「지방정부연구」 제27권 제1호(2023. 5): 265~292

The Korean Journal of Local Government Studies, Vol.27 No.1 (May 2023)
http://dx.doi.org/10.20484/klog.27.1.11

The effect of regional R&D input share on innovative output and outcome: From the case of National R&D Project of Republic of Korea

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Abstract

Direct R&D policies, such as subsidy granted to agents performing R&D, are considered effective tools for promoting innovation outcomes and economic performance. However, little attention has been paid to the geographical distribution of R&D subsidy and their empirical effectiveness. This study aims to uncover the relationship between the share of R&D subsidy(a portion of the subsidy) and innovative output (patents granted in logarithm) or outcome(GRDP per capita in logarithm). Using unbalanced regional panel data of R&D subsidy granted through the National R&D Project of the Republic of Korea, the author found that a higher share of R&D subsidy is negatively associated with the volume of patents granted, even drawing an inverse-U curve in general. Furthermore, a higher share of R&D subsidy appears to have a positive association with the level of GRDP per capita. This result suggests the need for a tailored systematic policy approach to the allocation and distribution of R&D-related inputs across regions, ultimately aiming for promoting regional economic performance also.

Key Words: Balanced regional growth policy, Local R&D, National R&D Projects, R&D inputs disparity, Regional Growth

Ⅰ. Introduction

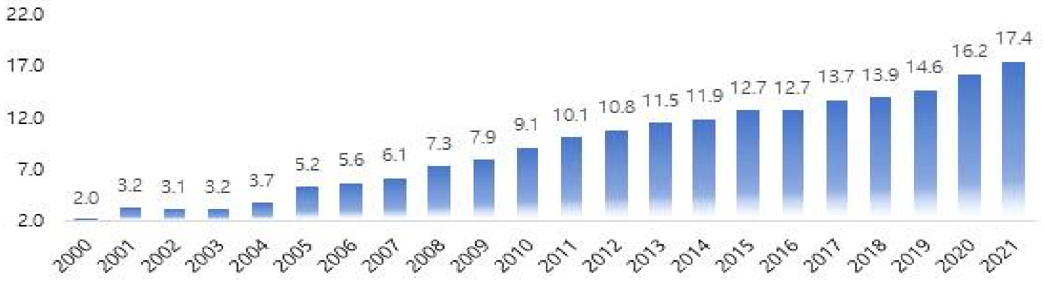
According to Mulligan(1984), “Spatial distribution of human activities tends to be uneven,” and the degree of regional growth differences within a country is determined by various factors, such as resource endowment and spatial characteristics. Policy options can also affect these patterns. The Republic of Korea(hereafter Korea) has achieved remarkable economic development, and its

* The first draft of this paper was presented at the Winter Seminar of The Korean Local Government Studies in February 2023.

main policy tools have been based on a concentration strategy, which provides more development-related inputs to specific fields or geographical units. The Seoul metropolitan(or Greater-Seoul) area has been the main beneficiary, now encompassing more than 50% of the population and accounting for 52.53% of total GRDP in 2021. As a result, concerns about excessive R&D source concentration have been voiced, as economic polarization can undermine social cohesion and stable growth(KRIHS, 2017: 117). The R&D capabilities among different regions shows more stark disparities. According to BISTEP(2022: 14), the Greater-Seoul region accounts for 65.8% of R&D personnel and 69.2% of R&D expenditures in 2021. As R&D is instrumental in both current and future growth, an imbalanced or excessive allocation of R&D resources can exacerbate existing patterns and other adverse consequences arising from unequal spatial traits, such as increasing costs of traffic congestion and environmental pollution(KRIHS, 2001). Furthermore, R&D is intrinsically a decision-making process for economic agents to maximize future profits by investing present resources while taking risks of potential failure. Without sufficient policy intervention, the issue of concentration might not be easily reversed or improved.

So there has been a continuance of trials to tackle the disparities in R&D sources between regions, and various measures have been implemented to mitigate any potential negative impacts of excessive concentration of R&D expenditure. One possible strategy to address this problem is to change resource allocation by dispersing R&D-related inputs. According to HEPI(2021: 5), "A broader geographic spread of R&D has the potential to attract more people to research careers, expand opportunities for university-business collaboration, and provide additional research capacity.". Several countries around the world are implementing various policies to address these problems by building R&D-related clusters, such as the EDA or regional industry clusters in the USA, and the GO cluster in Germany(KISTI, 2021: 4). In Korea, National R&D projects have served as one of the policy tools to achieve this goal because all types of applicants can participate in these programs as long as they can verify their own capacity to conduct the given R&D projects. This results in alleviating budget constraints related to R&D activities, especially in the case of SMEs. At a glance, the National R&D project has consistently grown and achieved its highest numbers in 2021, amounting to 24.2 trillion won for the initial time. Nevertheless, this trend solely reflects the current state and the overall amount of R&D funding, without any indication of how the project is distributed spatially. Such a limitations introduces a comprehensive inquiry into the relationship between R&D investment concentration and its impact, with a focus on the R&D output.

〈Figure 1〉 The trend of total volume of National R&D subsidy(unit: trillion won), Source: NTIS, author's calculation



Several studies have estimated the degree of dispersion of R&D resources or the effect of relevant policies using provincial data or indicators(Hwang, 2013; Kim, 2014; Yoo, Y.; Choi, S, 2022). However, they do not directly answer the aforementioned question, and to my knowledge, there is little empirical literature regarding this theme. Thus, this paper aims to empirically evaluate the effectiveness of the National R&D Project on regional development in terms of innovative and economic outcomes by region. By answering these questions, the author hopes to analyze the relationship between discrepancies in R&D input distribution and regional outcomes. The remainder of the paper consists of the following: a literature review on R&D concentration, research setup, main findings from regression, and remarks for policy implications.

Ⅱ. Literature Review

1. Changing views on R&D: from 'economy' to 'region'

Innovation itself is a constant and profound key to economic growth, so every government is eager to promote innovation using various tools at their disposal. This encourages research and development(R&D) through subsidy, which are a standard tool because R&D represents an important ingredient in the innovation process(IMF, 2022: 4). As R&D investment is regarded as one of the main channels to foster technological innovation and economic growth, a subsidy for R&D is justified as a core element of the aforementioned investment on several theoretical backgrounds.[1)]

1) The justification for governmental intervention, including direct R&D policy such as subsidy or grants, mainly arises from three perspectives: market failure, which emphasizes the intangible and

Although each rationale is based on different assumptions and policy solutions, governmental intervention is accepted worldwide but expectation for R&D policy differs from each country according to their socio-economical context. As early Korean government placed a top priority on economic development, accordingly, R&D policy has been regarded as viable and effective tools for this goal. For instance, Article 127 of Constitution of the Republic of Korea states that "The State shall strive to develop the national economy by developing science and technology, information and human resources and encouraging innovation.", assuring R&D should be conducted in accordance with the goal of economic development. This approach has been prevailing and recognized as a principal way to understand R&D ecosystem in Korea.

In recent times, it has been suggested that the previous approach towards R&D has reached a plateau, with no further breakthroughs for economic advancement available. As a result, several criticisms have been made, insisting that R&D should encompass a wider range of values. This includes not only efficiency or effectiveness in terms of scientific excellence and industrial innovation, but also social values such as participation and end-user civil society. This can be categorized as social problem-solving R&D(Song, Wichin and Seong, Ji-Eun, 2018: 295). In line with these changes, the law regulating National R&D was amended on December 28, 2021, to consider 'regional ripple effects' as a criterion for selecting institutions to perform R&D projects. This is aimed at nurturing balanced industrial development between regions.[2)]

2. Debates on the regional distribution of R&D inputs

As Hwang(2014: 36) points out, the strategy of "choice and concentration," which favors particular players who are strong enough to compete as "national champions," has been one of the dominant arguments shaping Korea's socio-economic system. Additionally, the concentration of R&D resources towards certain regions can be a natural phenomenon resulting from the collective decision-making of individual economic agents. However, it may harm nationwide

risky nature of knowledge; the innovation systems approach, which focuses on the interplay between different system components; and industrial policy views. For more detailed discussions, refer to J. Adler(2016), Tea Petrin(2018), and Moon(2020).

2) Article 10, Clause 2 of the National Research and Development Innovation Act states that the head of a central administrative agency must evaluate certain matters when selecting a research and development project and institute to perform it. This evaluation, referred to as "proposal evaluation," may exclude some or all of the matters listed in subparagraphs 3 through 5, depending on the purpose and nature of the national research and development program. Subparagraph 3 requires consideration of the academic, technical, social, economic, and regional impacts of the project, as well as the potential for utilizing its outcomes. However, some critics argue that this amendment reflects a "traditional" understanding of R&D and aims to balance economic and industrial disparities between regions.

efficiency and efficacy, so many countries adopt and implement various policies to curb this kind of concentration through different forms of fiscal assistance(KDI, 2022: 135). In the UK, it is evaluated that focusing on higher levels of R&D funding in diverse geographic locations could address regional inequalities and support international competitiveness simultaneously, meaning that ambitions for achieving seemingly contradictory goals simultaneously will align in the longer term(HEPI, 2020: 14-15).

In particular, "flattening" the disproportionate distribution of "inputs to innovation" leads to more resources available for various R&D performers, including local governments. With respect to the overall capacity to plan and implement their own R&D policy, local governments generally lag behind the central government due to several reasons. First, a significant portion of the R&D budget relies on subsidy from the National R&D Project, which are often granted as a form of matching funds (KISTEP, 2019: 146). Additionally, planning and evaluation for the National R&D Project are mainly performed by the central government. Local governments, at best, participate in the process of delivering matching funds to applicants for projects. This framework deepens asymmetric dependence between central and local governments, worsening future potential regional growth(Oh, Young Kyun, 2011: 316). These claims advocate for mitigating the uneven distribution of R&D resource allocations.

However, questions about rationale, adequacy and effectiveness of this effort remain still not clearly answered. Rather it seems there exist no agreements on the effect of any policies for any balanced regional development, including National R&D project. Presidential Committee for Balanced National Development has suggested two main pillars of regional balancing policy; first is to bolster national competitiveness and another to unite people, but there is a critique that these two policies might be complimentary in long run, but trade-off in short run, for instance 5 years which equals to presidential term of office(KIET, 2005: 118).[3]

3. An overview of the literature on various dispersion in R&D

A multitude of studies has focused on the effect of R&D input dispersion but its contents and conclusions vary from each other due to different research designs and viewpoints. Previous

3) On the relationship between regional innovative policy and balanced national development, some assert framework of regional innovative system(hereafter RIS) can contribute to alleviating unequal economic development between frontiers and lagging regions. However, RIS itself aims for improving growth of a certain region based on its competitiveness, not overall enhancement at national level. Rather essential factors of RIS, which entails a knowledge creation, diffusion and facilitating interactive learning between regional R&D participants might deepen or broaden imbalance between regional disparities(KIET, 2005: 136~138).

studies can be categorized into three aspects according to level of analysis and data; micro, meso(region or industry) and macro(country) level.[4] At the micro-level, Kim and Kim(2021) analyzed whether the concentration of regional spatial and ecological capabilities had positive external effects on firms' growth. They used firm-level panel data collected from 2012 to 2017 and concluded that several measurements for agglomeration had a positive impact on the growth of Small-Medium Enterprises.

Second, a group of studies focus on the effect of concentration of R&D inputs at industry or regional level but they derive mixed results of concentration itself or policies to lessen it. Moon(2021b) investigates effects of concentration of R&D subsidy on industrial productivity, mainly using NTIS R&D data of Korea with fixed-effect panel estimation. Author finds that degrees of concentration draws an inverse-u curve, implying excessive concentration of R&D subsidy yields a negative influences of innovation outcomes.

Some studies measured the distribution of R&D resources at region level using different data. Kim(2014) calculated Location Quotient(LQ) at regional level and showed which region are behind average level of LQ, considering diverse components regarding criterion to measure 'equitable' region growth. KRIHS(2017: 37~39) used Inter-region and Within-region Gini coefficient, CV, Enthropy Gini(Theil, 1967) using 1) population, 2) GRDP or private consumption expenditure, 2) other qualitative measures(concentration of secondary education institutions, new job openings, big 100 firms location. Similar approach can be found in the work of Choi, Bae(2018). Yoo, Y & Choi, S(2022) adopted and analyzed the balanced development indicators suggested by the Korea Balanced Development Committee based on public big data, which is available through the National Balanced-Development Information System(NABIS). Authors confirmed the fact that changes on indicators witness disparities between region are continuing, not ameliorated though several policy options have been adopted.

Other studies have shown a statistical correlation between dispersion measurements and various policy outputs. KDI(2009: 45-57) researched disparities in innovation capacity and economic activity across regions, using the CV approach to measure degrees of inequality. Additionally, it demonstrated the effect of government R&D expenditures on per capita GRDP from 2000 to 2005. To ensure the robustness of their findings, authors employed a 2SLS strategy using per capita patent output as an instrument variable. In another study, Moon (2019) examined the impact of changes in the agglomeration level of the knowledge-based service industry on regional economic growth, as measured by GRDP per capita. Using employment data

4) It is possible to argue that a region should be treated as macro term because it encompasses individual or micro agents within its legitimate or other categorical boundary. However, R&D system theory such as RIS deems region as a valid unit of analysis, which lies between micro and macro level. Similar approach can be found in other fields of studies i.e. labor market analysis(KLI, 2019: 7).

from the knowledge-based service sector for cities in Gyeonggi province from 2007 to 2016 and static and dynamic panel model estimation, the author found that changes in the agglomeration level of the knowledge-based service industry in cities with populations over 500,000 and overpopulated constraint districts had a significant and positive influence on regional economic growth.

Next, some studies had drawn a conclusion that concentration in terms of population doesn't always produce positive innovation output with macro-level data. Fritsch, M., & Wyrwich, M.(2021) analyzed whether innovation is concentrated in large cities using patent output data of countries, concluding that there was no significance relationship between level of innovation outputs and the size of cities.

〈Table 1〉 An overview of recent literature on R&D dispersion by unit of analysis

	Suggestion for a method of measurement	Finding Association between measurements and innovative output or outcome
Micro-leve l(firm, establishment)	·Kim and Kim(2021): SMEs	
Meso-leve l(Industry, Local, province)	·Kim(2014): LQ ·KRIHS(2017): Gini, CV, Theil ·Choi and Bae(2018) : CV ·Yoo,Y & Choi(2022) ·Moon(2019): Coagglomeration	·Industry: KDI(2009), Moon(2021b) ·Region: Moon(2019) ·Industry&Region: Byeon(2015)
Macro-level (State, County)		·Cho, Kim(2020): 39 countries ·Fritsch, M., & Wyrwich, M. (2021): population density & patent

Ⅲ. Research Design

1. Data source and measurement

1) Main dataset

The main dataset used for analysis is a combination of regional indicator integrated data by Ko, Kim, and Kim(2022) and augmented variables that were hand-collected by the author. Time period for analysis ranges from 2000 to 2020. However, the data structure is an unbalanced panel due to the creation of Sejong special self-governing city in July 2012. Therefore, the unit of analysis is 16 until 2011 and 17 from 2012, and the level of analysis is the region(province). Many arguments confirm (e.g. Yang et al. 2023: 1) that recent R&D or science and technology(S&T)

policies aim for building and improving innovation systems not only at the national level but also at the regional level, ultimately increasing R&D inputs and outputs. Additionally, regions are considered efficient mechanisms for addressing stagnant growth and responding to regional demands(STEPI, 2012: 36). On regional data quality, some studies suggest that it has limitations due to its intrinsic nature. For instance, regional data on the changes in the variables of interest is generated through an endogenous process, rather than a random process. Therefore, macro-level data may be more suitable for analysis(Lee and Hwang, 2015: 9). However, macro-level data(i.e., country-level data) is primarily produced through aggregation and does not reveal detailed information compared to that of sub-level governments or regions. Therefore, the author uses region-level data for analysis.

2) Regressand: GRDP per capita and patents granted

cs in various ways. For instance, Article 2, clause 5 of the "National Research and Development Innovation Act" defines these outcomes as "tangible and intangible outcomes prescribed by Presidential Decree, including products, facilities, equipment, and intellectual property rights." Additionally, the "Act on the Performance Evaluation and Management of National Research and Development Projects" expands the definition of outcomes by encompassing "any other economic, social, and cultural performances that are tangible or intangible." Each different proxy represents innovation output and outcome respectively. For instance, the output may be indicated by statistics on patents, publications, prizes, invention disclosures, and degrees awarded, while outcome proxies include patent and paper citations, expert evaluations, innovation counts, new product sales, measured productivity growth, and benefit/cost or rate-of-return estimates(National Academies of Sciences, Engineering, and Medicine, 1997: 24).

This research selects two variables to measure R&D-related outcomes. The first variable is Gross Regional Domestic Product(GRDP) per capita, which is used to assess whether the distribution of R&D subsidy affects its enhancement. GRDP is considered basic information for regional development policy and innovation policy, so it is accepted as the main variable for evaluating innovation policy(Chang, 2007: 26; Kim, 2010: 209). Data on GRDP per capita is obtained from Ko, Kim, and Kim(2022) and is logarithmically transformed.

Secondly, the number of patents granted by region is used to evaluate innovative capacity based on several characteristics. Firstly, patents are not only a representative outcome of the knowledge production function but also a proxy for knowledge capital(Kwon, 2021: 6). Secondly, patents granted differ from filed patents in terms of the completeness of the patent application procedure. A filed(pending) patent means that someone has submitted a patent to the authorities, whereas a granted patent means that no other individual or company is legally allowed to benefit from it. Thus, patents granted are often regarded as 'actual' patents. The figures for patents granted by region are derived from the Korea Intellectual Property Rights Information Service (KIPRIS) and are presented in logarithmic form.

3) Main regressor: the proportion of R&D subsidy allocated by region

This study measures the regional distribution of R&D as a share of subsidy for each region, following the approach of Moon(2021b: 277-278). There are various ways to construct indicators to measure dispersion or distribution of variables, each with its pros and cons. Frequently used indicators include the Gini coefficient, CV, Entropy Gini, or Theil indexes, as analyzed by KRIHS(2017: 37-39). However, these variables have a limitation in that they only produce one-dimensional factors using multiple pieces of information.5) Additionally, the Herfindahl-Hirschman Index(HHI) can show extremely high values depending on the number of analysis units within each sector.

As an alternative, this study uses a share of a certain region's R&D subsidy compared to the entire subsidy given through the National R&D Project, following the suggestion of Moon(2021b). The main source for the R&D subsidy is the National Science & Technology Information Service(NTIS) data, which provides detailed information on projects undertaken in a given year. This dataset surveys the location where each project has been conducted, so the subsidy of specific regions is a summation of project expenses during a certain period in a designated region.6) Analytical expression for this indicator is as following; $\log(\frac{Grants_{i,t}}{Grants_t})$, which is the ratio of region i at time t to the total subsidy at time t.

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5) Gini coefficients are often used to measure or decompose the current status of inequality in various fields. However, they have a limitation of "condensing" original data, creating a many-to-one indicator, which might provide different dimensions of information than what you are interested in. Furthermore, in order to use Gini coefficients as independent variables in regression models, additional econometric tests may be required, such as the Granger-Causality test or unit root test, to ensure the stationarity of variables(KERI, 2019: 4-6).

6) Some may criticize the "excessive simplicity" of measurement, which could be a major weakness in terms of the validity of the variable of interest. Of course, a more detailed sub-category of subsidy information could broaden and deepen the scope of analysis. However, to the best of the author's knowledge, there is currently no dataset available that incorporates information at the regional level and other levels of data, except for those related to project performance. Industry classification may be a good option, but constructing such a dataset would require significant effort. For practical reasons, the author has chosen a manageable approach while acknowledging its limitations.

4) Controls

For the control variables, socio-economic indicators related to GRDP growth have been chosen, following the suggestions of previous studies. First, private R&D investment and R&D employees have been selected. Tons of researches generally report the positive relationship between private R&D inputs and economic growth. Plus, it is generally accepted that R&D personnel can play a crucial role in the innovation process and that innovation is a key driver of economic growth. R&D personnel are responsible for generating new knowledge and ideas that can lead to the development of new products, processes, and technologies. These innovations can increase productivity and efficiency, leading to economic growth. Next, to control for the effect of international trade on growth the volume of exports measured in the logarithm has been included. Generally, exports themselves exert positive effects on economic growth through channels of knowledge diffusion, economies of scale, improving efficiency, and relaxing constraints of foreign exchange reserves(Park, 2019: 110). Next, local financial soundness can influence regional economic growth through several paths, or vice versa, as Song(2013) showed a Granger-causality between local share tax and GRDP using data from 16 provinces from 1985 to 2010. In line with the suggestion above, the fiscal autonomy ratio has been adopted to control for the impact of fiscal soundness on growth. Reversely, when regions or local governments have high levels of fiscal autonomy, they have more control over their own resources and may prioritize short-term spending or rent-seeking behaviours rather than focusing on long-term growth-oriented factors, which may create inefficiencies and negatively impact overall economic growth. Finally, considering the significance of the Greater-Seoul area to the Korean economy, it is essential to account for these regional impacts. Hence, we incorporate a dummy variable for the Greater-Seoul area, which equals 1 if a particular region is a part of it.

〈Table 2〉 Definition of variables for analysis and its source

Type	Variable	Measurements and explanation	Source
Regressand	Log of GRDP per capita of region *i* at time *t*	$\log\left(\frac{GRDP_{i,t}}{Population_{i,t}}\right)$	e-Regional Indicator by Koh, Kim and Kim(2022)
	Log of patents granted of region *i* at time *t*	$\log(Registered\ Patents_{i,t})$	KIPRIS
Regressor	Share of subsidy (grants)(%)	$\log\left(\frac{Grants_{i,t}}{Grants_{t}}\right)$	Author's calculation using NTIS data

Control	Log of total R&D by private firms	$\log(privateRnD_{i,t})$	Survey of Research and Development in Korea, 2000~2020
	Log of private R&D personnel	$\log(RnDEmployees_{i,t})$	
	Log of the volume of regional export	$\log(\mathrm{Exp}ort_{i,t})$	e-Regional Indicator by Koh, Kim and Kim(2022)
	Fiscal Autonomy Ratio	[(Local tax+non-tax revenue)+local shared tax)] ÷ General account budget] of i region at time t	
	Greater-Seoul Dummy	1 is given if a region belongs to Greater-Seoul area(Seoul, Gyeonggi or Incheon)	

2. Estimation strategy

$$Performance_{i,t} = \beta_0 + \beta_1 GrantsShare_{i,t-1} + \beta_2 GrantsShare^2_{i,t-1} + \beta_3 Control_{i,t-1} + \alpha_i + \tau_t + \epsilon_{i,t}$$

$performance_{i,t}$ is dependent variable defined as economic growth(logarithm of GRDP per capita) and innovative output(logarithm of patents granted). Each regressand represents two different measurements regarding innovative-related output or outcome in different aspect. Next, β_1 captures the linear effect of regional dispersion on each region's regressors. β_2, squared term of grants share focuses on non-linear effect of regressors. Linking these two coefficients together policy implication might be inferred. For example, with positive sign of β_1 and negative sign of β_2 means an inverse-u curve, which leads to conclusion that excessive degrees of R&D subsidy concentration might hamper production of patent and regional economic growth beyond certain threshold. $Control_{i,t}$ is a covariate of control variables including growth related factors. α_i is an unobservable region-specific trait. τ_t stands for year-dummies to control year-specific events, with $\varepsilon_{i,t}$ indicating a error term.

Meanwhile, there is a consensus that it takes time for R&D investment to produce output or outcomes. Therefore, selecting a valid time lag(gestation period) can be a primary key to assessing the effect of R&D input. Several econometric problems can arise when there is no time lag between the regressor and regressand, such as the issue of reverse causality. This problem is caused by endogeneity or simultaneity, and it can blur the causal relationship(Son, 2018: 34). Various articles have examined the optimal time lag for private R&D investment. For instance, Lee, Baek, and Lee(2014) have recommended using an Almon distributed time lag model and R&D activity data obtained from KISTEP, suggesting a time lag of either one or two years. Another study suggests the same gestation period for National R&D Projects(KISTEP, 2015). In a survey conducted on SMEs, which are among the main participants of National R&D projects, it was found that on average, it takes 14.3 months from R&D planning to commercialization(Lee, 2017: 25). However, the actual time lag may be shorter than the results of previous studies, as there is a relative concentration of R&D inputs in the developmental phase of R&D, which typically requires a shorter time than other types of R&D, such as basic R&D(Lee, Baek, and Lee, 2014: 17).7) Therefore, a one-year lag for the regressor is applied to the analysis model here.

However, panel data may be subject to the pitfalls of contemporaneous correlation between cross-sectional units and serial correlation between different periods(Kim & Lee, 2018, p. 121). Additionally, in a long-term panel, individual fixed effects can be incorporated into regressor terms, resulting in too many time effect dummies(Cameron & Trivedi, 2010/2017, p. 353). Furthermore, the model diagnostics for the fixed model showed the existence of heteroskedasticity8) and possible cross-sectional dependence,9) which may not provide efficient coefficients. Violation of these assumptions leads to alternative estimation methodologies, such as GLS estimation, to address these problems, which rely on relaxed assumptions of the error term. Merely, heteroskedasticity and serial correlation themselves do not harm the consistency of the estimator but rather its efficiency and the bias of the estimator is not a significant issue except in dynamic panel models with large samples(Kim & Lee, 2018, p. 125). In conclusion, the author mainly presents the regression result derived from Feasible GLS(FGLS) model with heteroskedasticity and AR(1) serial correlation between individual units. To assure robustness of estimation result, the author adopts panel-corrected standard error(PCSE) model additionally. When computing the standard errors and the variance-covariance estimates, PCSE model assumes that the disturbances are, by default, heteroskedastic and contemporaneously correlated across panels. When when the disturbances are not assumed to be independent and identically

7) On average, 33.2% of the entire subsidy was granted to development phase R&D through National R&D projects from 2017 to 2021. Despite the recent trend of emphasizing basic R&D for innovation breakthroughs, the ratio has increased to 35.6% in 2021. Additionally, the number of projects conducted by SMEs accounted for 24.2%(19,198 out of 74,745) in 2021. However, after excluding universities(39,215 cases, 52.6%), the ratio increased to 51.1%.

8) The Modified Wald test for groupwise heteroskedasticity in a fixed regression model (using the xttest3 command in Stata) did not reject the null hypothesis of homoskedasticity. However, it is important to note that for "large N, small T" panels, the power of this test may be low. In this particular dataset, the time span is long (21 years) compared to the number of units (17), which is a valid data structure for testing. Nevertheless, it is crucial to keep in mind that these statistics are sensitive to the assumption of normality of the errors. For a more detailed discussion, refer to Christopher F Baum's (2000) work.

9) The test using the xttest2 command has been run and showed that the test statistics reject the null hypothesis, indicating the presence of cross-sectional dependence. Additionally, Pesaran's Cross-sectional dependence (CD) test also strongly rejected the null hypothesis of no cross-sectional dependence(using xtcsd command).

distributed(i.i.d.), PCSE model can be an alternative to FGLS for fitting linear cross-sectional time-series model(Stata Corp, 2013: 4~5).

Ⅳ. Results and discussion

1. Summary Statistics

The main descriptive statistics of the variables used in the analysis are shown in Table 3 below. Firstly, the GRDP per capita and the number of patents granted are much larger in the Seoul Metropolitan area. This trend is also observed for the volume of exports and the fiscal autonomy ratio. Considering that all the variables mentioned are directly or indirectly related to different aspects of economic performance of each region (province), this result reveals a somewhat high degree of uneven resource allocation in Korea, as much literature has already shown(Hwang, 2013; KRIHS, 2017; Kim & Kim, 2021). The correlation table for the variables is shown in Appendix 1 at the end of this paper.

〈Table 3〉 Trend of National R&D subsidy by year and area type

Vars.	Obs	Mean	Std. Dev.	Min	Max
Non Greater-Seoul Area					
log(GRDP per capita)	281	10.03	0.38	9.27	10.90
log(patent)	282	6.90	1.15	3.00	8.96
Share of Government R&D subsidy(-1)	280	0.04	0.07	0.00	0.35
Squaed-term of share(-1)	280	0.91	0.07	0.69	1.00
log(private R&D)(-1)	267	8.19	1.32	2.75	10.38
log(private R&D personnel)(-1)	267	8.04	1.12	3.76	9.74
log(the volume of export)(-1)	268	8.90	1.81	3.69	11.53
Fiscal autonomy ratio(-1)	254	74.70	5.40	62.10	90.60
Greater-Seoul Area					
log(GRDP per capita)	63	10.17	0.37	9.27	10.80
log(patent)	63	9.14	1.16	6.55	10.48
Share of Government R&D subsidy(-1)	60	0.14	0.09	0.02	0.33
Squaed-term of share(-1)	60	0.79	0.09	0.69	0.93
log(private R&D)(-1)	60	10.70	1.23	8.19	12.99
log(private R&D personnel)(-1)	60	10.45	1.10	8.24	12.09
log(the volume of export)(-1)	60	10.53	0.74	8.64	11.87
Fiscal autonomy ratio(-1)	57	84.47	6.50	73.70	96.10
Total					

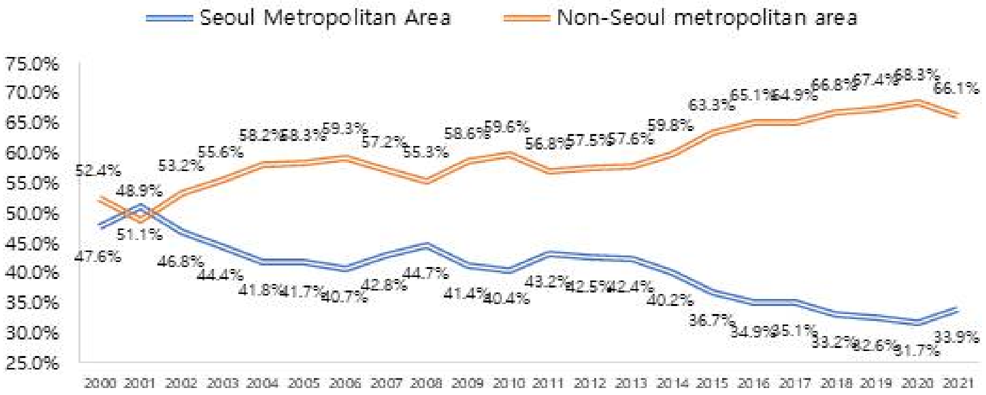
log(GRDP per capita)	344	10.05	0.38	9.27	10.90
log(patent)	345	7.31	1.44	3.00	10.48
Share of Government R&D subsidy(-1)	340	0.06	0.08	0.00	0.35
Squaed-term of share(-1)	340	0.89	0.08	0.69	1.00
log(private R&D)(-1)	327	8.65	1.63	2.75	12.99
log(private R&D personnel)(-1)	327	8.48	1.46	3.76	12.09
log(the volume of export)(-1)	328	9.20	1.78	3.69	11.87
Fiscal autonomy ratio(-1)	311	76.49	6.76	62.10	96.10

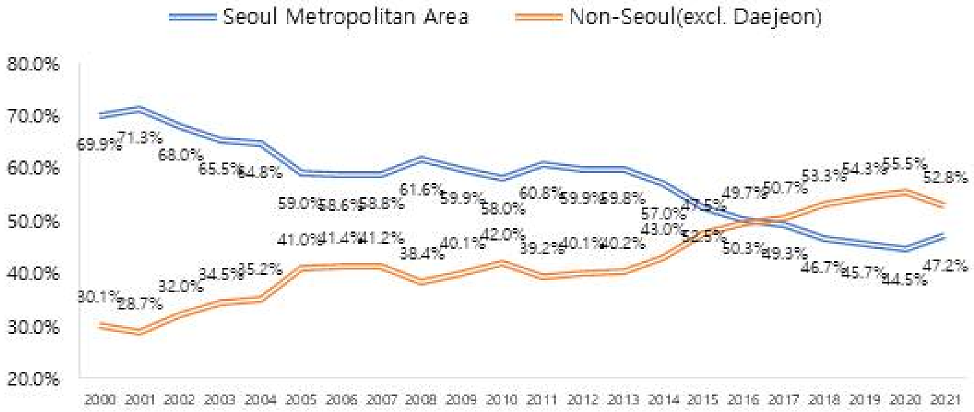
Source: author's calculation using NTIS
Note. Greater-Seoul Area= Seoul, Gyeonggi and Incheon

The primary focus of this study is the concentration of R&D subsidy. In this section, the author examines this variable in detail. The percentage of subsidy allocated to the Seoul metropolitan area has fluctuated over time, decreasing to 31.7% in 2020. Meanwhile, the percentage allocated to non-Seoul areas has significantly increased, reaching a high of 68.3% in 2020. However, it is important to note that Daejeon, the main hub of national research, is classified as a non-Seoul area, which significantly reduces this percentage to 52.8% in 2021 when excluding Daejeon from the sample. Additionally, the Seoul metropolitan area only consists of three regions, while the non-Seoul area has 13, which suggests that on average, fewer subsidies may be allocated to non-Seoul areas. According to the summary statistics, the mean subsidy share for non-Seoul areas is only 4%, which is much smaller than the average of 14% for the Seoul area(see Table 4).[10)]

10) The minimum share of subsidy allocated to the non-Seoul metropolitan area in 2012 was zero. This was also true for Sejong self-governing city, which was established in July 2012.

〈Table 4〉 Trend of National R&D subsidy by year and area type



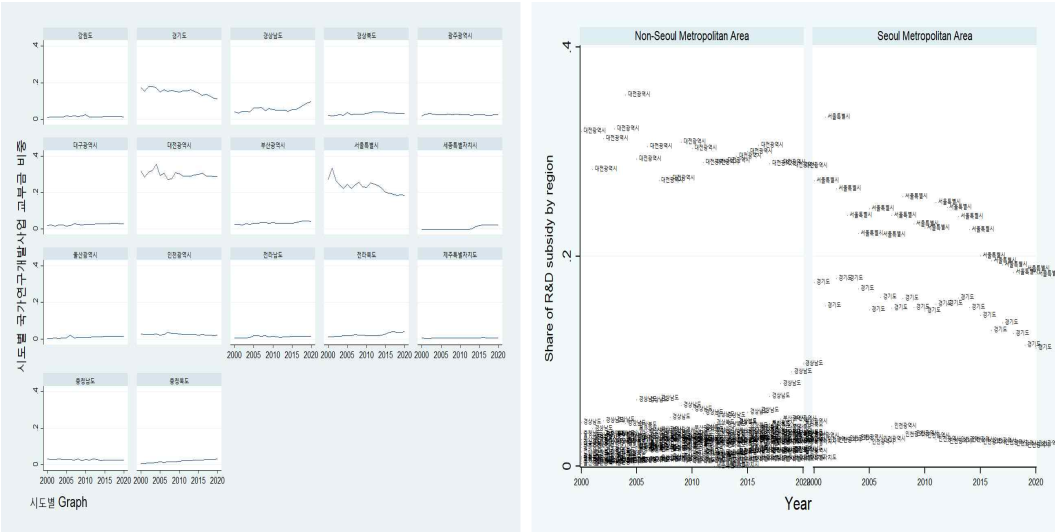


Source: author's calculation
Note. Seoul Area= Seoul, Gyeonggi and Incheon

Upon closer examination of distribution of R&D subsidy, it can be observed that the total amount given to each region has generally increased over time(as shown in the upper figure in Table 5). However, the absolute level of subsidy does not exceed 200 billion won in non-Seoul areas, except for Daejeon and South Gyeongsang Province. This trend is more evident in the panel-time plot of subsidy share(as shown in the lower figure in Table 5). With the exception of three provinces(Seoul, Gyeonggi, and Daejeon), the share of subsidy for almost all regions does not exceed 5%.

〈Table 5〉 Figure Trends in National R&D subsidy by year and area type

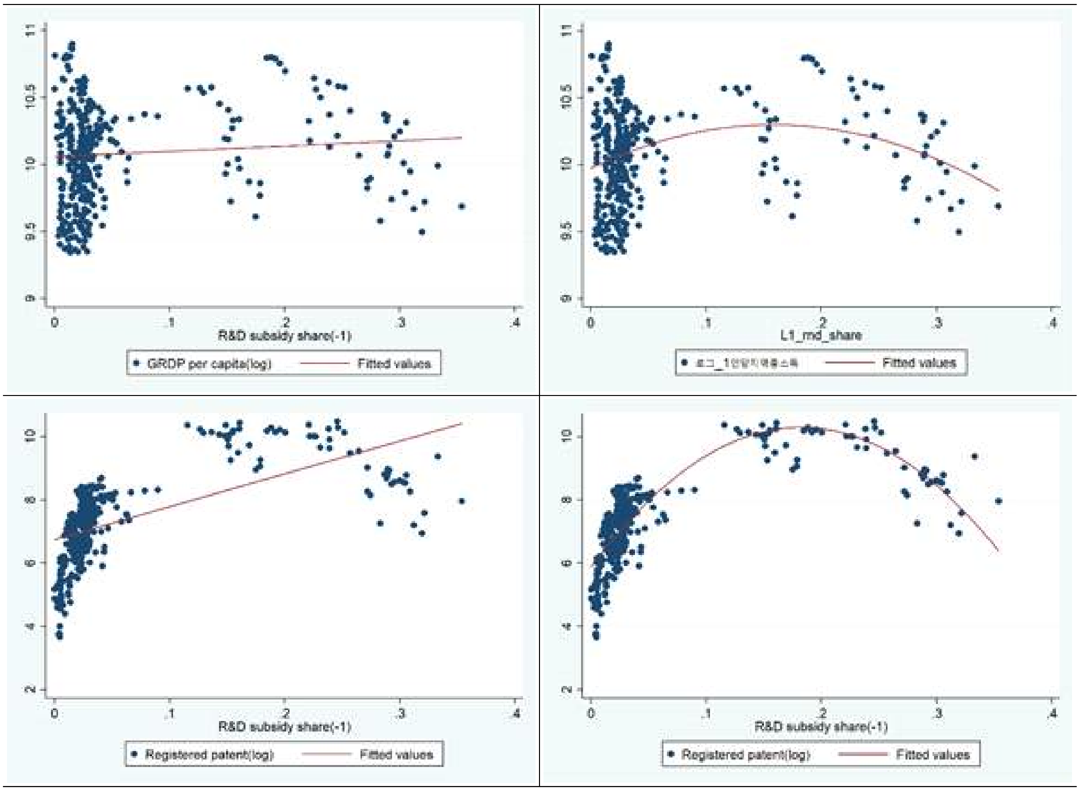
(unit: 100 billion KRW)



Source: author's calculation

The relationship between the R&D subsidy share and dependent variables is shown graphically in Table 6. The two upper figures display a linear and quadratic relationship between the subsidy share and GRDP per capita(log), respectively. The linear term has a positive slope, while the quadratic term has a negative sign. This tendency is also observed for patents granted(log), but the graphical association appears stronger. In general, the scatter and fit plots suggest an inverse-U curve, supporting the hypothesis that excessive concentration can undermine innovation-related output or outcome. However, this plot only indicates a correlation between variables and not a causal relationship. Therefore, the next section will display the regression results.

〈Table 6〉 Graphical relationship between the share of R&D subsidy(−1) and the log of GRDP per capita and granted patents



Source: author's calculation

2. Main estimation result

Regarding the basic regression model of OLS and fixed effect linear estimation model (see Table in Appendix 2), there are no statistically significant variables except for several control variables such as the volume of exports and fiscal autonomy ratio. The variables of interest mostly remain insignificant, but the squared term yields a strong negative coefficient for patents granted. However, these results are not reliable due to heteroskedasticity and cross-dependence(AR(1)) between observations. Therefore, we turn our attention to the results of the FGLS model, which considers heteroskedasticity and serial correlation(see Table 7).

〈Table 7〉 Regression table of FGLS estimation

	log(GRDP per capita)		log(patent)	
Share of Government R&D subsidy(−1)	−0.138	0.745***	−1.752	−2.010***
	[0.403]	[0.277]	[1.360]	[0.729]
Squaed−term of share of Government R&D subsidy(−1)	0.0562	0.712**	−7.455***	−7.767***
	[0.479]	[0.308]	[1.591]	[0.925]
log(private R&D)(−1)	0.0666***	0.00636	0.166***	0.0625**
	[0.0164]	[0.00972]	[0.0579]	[0.0311]
log(private R&D personnel)(−1)	0.035	−0.00431	0.234***	0.209***
	[0.0220]	[0.0140]	[0.0735]	[0.0437]
log(the volume of export)(−1)	0.0858***	0.0522***	0.170***	0.146***
	[0.0163]	[0.00857]	[0.0416]	[0.0242]
Fiscal autonomy ratio(−1)	−0.00869***	0.00176	−0.0225***	0.0104***
	[0.00169]	[0.00129]	[0.00555]	[0.00392]
Region dummy(=1 when in Greater−Seoul)	−0.128*	0.0610*	0.439***	0.441***
	[0.0701]	[0.0341]	[0.141]	[0.0769]
Constant	9.031***	8.290***	10.75***	9.148***
	[0.545]	[0.354]	[1.775]	[1.080]
Observations	311	311	311	311
Number of unit	17	17	17	17
Year−effect		O		O

Note 1. FGLS estimation model considering heteroskedasticty and AR(1) was adopted.
2. Robust standard errors in brackets
3. *** p〈0.01, ** p〈0.05, * p〈0.1

Firstly, a higher local subsidy share is negatively and significantly related to patent production on average, indicating that it might be more advantageous to assign inputs to innovation diversely, which might induce various participants to conduct R&D. Additionally, the squared term of regional subsidy share takes a negative sign, drawing an inverse-u curve towards registered patents, which suggests that excessive dependence of subsidy share against certain regions can be harmful to producing patents. As Kwon(2019) demonstrated, the output of total publications and patent applications was higher in technology and research fields where various subjects participated in research activities. Similar advocacy was also witnessed in the study of the effects of R&D disparity on economic growth in 39 countries from 1990 to 2017(Cho, Kim: 2020). Next, author finds that the first and squared terms of the government subsidy share are generally positively related to GRDP per capita. However, caution must be exercised when interpreting regression results, particularly about GRDP. As we are aware, resource endowment and allocation in Korea are distributed disproportionately. Therefore, the regression results may reflect this reality rather than a causal relationship. One possible explanation for this phenomenon is the innate functioning of a "selection bias," which means that subsidies are not randomly distributed but based on certain criteria. For example, the regional capacity to execute specific projects without a failure may be emphasized internally when deciding who receives subsidy, or specific policy agendas may influence the selection of recipients(Moon, 2021a: 100-101). All of these factors may work together, seemingly supporting the "choice and concentration" argument not only at the industry level(Moon, 2021b) but also at the local government level.

The two aforementioned results of the analysis suggest that redistributing public R&D investment by adjusting the volume of subsidy from National R&D Projects may increase innovative output (patents), but it may not have an impact on economic growth(Ahn, Kim, 2009: 116-117). To enhance the innovative capacity of local governments or regions, it is generally advised to increase the proportion of public R&D in underdeveloped regions so that they can harness more R&D-related resources. However, more practical measures are necessary to establish an innovation system that effectively utilizes R&D results and provides opportunities for 'de facto' their dissemination and application. For instance, in lagging regions the arrangement of institutions for knowledge creation(including innovation itself) and its commercialization tends to be less well established or fragmented, and this can be a barrier to enabling innovation(KIET, 2005: 182). Whereas the earlier policy relatively focused on building blocks for basic infrastructure through policies such as clustering, recent ideas have emphasized to improve human capital capabilities and forming R&D networks that can facilitate communication between primary actors in the region to support diffusion of ideas(KIRD, 2022: 15). Examples of such policies may include measures to make patent commercialization more profitable or to facilitate the establishment and efficient operation of Technical Licensing Office(TLO) in lagging regions.

The control variables generally align with theoretical expectations, mostly indicating a positive correlation with patents and GRDP. However, the coefficient for the fiscal autonomy ratio occasionally shows a negative correlation, reflecting the myopic or rent-seeking tendencies of local governments that result in inefficiencies and a negative impact on economic growth or knowledge production. Furthermore, the coefficients for the volume of private R&D and the number of R&D personnel vary depending on the model specification and may not always exhibit statistical significance. This could be attribuetd to that aggregated and time-series R&D data may not demonstrate significance or may yield counter-intuitive outcomes, particularly when extending the data scope from micro to macro units(U. Demiro?lu, D. Hamilton, A. Holen, 2005: 14~17). The Greater-Seoul dummy variable shows generally positive signs, indicating that regions in the Seoul metropolitan area are linked to producing more GRDP per capita and patents.

Further analyses conducted using the Panel-Corrected Standard Errors(PCSE) estimator for AR(1) have yielded outcomes that are largely consistent with those obtained through the FGLS estimation model(See Table 8). The sign of the main variable of interest, the share of government subsidy and its squared terms, is generally consistent with the previous regressions, and the results for the control variables are similar. These additional analyses further demonstrate the robustness of the regression results.

〈Table 8〉 Regression table of PCSE estimation

	log(GRDP per capita)		log(patent)	
Share of Government R&D subsidy(−1)	0.0502	1.454***	−2.224***	−1.831***
	[0.483]	[0.357]	[0.790]	[0.646]
Squaed−term of share of Government R&D subsidy(−1)	0.407	1.669***	−8.335***	−7.827***
	[0.665]	[0.446]	[1.195]	[0.924]
log(private R&D)(−1)	0.0523***	0.00933	0.166***	0.0629**
	[0.0183]	[0.00859]	[0.0518]	[0.0253]
log(private R&D personnel)(−1)	0.0161	−0.0199	0.204**	0.251***
	[0.0389]	[0.0133]	[0.0974]	[0.0428]
log(the volume of export)(−1)	0.0785***	0.0663***	0.146***	0.123***
	[0.0237]	[0.00984]	[0.0364]	[0.0171]
Fiscal autonomy ratio(−1)	−0.00721**	0.00647***	−0.0248***	7.05E−05
	[0.00297]	[0.00159]	[0.00732]	[0.00368]
Region dummy(=1 when in Greater−Seoul)	−0.0659	0.0484**	0.568***	0.548***
	[0.0537]	[0.0217]	[0.0771]	[0.0484]
Constant	8.996***	7.030***	12.18***	9.813***
	[0.811]	[0.484]	[1.481]	[1.048]
Observations	311	311	311	311
Number of unit	17	17	17	17
R−squared.	0.991	0.997	0.863	0.946
Year−effect		O		O

Note 1. PCSE estimation model for AR(1) has been adopted hereby.
2. Robust standard errors in brackets
3. *** p〈0.01, ** p〈0.05, * p〈0.1

V. Concluding Remarks

This study examined the relationship between the proportion of R&D subsidy and innovative output, measured by patents granted in logarithm, and the outcome measured by GRDP per capita in logarithm. The main findings revealed significant disparities between provinces, which have been partially improved recently. However, except for three provinces(Seoul, Gyeonggi, Daejeon), the proportion of R&D subsidy in almost all regions does not exceed 5%. Using the

FGLS and PCSE estimation model mainly, the author discovered that a higher proportion of R&D subsidy is negatively associated with the production of patents granted, even drawing an inverse-U curve in general. Furthermore, a higher proportion of R&D subsidy appears to have a positive association with GRDP per capita. This result suggests that more feasible policies are necessary to establish an innovation system that utilizes R&D outcomes more efficiently and provides opportunities for spreading its usage or application.

Several limitations of this paper need to be addressed in future research. Firstly, the methodology, such as spatial regression analysis(Lee, 2014), needs to be considered, as R&D-related spillover can also affect neighboring areas. As stated by Rafael E. De Hoyos and Vasilis Sarafidis(2006: 482), "panel-data models are likely to exhibit substantial cross-sectional dependence in the errors, which may arise because of the presence of common shocks and unobserved components that ultimately become part of the spatial dependence, and idiosyncratic pairwise dependence in the disturbances with no particular pattern of spatial dependence." Therefore, additional empirical analysis is necessary to investigate the interconnected effects of R&D policy within and between regions. Furthermore, the presence of individual or common unit roots in panel data can result in nonstationary time series, which may introduce bias in the estimator and lead to spurious causality. To address this issue, various tests such as the augmented Dickey-Fuller test and Phillips-Perron test can be employed.[11)]

Secondly, the dimension of the distributional indicator should be expanded to include technology or industry classification. For example, Choi and Bae(2018) analyzed the effectiveness of local R&D investments by utilizing the coefficient of variation(CV) and Herfindal-Hershman index(HHI) measurements, using regional R&D investment data at the sub-level of S&T classification.[12)]The concept of coagglomeration can contribute to a broader understanding of the interaction between regions and industries at the same time(Byeon, 2015). This requires more detailed microdata, which is surveyed at the level of establishments or firms. Regarding the validity of regressands, the quality of patents needs to be addresed in further studies to come. While the author has harnessed the number of patents registered, its impact varies depending on its spillover potential. Relying solely on a quantitative indicator may be insufficient, in that it cannot determine the extent to which a particular patent has a spillover effect(Choung and Koo,

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11) The Phillips-Perron test yields more reliable test statistics when time-series data exhibit greater structure, high autocorrelation, and heteroskedasticity. For a comprehensive discussion, please refer to Song and Won(2011: 23-25).

12) The conventional classification of research stages in R&D (basic, applied, and development) or the variety of project performers may serve as good examples for determining sub-analysis levels. However, the results obtained using this categorization should be interpreted with caution because each research stage or field has its own unique characteristics.

2023: 5). Therefore, alternative approaches such as investigating trends of backward and forward citations, the number of patent claims, and patent renewals can provide valuable insights into patents as outputs of R&D.

Moreover, simply lagging regressors may not resolve or reduce the likelihood of reverse causality because it introduces the equally strong and untestable assumption that unobserved variables are serially uncorrelated(Lars Leszczensky and Tobias Wolbring, 2022: 842).[13] Although there are theoretical foundations regarding the time-lag for R&D input, a more comprehensive investigation needs to be conducted in a future study.

Additional research questions should focus on more disputable or practical issues related to the effects of R&D policies, such as determining who is responsible or accountable for improving or equalizing regional capacity through R&D policies and whether national performance and regional parity are complementary or substitutional(HEPI, 2021: 45-46).

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13) Authors states that "Identification requirements in models with lagged regressors are usually strong as those in models with contemporaneous values of X. Therefore, simply lagging X in RE or in FE models less contributes to solving the endogeneity problem posed by unobserved variables." Based on simulation results, the author suggests using an estimation model that combines the maximum likelihood (ML) and structural equation modeling (SEM) frameworks.

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보도자료

“경제성장률이 상승하면 지니계수로 본 소득불평등 개선돼”, Korea Economic Research Institute, 2019.05.30.

문석휘(文碩輝): 서울대학교에서 행정학 박사 학위를 취득(2021년 8월)했으며, 현재 국회예산정책처 추계세제분석실에서 추계세제분석관으로 근무 중이다. 주요 관심 분야는 R&D 정책을 위시한 혁신 및 산업정책, 계량 및 정책효과 분석, 지역발전 담론 등이다. 최근 논문으로 "선택과 집중 돌아보기: 국가연구개발사업의 제조업별 지원금 집중도가 생산성에 미치는 영향의 실증분석 "(2021), "The Longer the Better? The Impact of Internal vs. External CEO Hires and Tenure on Organizational Performance: Evidence from the Banking Industry of the Republic of Korea"(2020) 등이 있다.(slugnoid@hanmail.net)

〈논문접수일: 2023. 4. 6 / 심사개시일: 2023. 4. 6 / 심사완료일: 2023. 5. 22〉

Appendix 1: Correlation table of variables for analysis

	log (GRDP per capita)	log (patent)	Share of Government R&D subsidy(−1)	Squaed−term of share(−1)	log(private R&D)(−1)	log (private R&D personnel) (−1)	log (the volume of export) (−1)	Fiscal autono my ratio (−1)
log(GRDP per capita)	1							
log(patent)	0.4606*	1						
Share of Government R&D subsidy(−1)	0.0906	0.6310*	1					
Squaed−term of share(−1)	−0.1284*	−0.7766*	−0.9497*	1				
log(private R&D)(−1)	0.4745*	0.9071*	0.5659*	−0.7156*	1			
log(private R&D personnel)(−1)	0.4155*	0.9199*	0.5952*	−0.7502*	0.9756*	1		
log(the volume of export)(−1)	0.4820*	0.6502*	0.1308*	−0.3006*	0.7829*	0.7604*	1	
Fiscal autonomy ratio(−1)	−0.0984	0.3015*	0.4689*	−0.4688*	0.3089*	0.3952*	0.1730*	1

Note 1. * p<0.05

Appendix 2. Result of other estimation(OLS, FE estimation)

	OLS estimation				Fixed Effect Panel estimation			
	log(GRDP per capita)		log(patent)		log(GRDP per capita)		log(patent)	
Share of Government R&D subsidy(−1)	5.300***	2.888***	−1.88	−2.19	−0.997	0.619	−1.435	1
	[1.011]	[0.458]	[1.521]	[1.443]	[0.926]	[0.556]	[1.824]	[1.762]
Squaed−term of Gov. R&D subsidy share(−1)	6.881***	3.022***	−7.164***	−7.433***	−0.0233	1.187	−8.124***	−5.652**
	[1.223]	[0.611]	[2.103]	[1.940]	[1.382]	[0.969]	[2.929]	[2.567]
log(private R&D)(−1)	0.08	0.0917**	−0.10	−0.245**	0.0459	0.00488	0.0977	−0.0364
	[0.0779]	[0.0365]	[0.119]	[0.100]	[0.0668]	[0.0116]	[0.0676]	[0.0887]
log(private R&D personnel)(−1)	0.09	−0.181***	0.671***	0.769***	0.216***	0.0305	0.332***	0.307**
	[0.0921]	[0.0420]	[0.160]	[0.137]	[0.0540]	[0.0236]	[0.119]	[0.136]
log(the volume of export)(−1)	0.0492**	0.110***	0.04	0.0433**	0.116***	0.0441*	0.340***	0.168**
	[0.0218]	[0.0115]	[0.0282]	[0.0214]	[0.0294]	[0.0263]	[0.0619]	[0.0706]
Fiscal autonomy ratio(−1)	−0.0146***	0.0257***	−0.0369***	−0.0147**	−0.0176***	0.00318**	−0.0253**	0.0134**
	[0.00374]	[0.00268]	[0.00593]	[0.00659]	[0.00279]	[0.00134]	[0.0120]	[0.00586]
Region dummy (=1 when in Greater−Seoul)	0.06	0.00	0.474***	0.398***	−0.456**	0.0254	0.0621	0.454
	[0.0604]	[0.0354]	[0.101]	[0.0704]	[0.183]	[0.153]	[0.274]	[0.302]
Constant	2.866**	4.469***	11.35***	9.564***	8.353***	7.616***	9.823***	6.513**
	[1.311]	[0.652]	[2.336]	[2.070]	[1.274]	[0.795]	[3.408]	[2.898]
Observations	311	311	311	311	311	311	311	311
Number of unit					17	17	17	17
R−squared.	0.40	0.87	0.90	0.95				
Year−effect		O		O		O		O

Note 1. Robust standard errors in brackets for result of fixed effect panel estimation model.
2. *** p<0.01, ** p<0.05, * p<0.1

국문요약

연구개발혁신 투입의 지역별 비중이 혁신 산출 및 결과에 미치는 영향: 국가연구개발사업의 사례를 중심으로

문 석 휘

연구개발(R&D) 수행 주체에게 교부되는 보조금 형태의 직접 R&D 지원정책은 혁신 산출 및 경제적 성과 창출을 증진하는 효과적인 수단으로 알려져있다. 그러나 이러한 R&D 직접지원의 지역적 분포 및 그 실증적 효과에 대한 관심은 상대적으로 부족한 실정이다. 본 연구는 지역별 R&D 지원금의 비중 및 이와 관련한 혁신 산출(등록 특허의 로그)과 결과(1인당 GRDP의 로그)와의 관계를 밝히는 것을 목표로 한다. 국가연구개발사업을 통해 교부된 R&D 직접지원금과 관련한 광역 지방자치단체별 불균형 패널자료를 구축·활용하여, 본 연구는 높은 정도의 R&D 지역 집중이 등록특허와 역U자형의 관계를 나타내는 등 음(-)의 관계를 보이지만 경제적 성과와는 정(+)의 관계를 보임을 실증했다. 이러한 결과는 경제적 성과를 증대할 수 있도록 R&D 투입의 지역적 배분과 분포와 관련한 지역별로 특화, 체계화된 정책 접근의 필요성을 시사한다.

주제어: 국가연구개발사업, 연구개발투입 불균형, 지역 균형 성장정책, 지역 성장, 지역 연구개발