F test of the regression: F(3,2) =5.39, p = 0.16, R-squared = 0.89

	Coefficient	s.e.	t	p
Constant	-14448.639	10210.509	-1.415	0.293
Gov_exp	1.447	2.697	0.537	0.645
Pri_exp	0.326	0.098	3.333	0.079
Exc_rate	-1.328	7.694	-0.173	0.879

Ninth, in the case of Food, Agriculture, Forestry and Fisheries, the correlation between each independent variable and dependent variable is not statistically significant because the p-value exceeds 0.05 confidence level in both government R&D expenditure, private R&D investment, and exchange rate.

Table 17. Regression result (Food, Agriculture, Forestry and Fisheries)

Dependent variable: Food, agriculture, forestry and fisheries
F test of the regression: F(3,2) =2.00, p = 0.35, R-squared = 0.75

	Coefficient	s.e.	t	p
Constant	321.1346	541.1816	0.593395	0.613086
Gov_exp	-0.58493	0.266017	-2.19884	0.158939
Pri_exp	-0.07641	0.127892	-0.59743	0.61085
Exc_rate	-0.01815	0.405806	-0.04472	0.968391

Combining all of the categories into one regression

Each of the regressions here has just six annual observations, allowing very little power for the statistical estimation. Combining all nine categories in one regression would exploit all 54 observations of nine categories. A dummy variable is included for each category to account for the different sizes of the categories. The point is to estimate the effect of government R&D and private R&D. The result of that estimation is Table 18.

The value of combining the data is that the statistical power is much greater. The findings show that, controlling for the different sizes of the categories, that private R&D statistically significantly increases TBP, but government industrial R&D does not. The conclusion based on this estimation would be that private R&D is much more effective, and that government industrial R&D is not having the desired effect. One possibility would be for the government to fund competitive grants for private R&D. Tax incentives could also be considered.

Table 18: All categories together

Sample size: 54, R squared = 0.95, F(11,42) = 34.67, p < 0.0001

Dependent: TBP	Coef.	Robust Std. Err.	t	P>|t|
Government R&D				
Lagged 2 years	-0.136	0.456	-0.30	0.767
Private R&D				
Lagged 2 years	0.304	0.041	7.36	<0.001
Field (Chemicals are the omitted category)				
Construction	1748.4	229.5	7.62	<0.001
Earth	1732.9	251.8	6.88	<0.001
Electrical	-11131.9	1496.0	-7.44	<0.001
Energy	1640.1	365.3	4.49	<0.001

Environment	1725.5	211.2	8.17	<0.001
Food etc.	1551.1	255.4	6.07	<0.001
Material	847.6	223.4	3.79	<0.001
Health & medical	1766.4	482.0	3.66	0.001
Exchange rate	0.113	0.740	0.15	0.879
Constant	-1914.9	790.8	-2.42	0.020

Conclusion

As a result of multiple regression analysis, the energy sector is the only field where the correlation between government R&D expenditure and TBP is statistically significant. In the energy sector, the correlation between private R&D investment and TBP was also found to be statistically significant. In other words, an increase in TBP can be expected due to an increase in government R&D expenditure in the energy sector. Therefore, in the energy sector, strategies to set TBP achievement goals and expand government R&D spending can be considered. In addition, it is recommended to establish detailed strategies for expanding government R&D expenditures for each detailed energy source such as nuclear power and renewable energy.

However, as a result of multiple regression analysis of individual industries, a total of 9 science and technology fields, it is highly suggestive that only the energy sector showed a correlation between TBP and government R&D expenditure. This is because in the case of eight fields excluding the energy sector, questions are raised about the effectiveness of the existing government R&D budget input method. Except for energy, the rest of the fields need to come up with innovative strategies to fully improve the existing government R&D spending method by discovering additional factors that affect technology competitiveness such as TBP and analyzing effects.

Combining all industries in one regression with controls for the size of the industry results in the finding that private R&D statistically significantly raises TBP. Government industrial R&D has no statistically significant effect. That result would be expected by analysts who emphasize the greater relevance of private R&D activity. At the least, the result suggests the Government industrial R&D is less effective and should perhaps not be targeted in the way it is at present.

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