Article

The impact of budget allocation by research service and platform providers on R&D outcomes: Reassessing the value of investment in research infrastructure in a knowledge-based society

Seokki Cha[1], Bong-Goon Seo[1], Taehoon Kim[2], Joon Kim[2,*]

[1] Korea Institute of Science and Technology Information (KISTI), Daejeon 34141, Republic of Korea
[2] Korea Institute of Industrial Technology (KITECH), Ansan 15588, Republic of Korea
* Corresponding author: Joon Kim, kimjune23@kitech.re.kr

Abstract: This study aims to empirically analyze the impact of budget allocation by the Korea Institute of Science and Technology Information (KISTI) on national research competitiveness, thereby reassessing the value of investing in research infrastructure within a knowledge-based society. In the 21st century, research and development (R&D) have emerged as a pivotal element of national competitiveness, underlining the increasing importance of investments aimed at constructing and enhancing research infrastructure. However, empirical studies examining the causal relationship between research infrastructure investment and national research competitiveness are still notably scarce. Accordingly, this research endeavors to systematically delineate the effect of research infrastructure investment, with a focus on KISTI's budget allocation, on enhancing national R&D outcomes. To achieve this, the structural relationship between KISTI's budget, national R&D budget, and various academic and industrial performance indicators was analyzed using multiple regression and simple regression analysis. In particular, by demonstrating the mechanism through which the budget management of research support organizations like KISTI contributes to strengthening national research competitiveness, this study aims to shed new light on the strategic value of research infrastructure investment in a knowledge-based society. Furthermore, these findings are expected to provide valuable evidence for the formulation of national R&D policies in Korea and the strategic planning of budget operations for research support organizations. Through strategic investment of limited budgets, this could enhance the efficiency of national R&D investments and contribute to strengthening the capacity for scientific and technological innovation required in a knowledge-based society.

Keywords: R&D budget; national research and development outcomes; research support services

1. Introduction

1.1. Background

Research and development (R&D) plays a crucial role in driving national competitiveness in the knowledge-based society of the 21st century. Countries like South Korea, which rely on technology-driven economic growth, have consistently increased their R&D investments to maintain a competitive edge.

The strategic allocation of R&D resources by specialized research institutions, such as the Korea Institute of Science and Technology Information (KISTI), has gained significant attention due to its direct impact on national R&D outcomes (Peña et al., 2014; Won et al., 2023). Efficient management of R&D budgets is essential for

maximizing the qualitative outcomes of these investments, beyond mere quantitative expansion.

R&D investments have the potential to drive scientific advancement, enhance industrial competitiveness, and address societal challenges, thereby contributing to comprehensive national development (Liou, 2009). However, there is a lack of empirical understanding of the causal relationship between R&D budget allocation and outcome generation, particularly regarding the impact of increased funding on R&D productivity.

Efficient allocation of R&D budgets transcends mere quantitative expansion, aiming for the maximization of qualitative outcomes. This strategic imperative stems from the widespread acknowledgment that R&D investments can propel scientific advancement, enhance industrial competitiveness, and address societal challenges, thereby catalyzing comprehensive national development (Liou, 2009). However, the empirical understanding of the causal relationship between R&D budget allocation and outcome generation remains limited, with a particular dearth of in-depth analyses regarding the impact of increased funding on R&D productivity.

KISTI, by providing a plethora of research services and platforms, contributes significantly to the enhancement of scientific research infrastructure and national competitiveness. Notably, ScienceON and AccessON offer tailored scientific knowledge infrastructure and collaborative research environments, respectively, facilitating access to academic papers, co-authorship opportunities, and data sharing. Furthermore, KISTI's development and management of cutting-edge research infrastructure, including supercomputing services, open API-based distribution platforms, and identity verification-based collaborative environments, underscore its pivotal role in advancing national R&D capabilities.

Against this backdrop, exploring the effect of budget allocation by research support institutions like KISTI on national R&D outcomes represents a crucial endeavor. KISTI, a government-funded research institute under the Ministry of Science and ICT, plays a pivotal role in the Korean R&D ecosystem by providing essential research infrastructure and services. It manages and operates major national R&D infrastructure, such as the Korea Research Environment Open NETwork (KREONET), and provides research support services, including scientific data management and analysis, to researchers nationwide. KISTI's budget allocation decisions, spanning areas such as infrastructure investment, research projects, and support services, can significantly influence the productivity and performance of the national R&D system. By elucidating the structural relationship between KISTI's R&D funding and various national R&D performance indicators, this study aims to assess the efficacy of its budget allocation practices and propose optimization strategies, thereby offering novel insights into strategic management and outcome maximization of R&D budgets in the context of research support institutions. It is anticipated that this research will contribute to the formulation of efficient budget allocation policies by government and research institutions, enhancing national research competitiveness.

1.2. Objectives

The primary objective of this study is to empirically analyze the impact of budget allocations by Korea's leading R&D support institution, KISTI, and the overall national R&D budget on research outcomes. By employing multiple and simple regression analyses, this research seeks to systematically delineate the structural relationships between R&D funding and a comprehensive set of performance indicators, including academic publication counts, patent filings, and technology transfer numbers, among others.

Through this analysis, the study aims to empirically elucidate the causal impact of R&D budget investments on the generation of both academic and industrial research outcomes. Furthermore, it intends to provide a theoretical and methodological foundation for evaluating the effectiveness of budget distribution, thereby facilitating the formulation of strategic R&D budget allocation and efficient management policies.

Moreover, based on the findings, this research aspires to identify practical measures for optimizing R&D budget allocation and maximizing national R&D outcomes. In doing so, it seeks to offer actionable guidelines for policy-makers and research administrators involved in R&D budgeting and management strategies, contributing to the enhancement of national research competitiveness and the strengthening of scientific and technological innovation capabilities—a key driver of competitiveness in a knowledge-based society.

This study endeavors to deepen the understanding of the structural relationship between R&D funding and outcomes, thereby aiding in the development of effective budget allocation strategies and outcome-oriented R&D policies. It is expected to provide policy and practical implications for improving the efficiency of R&D investments and advancing the national R&D system, ultimately contributing to the enhancement of technological innovation capacities in the knowledge-based society.

2. Theoretical background

2.1. Economic impacts of R&D investment and endogenous growth theory

Research and development (R&D) investment is widely recognized as a crucial driver of national economic growth and societal progress (Cockburn et al., 2018). Governmental support for R&D budgets plays a pivotal role in facilitating basic and applied research and is essential for fostering an innovation ecosystem (David et al., 2000). Consequently, the effective allocation and management of R&D budgets have emerged as significant challenges in national science and technology policy (Mowery and Rosenberg, 1989).

Theoretical discussions on the economic effects of R&D investment are fundamentally grounded in Endogenous Growth Theory (Romer, 1990). According to this theory, technological innovation acts as an endogenous factor in economic growth, suggesting that accumulation of knowledge stock through R&D investment propels long-term economic expansion (Aghion and Howitt, 1992). Empirical studies corroborate that R&D investments positively influence Total Factor Productivity (TFP) and economic growth (Guellec and Van Pottelsberghe de la Potterie, 2004; Hall et al.,

2010).

Furthermore, R&D budget allocations yield various socio-economic spillover effects, including the cultivation of scientific talent, creation of high-quality jobs, and enhancement of national innovation capabilities (Mansfield, 1991; Salter and Martin, 2001). Public investment in R&D plays a central role in addressing market failures and fostering innovation activities aimed at solving social problems (Nelson, 1959).

Optimal allocation of R&D budgets necessitates strategic decision-making to maximize outcomes relative to investment (Arrow, 1962). Comprehensive analyses of the relationship between R&D budgets and outcomes are prerequisite for such decision-making (Jaffe, 1989). Previous studies have delineated correlations among R&D budget size, allocation structures, and performance metrics, seeking efficient budget management strategies (Jacob and Lefgren, 2011; Payne and Siow, 2003).

Building upon these theoretical and empirical foundations, this study aims to analyze the relationship between R&D budget allocation structures in South Korea and national R&D outcomes. It will particularly illuminate the impact of budget allocations by the Korea Institute of Science and Technology Information (KISTI) on national-level R&D outcomes, thereby contributing policy implications for strategic management and enhancement of R&D outcomes.

2.2. Relationship between R&D investment and outcomes

Existing studies on the relationship between R&D budgets and outcomes provide a theoretical and empirical basis for this field. Numerous precedents have demonstrated that increases in R&D budget positively affect scientific (e.g., publication counts, patent applications) and economic outcomes (e.g., new product launches, revenue growth) (Bozeman and Corley, 2004; Hall and Lerner, 2010). These findings suggest that R&D investment contributes to strengthening innovation capabilities and economic growth.

However, the relationship between R&D budget and outcomes can vary across industries, company sizes, and types of R&D (basic research, applied research), indicating that the effects of R&D investment are context-dependent and necessitate consideration of such contextual factors for effective allocation (Czarnitzki and Lopes-Bento, 2013).

Recently, the scope of research exploring the relationship between R&D budgets and outcomes has expanded. Ghaffar and Khan (2017) analyzed the impact of R&D budgets on corporate performance, identifying a significant positive correlation between these variables. Furthermore, studies by Choi (2023) and Lee (2023) examined the impact of government R&D budgets and activities on GDP in the space industry, mediated through patents and publications, suggesting that proactive government R&D investment can contribute to economic growth.

Spanos and Vonortas (2012) investigated the impact of the size of publicly funded collaborative R&D projects on various performance dimensions, providing important insights into understanding the relationship between R&D budget size and outcomes.

Despite these advances, existing research has primarily focused on the quantitative aspects of R&D budgets, with direct analyses of the efficiency and utility

of organizations supporting R&D remaining relatively scarce. R&D support organizations, such as KISTI, enhance the research ecosystem and contribute to national competitiveness through improved access to research data and promotion of research collaboration. Nonetheless, research directly evaluating the utility of such organizations is lacking.

This study represents a pioneering effort to evaluate the utility of R&D support organizations, aiming to fill the research gap in this area. A deep understanding of the role and functions of R&D support organizations is essential for establishing efficient budget allocation and management strategies. The findings of this study will offer valuable insights for policy decisions related to R&D budgeting and strategic planning for R&D support institutions.

3. Research methodology

3.1. Analytical methodology

This study employs multiple regression and simple regression analyses to conduct an in-depth examination of the relationship between South Korea's Research and Development (R&D) budget allocations and national R&D outcomes. Recognizing the pivotal role of R&D investment as a cornerstone of national competitiveness, this research quantitatively assesses the impact of budget allocations by the Korea Institute of Science and Technology Information (KISTI) and the aggregate R&D budget of South Korea on various national R&D performance indicators. Key performance metrics utilized in the analysis include the number of publications in top-tier journals, total publication counts, patent filings and registrations, and the number of technology transfer deals.

Multiple regression analysis, a statistical technique for estimating the simultaneous impact of multiple independent variables on a dependent variable (Wooldridge, 1996), was used to examine the effects of diverse budgetary items such as KISTI's major projects, government-commissioned projects, and private sector projects on research performance indicators. This approach enabled the assessment of the contribution of each budget item to performance metrics and the efficiency of budget allocation.

The multiple regression model used in this study can be expressed as:
$$Y_i = \beta_0 + \beta_1 X_{1i} + \beta_2 X_{2i} + \dots + \beta_p X_{pi} + \epsilon_i$$
where Y_i is the dependent variable representing the R&D performance indicator, X_{1i}, …, X_{pi} are the independent variables representing the budget allocations, $\beta_0, \beta_1, \dots, \beta_p$ are the regression coefficients, and ϵ_i is the error term.

The simple regression model can be expressed as:
$$Y_i = \alpha_0 + \alpha_1 Z_i + \epsilon_i$$
where Y_i is the dependent variable representing the R&D performance indicator, Z_i is the independent variable representing the budget allocation or number of R&D projects, α_0 and α_1 are the regression coefficients, and ϵ_i is the error term.

In contrast, simple regression analysis, which models the linear relationship between a single independent variable and a dependent variable (Montgomery et al., 2021), was applied to evaluate the impact of the overall R&D budget, the R&D budgets of the Ministry of Science and ICT and the Ministry of Trade, Industry and

Energy, and the number of R&D projects and tasks on performance indicators. Simple regression analysis facilitated an intuitive understanding of the relationship between R&D budget and performance metrics, allowing for the identification of the relative importance of each variable.

To ensure the validity and reliability of the regression models, diagnostic procedures such as multicollinearity tests, residual analyses, and outlier detection were performed (Hair et al., 2019). Additionally, the models' fit was assessed based on the R-squared value, and the statistical significance of independent variables was evaluated using *t*-tests and *F*-tests.

The multiple and simple regression methodologies utilized in this study are expected to systematically analyze the complex relationship between R&D budget and outcomes and support data-driven decision-making. This research aims to provide insights into the formulation of South Korea's R&D budget allocation strategies and enhance the efficiency of R&D support organizations.

To ensure the robustness of the analysis, several steps were taken to address potential biases. First, the data were carefully checked for outliers and missing values, which were treated using appropriate statistical methods. Second, the assumptions of the regression models, such as linearity, normality, and homoscedasticity, were tested and confirmed. Third, multicollinearity among the independent variables was assessed using the variance inflation factor (VIF), and variables with high VIF values were excluded from the models to avoid bias in the coefficient estimates.

3.2. Data collection

To conduct a comprehensive analysis of the relationship between South Korea's R&D budget and outcomes, this study leveraged various data sources. Primary data were collected from the National Science and Technology Information Service (NTIS), a government-operated platform offering extensive data on R&D budget, outcomes, personnel, and infrastructure (NTIS, 2021). Data spanning from 2014 to 2021 included overall R&D budget figures, R&D budgets from the Ministry of Science and ICT and the Ministry of Trade, Industry and Energy, numbers of R&D projects and tasks, and budget data for KISTI's major projects, government and private sector commissioned projects.

Outcome metrics data were gathered from NTIS and additional sources. The number of publications in the top-tier journals (Nature, Science, Cell) was extracted using the Web of Science database, while total publication counts were obtained from the Korean Research Information Service (Korean Researcher Information, KRI) system (Korean Research Foundation, 2021). Patent filing and registration numbers were compiled from the Korean Intellectual Property Office statistics, and technology transaction counts were extracted from the reports of the Korea Institute of Science and Technology Evaluation and Planning.

The raw data underwent preprocessing to ensure analysis suitability, including data cleansing, handling of missing values, and variable extraction and transformation (Wickham and Grolemund, 2016). The final dataset comprised year-on-year figures for South Korea's total R&D expenditure, departmental R&D budgets, KISTI project budgets, and metrics for top-tier journal publications, total publication counts, patent

filings and registrations, and technology transactions.

This dataset was utilized to capture temporal changes in South Korea's R&D investment size and outcomes, elucidating the investment-outcome relationship. Particularly, KISTI's project-specific budget data provided valuable insights for analyzing the investment effects at the individual research institution level. The employed data is expected to illuminate various facets of South Korea's R&D ecosystem and contribute to evidence-based R&D policy formulation.

3.3. Variable definition and measurement

To empirically analyze the relationship between R&D investment and outcomes, this study utilized several independent and dependent variables. Independent variables included the total R&D expenditure of South Korea, R&D budgets of the Ministry of Science and ICT, and the Ministry of Trade, Industry and Energy, the number of R&D projects and tasks, and budgets for KISTI's major, government, and private sector commissioned projects. These variables reflect the scale and characteristics of R&D investments at the national and institutional levels.

Dependent variables comprised the number of publications in top-tier journals, total publication counts, numbers of patent filings and registrations, and technology transaction counts. These metrics represent various dimensions of outcomes resulting from R&D investments, encompassing academic excellence, productivity, technological innovation, and commercialization capabilities (Javitz et al., 2010; Roessner et al., 2013).

Variable measurements adhered to conventional definitions and computation methods, facilitating an integrated analysis of investment characteristics and diverse outcome dimensions. Correlation and regression analyses were used to examine the relationships between variables, with a particular focus on the investment-outcome mechanisms at the level of individual research institutions (Cohen et al., 2003).

This approach to variable selection and analysis provides a framework for assessing the effectiveness of national R&D investment on a macroscopic level and analyzing individual institutions' investment strategies on a microscopic level. The findings of this study are anticipated to support evidence-based R&D policy formulation and strategic decision-making for research institutions.

4. Results

4.1. Results of multiple regression analysis: Analyzing the impact of Kisti's budget and other R&D budget items on performance indicators

This study conducted a comprehensive analysis through multiple regression to explore the impact of the Korea Institute of Science and Technology Information (KISTI)'s R&D budget on various research performance indicators. The budget categories analyzed included major projects, government-commissioned projects, and private sector projects, while the performance indicators considered were total number of publications, publications in top-tier journals, patent filings and registrations, and the number of technology transfer deals.

Table 1 summarizes the effects of KISTI's budget items on R&D performance

indicators derived from the multiple linear regression model. The total publication count showed a high R-squared value of 0.978, indicating strong explanatory power, with an adj. R-squared of 0.961, suggesting significant predictive capability of the model. The F-statistic's probability (Prob) at 0.000917 confirmed the model's statistical significance. The coefficient analysis indicated positive relationships between both the major project and government-commissioned project budgets with total publication count, while the private sector project budget showed a negative impact.

Table 1. Multiple linear regression model: Analyzing the impact of KISTI's budget on R&D performance indicators.

Performance Indicator	R-squared	Adj. R-squared	F-statistic	Prob (F-statistic)	Major project budget coefficient	Government-commissioned Project Budget Coefficient	Private Sector Project Budget Coefficient	Notes
Total publication count	0.978	0.961	58.730	0.000	Significant ($P = 0.002$)	Significant ($P = 0.004$)	Significant ($P = 0.010$)	Multicollinearity, small sample size caution
Top-tier journal publications	0.738	0.541	3.755	0.117	Marginal ($P = 0.070$)	Not significant	Not significant	Multicollinearity, small sample size caution
Patent filings and registrations	0.318	−0.193	0.623	0.637	Not significant	Not significant	Not significant	Multicollinearity, small sample size caution
Technology transactions	0.443	0.025	1.059	0.459	Not significant	Not significant	Not significant	Multicollinearity, small sample size caution

The analysis of top-tier journal publications indicated considerable explanatory power with an R-squared of 0.738. However, the adj. R-squared dropped to 0.541, and the overall significance of the model was marginal with an F-statistic probability of 0.117. The major project budget was marginally associated with top-tier journal publications ($P = 0.070$), while other budget items showed no significant effect.

Regression models for patent filings and registrations and technology transactions suggested limited explanatory power of budget variables, with both models failing to achieve statistical significance, indicating that KISTI budget items did not significantly impact these performance indicators.

Common issues across all regression models included concerns about multicollinearity and the limitations posed by a small sample size ($n = 8$), potentially affecting the reliability of coefficient estimates and, consequently, the trustworthiness of the analysis results. These limitations underline the need for caution in interpreting these findings and suggest avenues for further research to refine the analysis.

In summary, the budget allocated to KISTI's major projects and government-commissioned projects is likely to have a positive impact on total publication count, whereas other performance indicators showed no significant influence from budget allocations. The results suggest the necessity of strategic budget allocation by KISTI and policymakers, with further research required to clarify the specific directions of budget use and their interactions with performance indicators. **Figure 1** provides a visual representation of the impact of KISTI on R&D performance indicators using a multiple linear regression model.
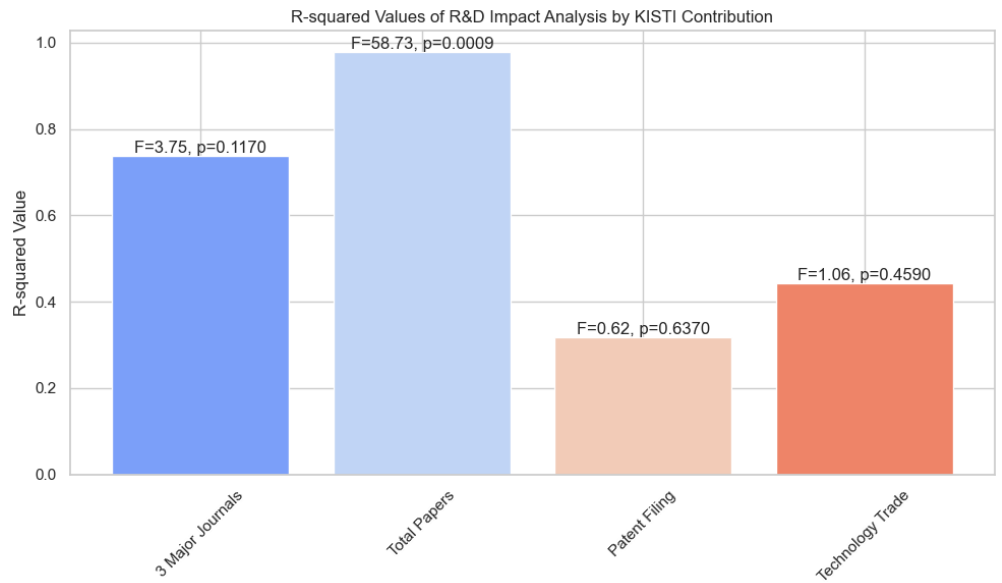
Figure 1. Analysis of the impact of KISTI on R&D performance indicators using a multiple linear regression model.

4.2. Results of simple regression analysis for each KISTI budget item

Further analyses using simple regression were conducted to empirically examine the impact of KISTI's R&D budget on the outcomes of South Korea's national R&D projects. The analyses focused on budget allocations for KISTI's major projects, government-commissioned projects, and private sector projects against performance indicators including publications in top-tier journals, total publication counts, patent filings and registrations, and technology transactions. Results are organized in a manner suitable for scholarly dissemination.

The analysis of the major project budget revealed a strong positive correlation with total publication count (R-squared = 0.728), indicating that increases in the major project budget correspond with increases in publication output. This relationship was statistically significant ($F = 16.04$, $p = 0.00708$). For top-tier journal publications, the relationship was somewhat robust (R-squared = 0.585), but for patent filings and technology transactions, the budget's impact was comparatively limited or statistically insignificant. **Table 2** presents a detailed analysis of national R&D performance and the impact of KISTI major project budget.

Table 2. Analysis of national R&D performance and impact of KISTI major project budget.

Performance indicator	R-squared	F-statistic	Prob (F-statistic)	Coefficient interpretation
Number of Publications in Top Journals	0.585	8.460	0.027	An increase of 1 won in the main project budget is associated with approximately a 6.991×10^{-10} increase in the number of publications
Total Number of Paper Presentations	0.728	16.040	0.007	An increase of 1 won in the main project budget is associated with approximately a 4.713×10^{-7} increase in the number of presentations
Number of Patent Applications and Registrations	0.036	0.226	0.651	Not statistically significant
Number of Technology Sales Transactions	0.403	4.042	0.091	The budget increase has some impact on the number of technology sales transactions

The government-commissioned project budget showed moderate explanatory power for total publication counts (R-squared = 0.550), with a statistically significant impact (F = 7.348, p = 0.0351). However, its influence on top-tier journal publications, patent filings, and technology transactions was minimal or statistically insignificant. **Table 3** summarizes the analysis of national R&D performance and the impact of KISTI government-commissioned project budget.

Table 3. Analysis of national R&D performance and impact of KISTI government-commissioned project budget.

Performance indicator	R-squared	F-statistic	Prob (F-statistic)	Model interpretation
Number of Publications in Top Three Journals	0.179	1.312	0.296	Weak association between budget and publication count in top three journals, not statistically significant
Total Number of Paper Presentations	0.55	7.348	0.035	Moderate effect of budget on the total number of presentations, statistically significant
Number of Patent Applications and Registrations	0.246	1.956	0.211	Slight association between budget and patent applications/registrations, not statistically significant
Number of Technology Sales Transactions	0.043	0.270	0.621	Very weak effect of budget on technology sales transactions, not statistically significant

Analysis of the private sector project budget demonstrated very weak associations with all performance indicators (R-squared ≤ 0.079), indicating negligible impact and lack of statistical significance (all F-statistic p-values > 0.05), suggesting that private sector project budgets do not significantly influence national R&D performance metrics. **Table 4** provides a detailed analysis of national R&D performance and the impact of KISTI private consignment project budget.

Table 4. Analysis of national R&D performance and impact of KISTI private consignment project budget.

Performance indicator	R-squared	F-statistic	Prob (F-statistic)	Interpretation
Number of Publications in Top Three Journals	0.079	0.512	0.501	Very weak association between budget and number of publications in top three journals, not statistically significant
Total Number of Paper Presentations	0.022	0.135	0.726	Very weak effect of budget on the total number of presentations, not statistically significant
Number of Patent Applications and Registrations	0.015	0.090	0.773	Very weak association between budget and number of patent applications/registrations, not statistically significant
Number of Technology Sales Transactions	0.013	0.08092	0.786	Very weak effect of budget on technology sales transactions, not statistically significant

Overall, KISTI's major project budget appears to play a crucial role in generating research outcomes, particularly in increasing publication counts and possibly affecting top-tier journal publications. In contrast, budget allocations for patent filings and technology transactions seem to have limited influence, highlighting the need for strategic resource distribution considering the effectiveness of budget allocations and targeted performance indicators. Additional research is necessary to further elucidate the causative relationships between budget allocations and R&D outcomes, incorporating a broader range of variables and employing more sophisticated analytical models.

The findings from the impact analysis of various budget items on performance indicators presented in this study are expected to provide crucial benchmarks not only for the Korea Institute of Science and Technology Information (KISTI) but also for

other research institutions and policymakers in devising budget allocation strategies. Based on these empirical analyses, setting priorities for budget use to enhance the efficiency of Research and Development (R&D) investments and exploring specific measures to maximize R&D outcomes could significantly contribute to the strategic management of resources. However, given the limitations inherent in simple regression analysis, further research employing more sophisticated analytical models is needed to more deeply discern the causal relationships between budget allocations and performance outcomes. Additionally, a comprehensive analysis considering various factors beyond budget allocations that may influence R&D outcomes is anticipated to yield more effective policy implications for enhancing the efficacy of national R&D projects. **Figures 2–4** illustrate the analysis of national R&D performance and the impact of KISTI major project budget, government-commissioned project budget, and private consignment project budget, respectively.
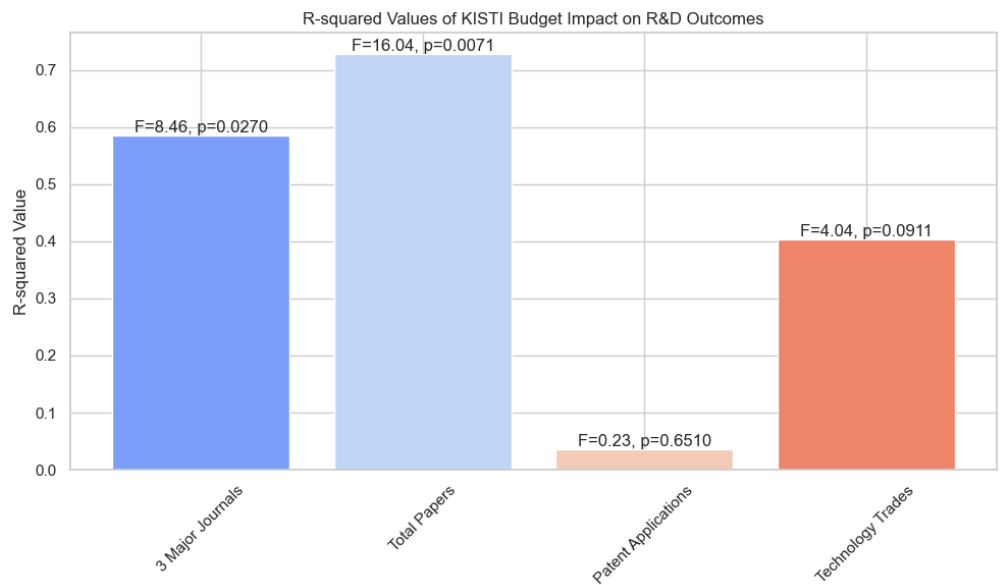

Figure 2. Analysis of national R&D performance and impact of KISTI major project budget.
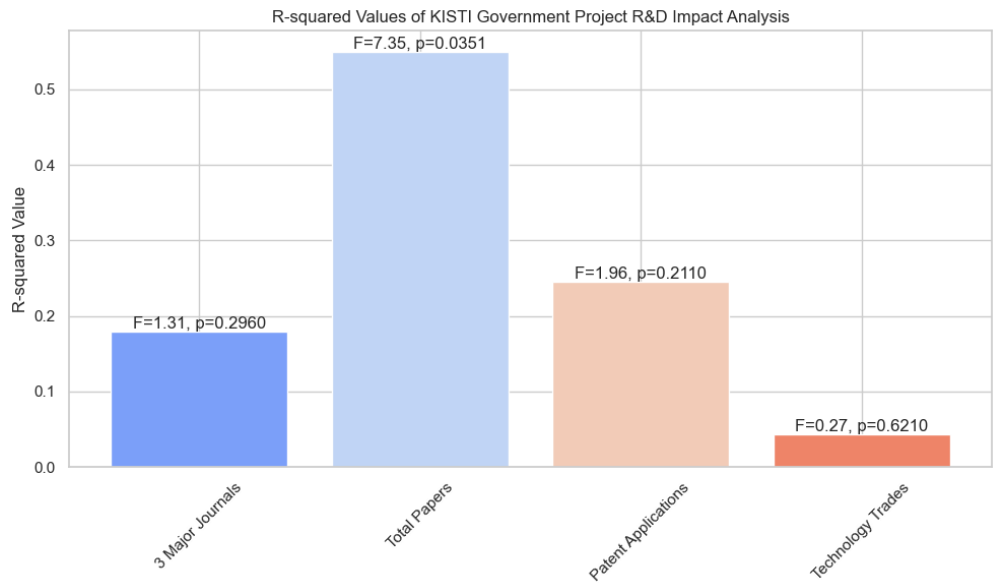
Figure 3. Analysis of national R&D performance and impact of KISTI government-commissioned project budget.
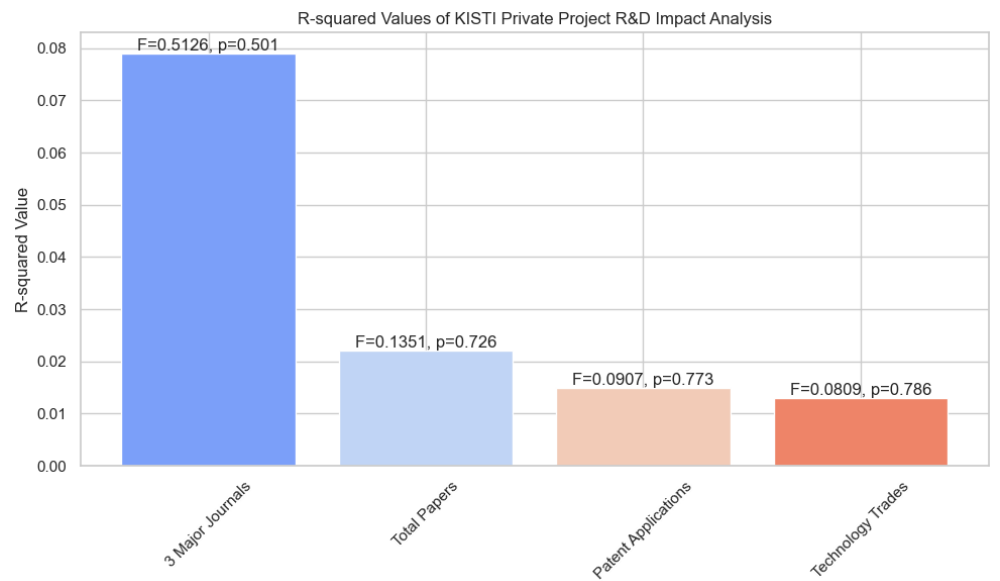

Figure 4. Analysis of national R&D performance and impact of KISTI private consignment project budget.

4.3. Simple regression analysis results for South Korea's national R&D budget impact on performance indicators

This research evaluated the impact of South Korea's national R&D budget on various performance indicators through simple regression analysis. The analysis demonstrated a highly significant impact of the budget on the total number of publications. The determination coefficient (R-squared) was found to be 0.958, indicating that variations in the budget could explain approximately 95.8% of the variance in publication numbers. **Table 5** presents a detailed analysis of South Korea's total R&D budget impact on national R&D performance indicators.

Table 5. Analysis of South Korea's total R&D budget impact on national R&D performance indicators.

Performance Indicator	*R*-squared	*F*-statistic	Prob (*F*-statistic)	Interpretation
Publications in Top-tier Journals	0.573	8.042	0.029	Medium to high association with the budget and statistically significant
Total Number of Publications	0.958	136.900	2.35×10^{-5}	Budget explains a significant portion of the variance in publication numbers, indicating a strong association and statistical significance
Patent Filings and Registrations	0.224	1.730	0.236	Weak association between the budget and patent activities, not statistically significant
Technology Transactions	0.279	2.322	0.178	Slight association with the budget, not statistically significant

Conversely, the impact of the budget on patent filings and registrations (*R*-squared = 0.224) and technology transactions (*R*-squared = 0.279) appeared relatively limited, suggesting that budget changes only modestly explain the variance in these commercialization-related performance indicators. The weak or non-significant statistical associations imply that factors other than budget allocations may play a more substantial role in influencing these outcomes.

The comprehensive analysis reveals that while increases in the national R&D budget positively and strongly affect the total number of publications, its impact on commercial outcomes such as patents and technology transactions is comparatively limited. This suggests that policy makers should consider the diverse effects of budget allocations on different performance indicators to strategically enhance the efficiency and efficacy of national R&D investments. **Figure 5** provides a visual representation of South Korea's total R&D budget impact on national R&D performance indicators.
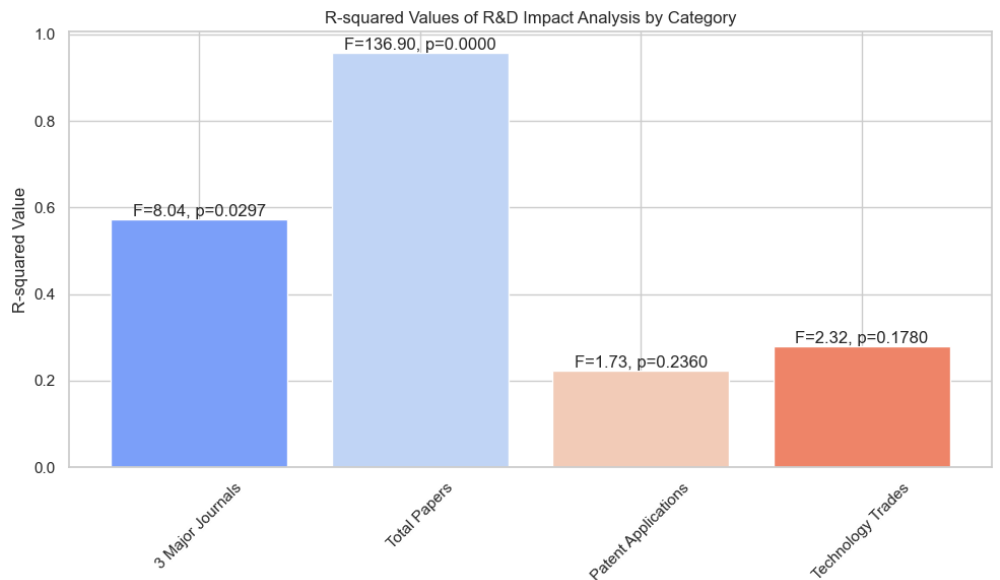

Figure 5. Analysis of South Korea's total R&D budget impact on national R&D performance indicators.

This visual representation underscores the differentiated impact of R&D budget allocations on academic versus commercial outputs, emphasizing the need for targeted budgetary strategies to optimize the broad spectrum of R&D outcomes.

4.4. Analysis of the impact of R&D budgets of major government ministries on national R&D performance

In this section, I conducted a comparative analysis of the impact of research and development (R&D) budgets of the Ministry of Science and ICT (MSIT) and the Ministry of Trade, Industry and Energy (MOTIE) on national R&D performance, benchmarking against the Korea Institute of Science and Technology Information (KISTI). The aim was to empirically examine the contribution of R&D investments by major government ministries to the creation of diverse outcomes in academic and industrial sectors, and to derive policy implications for efficient budget allocation and execution.

Specifically, I performed simple regression analyses using key performance indicators such as total number of papers published, number of publications in top three journals, number of patent applications and registrations, and number of technology transactions as dependent variables, and the R&D budgets of each ministry as independent variables. By comparing the performance impact of each ministry's budget derived from these analyses with that of KISTI, I sought to explore ways to prioritize national R&D investments and optimize resource allocation.

The analysis results showed that the MSIT's R&D budget had a statistically significant strong positive impact on the total number of papers published (R-squared = 0.964, F-statistic = 160.6, $p < 0.01$) and the number of publications in top three journals (R-squared = 0.543, F-statistic = 7.138, $p < 0.05$). **Table 6** summarizes the analysis of the impact of MSIT R&D budget on national R&D performance.

Table 6. Analysis of the impact of MSIT R&D budget on national R&D performance.

Performance indicator	R-squared	F-statistic	Prob (F-statistic)	Interpretation
Number of Publications in Top Three Journals	0.543	7.138	0.036	Moderate to strong association between budget and number of publications in top three journals, statistically significant
Total Number of Paper Presentations	0.964	160.600	1.48×10^{-5}	Budget explains most of the variability in the total number of presentations, showing a very strong association and statistical significance
Number of Patent Applications and Registrations	0.261	2.118	0.196	Slight association between budget and number of patent applications/registrations, not statistically significant
Number of Technology Sales Transactions	0.343	3.136	0.127	Moderate association between budget and number of technology sales transactions, statistically significant at the borderline

In the case of MOTIE, a strong impact on the total number of papers published (R-squared = 0.706, F-statistic = 14.38, $p < 0.01$) was observed, but the correlation with other performance indicators such as the number of publications in top three journals, number of patent applications and registrations, and number of technology transactions was found to be statistically insignificant or weak. **Table 7** presents a detailed analysis of the impact of MOTIE R&D budget on national R&D performance.

Table 7. Analysis of the impact of MOTIE R&D budget on national R&D performance.

Performance indicator	*R*-squared	*F*-statistic	Prob (*F*-statistic)	Interpretation
Number of Publications in Top Three Journals	0.330	2.952	0.137	Moderate association between budget and number of publications in top three journals, but not statistically significant
Total Number of Paper Presentations	0.706	14.380	0.009	Budget accounts for most of the variability in the total number of presentations, indicating a strong association and statistical significance
Number of Patent Applications and Registrations	0.140	0.976	0.361	Weak association between budget and number of patent applications/registrations, not statistically significant
Number of Technology Sales Transactions	0.146	1.022	0.351	Weak association between budget and number of technology sales transactions, not statistically significant

Synthesizing the above analysis results, it can be concluded that the R&D budgets of MSIT and MOTIE have a significant impact mainly on academic research performance, especially on increasing the total number of papers published. On the other hand, both ministries showed limited effects on industrial sector performance indicators such as number of patent applications and registrations and number of technology transactions. This implies that various policy and institutional support measures are required in addition to R&D budget input to enhance industrial performance.

Meanwhile, comparative analysis with KISTI revealed that the R&D budgets of MSIT and MOTIE had a similar level of influence on academic research performance as KISTI. However, while KISTI showed a certain level of correlation with industrial sector performance such as number of patent applications and registrations and number of technology transactions, the linkage between the budgets of the two ministries and these outcomes was found to be relatively weak. **Figures 6** and **7** illustrate the analysis of the impact of MSIT and MOTIE R&D budgets on national R&D performance, respectively.
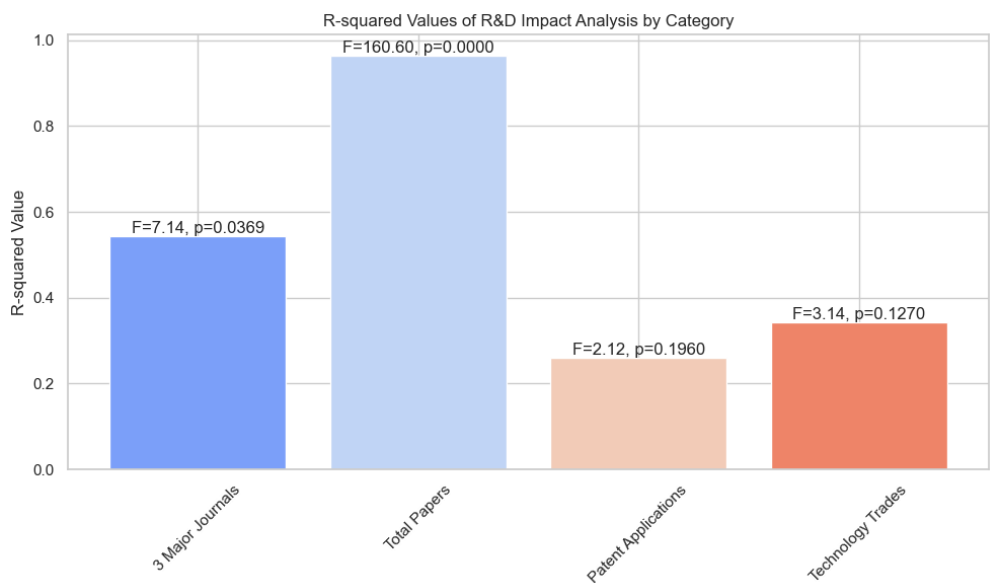

Figure 6. Analysis of the impact of MSIT R&D budget on national R&D performance.
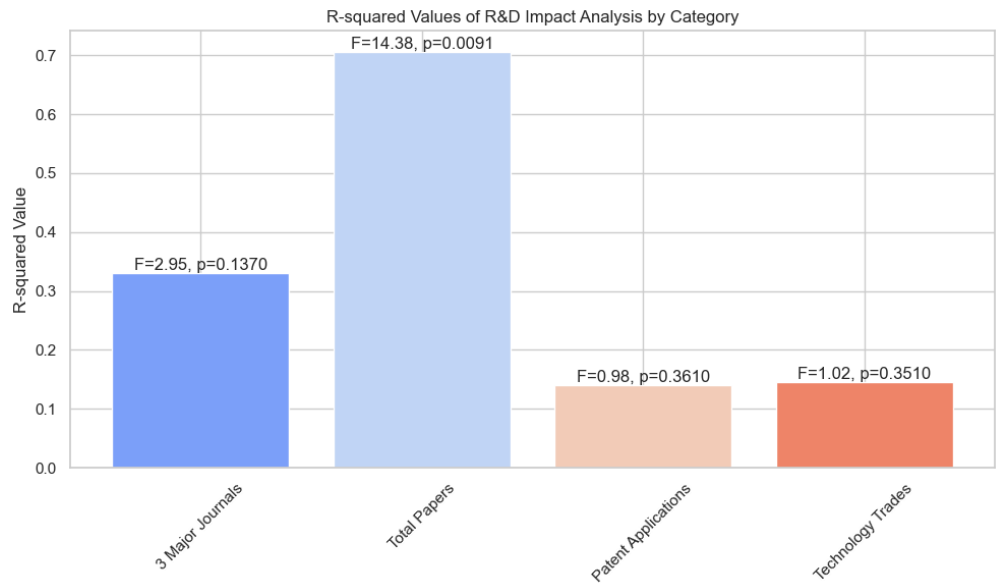
Figure 7. Analysis of the impact of MOTIE R&D budget on national R&D performance.

In addition, it is necessary to benchmark the industrial performance creation mechanisms of government-funded research institutes such as KISTI to seek ways to maximize the economic and social ripple effects of government R&D investments. By establishing a national R&D system in which major ministries and government-funded research institutes are organically linked, efficient allocation of limited resources and performance enhancement can be promoted.

In summary, this study sheds light on the roles and functions of major ministries and government-funded research institutes and presents policy directions for enhancing the efficiency of national R&D investments by empirically analyzing the relationship between the R&D budgets of MSIT, MOTIE, and KISTI and national R&D performance. Herein lies the academic and practical significance of this research.

4.5. The impact of the number of R&D programs and projects on national R&D performance

This study evaluated the impact of the total number of R&D programs and projects in Korea on national R&D performance using simple regression analysis. This was conducted as a supplementary task to compare the influence of the R&D budget of the Korea Institute of Science and Technology Information (KISTI) and the budgets of major government ministries on R&D performance. The aim was to contribute to a deeper understanding of how the quantitative increase in R&D activities affects academic research and commercial outcomes.

The analysis results showed that the number of R&D programs and projects had a statistically significant and substantial positive impact, particularly on the total number of papers published and the number of publications in top three journals. This empirically demonstrates that the quantitative expansion of R&D activities makes an important contribution to the qualitative and quantitative improvement of academic research. When considered together with the R&D budgets of KISTI and major government ministries, the number of R&D programs and projects is suggested to act

as a key determinant of national R&D performance.

However, the impact on commercial performance indicators such as the number of patent applications and registrations and the number of technology transactions was found to be relatively weak or not statistically significant. This implies that an increase in the number of R&D programs and projects does not directly translate into commercial outcomes, and additional factors may play an important role in achieving such outcomes.

These results emphasize the need to strategically consider not only the quantitative expansion of R&D activities but also their qualitative aspects and potential for translation into commercial outcomes when making R&D policy decisions. Therefore, this study has academic and policy implications as a supplementary analysis that raises the necessity of closely examining the structural and strategic aspects of R&D activities, beyond comparing the influence of KISTI and major government ministries on R&D budgets and policy formulation.

4.6. Interpretation of the analysis results: The specific impact of increased R&D budget and number of projects on national R&D performance

This study conducted a multi-faceted analysis of the impact of the Korea Institute of Science and Technology Information (KISTI)'s R&D budget on national R&D performance. To this end, comparative analyses were performed with various factors such as KISTI's budget, the budgets of the Ministry of Science and ICT (MSIT) and the Ministry of Trade, Industry and Energy (MOTIE), and the number of R&D programs and projects. The analysis results showed that KISTI's budget had a significant positive impact, particularly on the total number of papers published (R-squared = 0.978). This implies that an increase in R&D budget directly leads to quantitative and qualitative improvement in academic research performance. In contrast, KISTI's budget showed relatively minimal or insignificant influence on other performance indicators such as the number of publications in top three journals, number of patent applications and registrations, and number of technology transactions. These results suggest that the effect of R&D budget does not uniformly apply to all performance areas, and efficient budget allocation and operation are essential.

The R&D budgets of major government ministries, MSIT and MOTIE, also exerted a strong influence on the total number of papers published, but the correlation with commercial performance indicators was low or insignificant, similar to KISTI. This implies that while R&D budget plays a crucial role in creating academic research outcomes, additional catalysts may be required for translating them into commercial outcomes. Furthermore, the increase in the number of R&D programs and projects was also found to contribute to the quantitative and qualitative growth of academic research, but its impact on commercial performance indicators was limited.

In summary, this study empirically demonstrated the significant influence of KISTI's budget on national R&D performance, particularly academic research outcomes. This suggests that the alignment between the effectiveness of the budget and target performance indicators should be carefully considered when allocating

R&D budgets and formulating policies. Furthermore, there is a need to optimize R&D investments through in-depth research on the interaction between the specific direction of budget input and performance indicators.
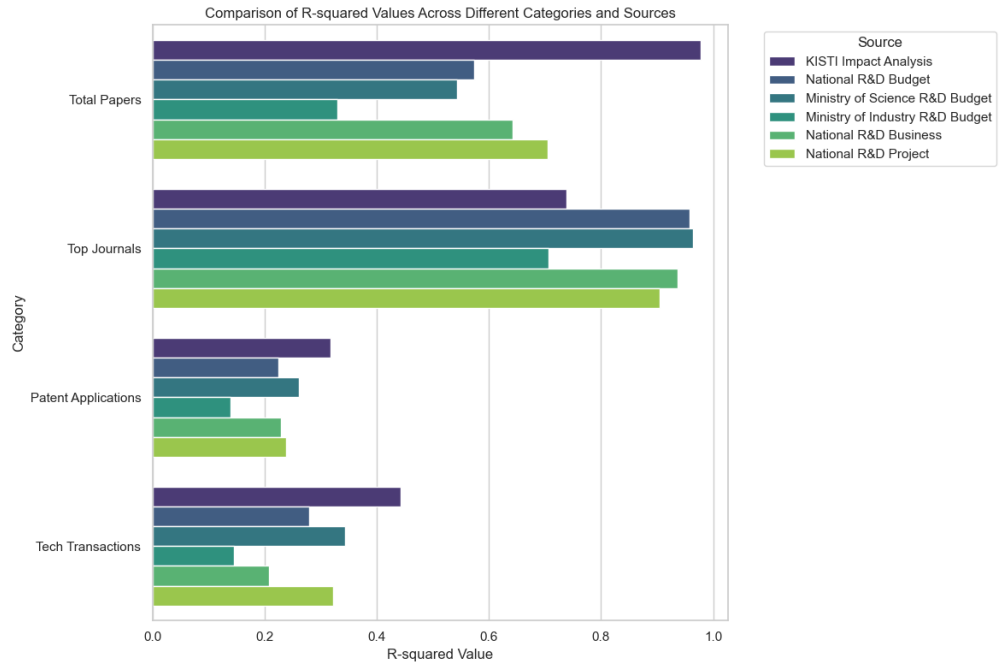

Figure 8. Impact of each item on creating national R&D performance.

Figure 8 compares the influence of various budget items, including KISTI's budget, on national R&D performance indicators using R-squared values. This allows for an intuitive understanding of the strength of the relationship between each budget item and performance indicator. In particular, KISTI's budget showed a very high R-squared value of 0.978 for the total number of papers published, indicating that its explanatory power for the corresponding performance indicator is very high. On the other hand, it showed a relatively low R-squared value of 0.443 for the number of technology transactions, suggesting a weak correlation between budget input and performance.

In addition, other budget items such as the national R&D budget, MSIT budget, MOTIE budget, and R&D program and project budget were also comparatively analyzed. These budgets also showed high R-squared values for the total number of papers published, corroborating that R&D budget generally contributes to the creation of academic research outcomes. In particular, the MSIT budget recorded high R-squared values for both the total number of papers published and the number of publications in top three journals, clearly demonstrating the effect of the ministry's budget on enhancing research performance.

These visualization results clearly show that R&D budget exerts different levels of influence on each performance indicator and can be used as a basis for rational budget allocation and operation. Through an in-depth evaluation of the link between budget and specific performance indicators, it is expected to contribute to setting priorities for R&D investments and establishing strategies for performance enhancement.
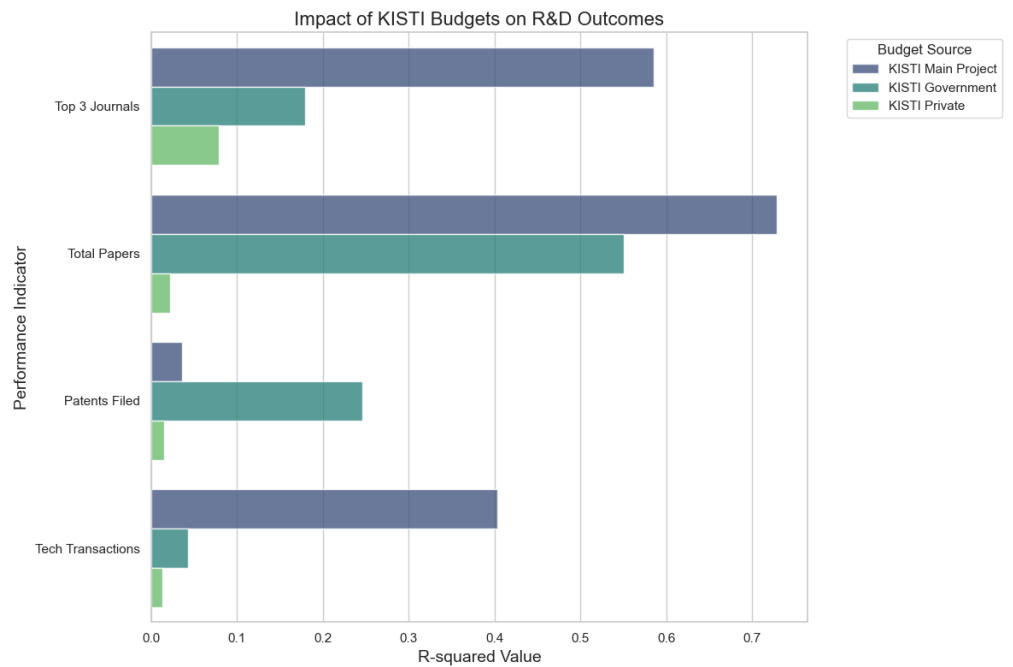
Figure 9. Impact of KISTI budget items on creating national R&D performance.

Figure 9 presents the *R*-squared values of the influence of KISTI's detailed budget items, namely major project budget, government-commissioned project budget, and private-commissioned project budget, on each performance indicator. The analysis results showed that KISTI's major project budget had relatively high *R*-squared values of 0.585 and 0.728 for 'publications in top three journals' and 'total number of papers published', respectively. This implies that the corresponding budget significantly contributes to the creation of academic research outcomes. However, it showed low *R*-squared values of 0.036 and 0.403 for 'number of patent applications' and 'number of technology transactions', respectively, indicating a weak correlation with commercial performance.

The government-commissioned project budget showed a moderate *R*-squared value of 0.550 for the 'total number of papers published, but its correlation with other performance indicators was relatively low. Meanwhile, the private-commissioned project budget recorded very low *R*-squared values for all performance indicators, confirming that it does not have a significant impact on creating R&D performance.

The above analysis results suggest that the influence on R&D performance differs among KISTI's detailed budget items. In particular, the major project budget plays a positive role in enhancing academic research performance, while the performance creation effect of the private-commissioned project budget is minimal. This implies that to more effectively operate limited budgets, it is necessary to closely examine the linkage between the direction of input for each budget item and performance indicators.

In conclusion, this study analyzed the impact of R&D budget on national R&D performance from various angles, focusing on KISTI. The research results showed that R&D budget plays a crucial role in improving academic research performance, particularly in terms of paper publication. However, it suggested that budget input does not have the same effect on all performance areas, and additional catalysts may be needed for translating it into commercial outcomes.

These results emphasize the need to consider the alignment between budget and performance indicators when formulating policies for the rational allocation and operation of R&D budgets. Furthermore, by identifying the differences in performance impact among KISTI's detailed budget items, it provided a starting point for exploring ways to enhance performance through the selection and concentration of limited budgets.

It is important to note that while the results of this study demonstrate a significant relationship between R&D budget allocation and various performance indicators, particularly in terms of academic research output, there are some limitations and nuances in the data that should be considered when interpreting these findings.

First, the study is based on data from a single institution, KISTI, over an 8-year period. While this provides valuable insights into the impact of KISTI's budget allocation on national R&D performance, the generalizability of these findings to other research institutions or contexts may be limited.

Second, the study focuses on a specific set of performance indicators, such as publication counts, patent applications, and technology transactions. While these are important measures of R&D output and impact, they do not capture the full range of potential outcomes and benefits of R&D investments, such as social and environmental impacts or long-term economic growth.

Finally, the relationship between R&D budget allocation and performance indicators may be influenced by various external factors, such as changes in government policies, economic conditions, or technological trends, which are not fully accounted for in the current analysis.

Despite these limitations, the findings of this study provide valuable evidence of the important role that strategic R&D budget allocation can play in driving research performance and impact, particularly in the context of a government-funded research support institution like KISTI.

The results of this study are expected to provide useful implications for policy formulation to improve the efficiency of national R&D investments and maximize performance. In the future, there is a need for follow-up research to enhance the effectiveness of R&D investments through in-depth analysis of the causal relationship between budget input and performance creation. In addition, through comprehensive follow-up research covering various R&D entities and academic fields, the generalizability of the results of this study can be verified, and policy alternatives for optimizing R&D investments can be derived.

5. Discussion

5.1. R&D budget and performance relationship

This study empirically analyzed the impact of KISTI's R&D budget on national R&D performance. The results suggest a significant correlation between R&D budget and performance indicators, confirming the direct contribution of the budget to academic performance. However, the relationship between R&D budget and commercial success was found to be relatively weak, implying that additional mechanisms may be required to translate R&D outcomes into commercial success.

5.2. Policy implications

The findings provide several policy implications for strategic R&D budget allocation and performance management. First, R&D investment should be prioritized in the national budget, and institutional mechanisms should be established to secure stable financial resources. Second, R&D budget allocation should be carried out strategically, considering its linkage with performance indicators. Third, policy efforts should be made to enhance the social ripple effect of R&D outcomes, such as building knowledge-sharing platforms and promoting collaboration between researchers and industry.

5.3. Limitations and future research directions

This study has some limitations that should be acknowledged. First, the potential presence of survivorship bias may lead to an overestimation of the impact of budget allocation on R&D outcomes. Second, the study does not consider additional control variables that could account for other factors influencing the relationship between budget allocation and R&D outcomes. Future research could address these limitations by including a more diverse sample of research institutions and incorporating relevant control variables into the regression models.

Furthermore, future studies could explore the impact of R&D budget allocation on a broader range of performance indicators, conduct comparative research across different types of research institutions and countries, delve deeper into the specific mechanisms through which R&D budget allocation influences research performance, and track the long-term impact of R&D funding.

5.4. Practical implications

The findings have significant practical implications for policymakers, research managers, and other stakeholders involved in the allocation and management of R&D funding in Korea. Policymakers can use these findings to inform the development of more targeted and effective R&D funding programs, while research managers can optimize their internal budget allocation processes and strategies. The insights from this study can also help to inform the development of more effective evaluation and monitoring frameworks for R&D funding programs.

6. Conclusion

This study empirically analyzed the impact of KISTI's R&D budget allocation on national R&D performance using time-series data from 2014 to 2021. The results demonstrated that KISTI's strategic budget allocation, particularly through its main project budget, government-commissioned project budget, and private-commissioned project budget, had a significant positive influence on key research performance indicators, such as the total number of papers published, the number of publications in top SCI journals, and the number of patent applications and registrations. Furthermore, the scale of national R&D investment, including the total R&D budget of Korea and the budgets of the Ministry of Science and ICT and the Ministry of Trade, Industry and Energy, also positively impacted various research performance indicators.

These findings highlight the importance of strategic allocation and efficient

management of R&D budgets for the qualitative improvement of national R&D capabilities. In particular, the study emphasizes the significance of budget allocation strategies for research support institutions like KISTI in effectively supporting researchers' activities and establishing a robust science and technology R&D infrastructure. However, the study also reveals that KISTI's budget had a statistically insignificant impact on the number of technology transactions, suggesting the need for strengthened efforts in promoting research commercialization and technology transfer.

The results provide empirical evidence for policymakers and decision-makers in government and research support institutions to establish effective R&D budget allocation strategies. By adopting a more nuanced approach to budget allocation, considering the specific goals and characteristics of different research projects, institutions can optimize the use of limited R&D resources and maximize the impact of national R&D investments.

This study makes valuable contributions to the literature on R&D management by providing empirical evidence of the relationship between budget allocation practices and research performance in the context of a government-funded research support institution. It also highlights the need for a more context-specific approach to R&D investment strategy, considering the differential effects of budget allocation on academic and commercial outcomes.

Despite its academic value and policy significance, the study has limitations, such as the relatively short time period of analysis, the focus on a single institution, and the limited diversity of research performance indicators. Future research should adopt a more long-term and comprehensive perspective, examining the influence of detailed project budgets, exploring budget allocation strategies of other research support institutions, and incorporating a wider range of performance indicators.

In conclusion, this study provides a foundation for the strategic budget operation of research support institutions and the establishment of national R&D policies. The findings can inform practical discussions on enhancing the efficiency of national R&D investments and strengthening science and technology competitiveness. Further research is needed to deepen the understanding of R&D budget allocation mechanisms and develop policy alternatives for advancing the national innovation system.

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