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Effects of Science, Technology, and Innovation Official Development Assistance on Innovative Capacity in Developing Countries

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Abstract: This study aims to empirically investigate the effect of Science, Technology, and Innovation Official Development Assistance (STI ODA) on the innovative capacity of developing countries. Particularly, this study attempted to examine the moderating effects of R&D investment and its effect on innovative capacity. To do this, a panel fixed model analysis was carried out with ODA and macroeconomic data on 84 developing countries from 2002 to 2018. The findings indicated that STI ODA was found to have no direct positive effect on innovative capacity. However, it had a positive effect on innovative capacity when the moderating effect of R&D investment was significant and when the proportion of R&D investment increased. The findings of this study serve as a guide for policymakers in terms of having better understanding of the relationship between STI ODA, R&D investment, and innovative capacity. Hence, policy makers and practitioners are able to design a good policy to be adopted such that absorptive capacity should be prioritized for STI ODA to be effective in helping developing countries to escape poverty and achieve sustainable development goals. To the best of the authors' knowledge, this paper is the first of its kind to analyze the moderating effect of R&D investment on the relationship between STI ODA and innovative capacity in a developing country context.

Keywords: ODA (Official Development Assistance); STI (Science, Technology, and Innovation); absorptive capacity; innovation; panel data econometrics

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1. Introduction

As Science, Technology, and Innovation (STI) plays a crucial role for developing countries to achieve sustainable development goals [1], the international community and developing countries have increasingly paid attention to building STI capacity and are promoting various programs to build the STI capacity of developing countries. The United Nations suggested STI as a key means to achieve 17 sustainable development goals (SDGs) for which all countries in the world must strive for 15 years from 2016 to 2030 [2].

Innovation plays an important role in sustainable mid- to long-term economic growth [3,4]. Despite many theoretical and academic contributions to innovation, there have been few empirical studies on the innovation capabilities of developing countries.

In particular, Lall et al. [5] studied that the technological capabilities of developing countries are information and technology, which enable productive enterprises to utilize equipment and technology. The problem of innovative capacity in developing countries is not simply to acquire foreign technologies but to efficiently utilize and distribute technologies tailored to local companies [6]. So, given the tacit nature of technology and knowledge, the ability to absorb this knowledge, learn, and innovate with new values is highly desirable [7].

Under the 2030 Agenda for Sustainable Development (Paragraph 70), the United Nations established the UN interagency task team (UN-IATT) within the Technology Facilitation Mechanism (TFM), which had been created based on multi-stakeholder cooperation among UN member states, civil society, and the private sector. Since then, the UN has globally promoted STI to achieve SDGs through cooperation among various countries [8]. Furthermore, as an initiative of the TFM, the UN has been hosting the UN Multi-stakeholder Forum on Science, Technology, and Innovation for the Sustainable Development Goals (STI Forum) every year since 2016 to achieve SDGs. In addition, the Political Declaration of the SDG Summit, adopted in September 2019, announced a commitment to utilizing STI with a greater focus on digital transformation for sustainable development. As can be seen from these efforts, international expectations for STI have increased as a means of contributing to the realization of SDGs with limited resources [9–11].

Official Development Assistance (ODA) means that donor countries support developing countries to help them achieve the socio-economic development of the latter. According to the OECD DAC, the ODA volume has continuously increased, from $33.1 billion in 1960 to $178.9 billion in 2021 [12]. In 2021, compared to the 1960s, the aid volume increased by approximately five times, and compared to 2000, it increased by approximately 2.47 times, indicating a dramatic increase in the aid volume [12]. In particular, the dramatic increase in ODA since the 2000s is based on the Millennium Development Goals (MDGs) adopted by the UN in 2000, which envision reducing world poverty by half by 2015 [13].

Although the ODA has been continuously promoted to help developing countries' economic growth, many developing countries are still unable to lift themselves out of poverty. Thus, more attention has been paid to whether the ODA achieves the expected outcomes [14,15]. There have been major discussions on the contributions of aid to reducing poverty in developing countries, that is, achieving economic development [16–18], and on the effectiveness of aid by sector (e.g., education and health) [19–21].

However, research on the contributions of STI ODA to the economic growth of recipient countries has not yet been sufficiently conducted [22]. In particular, the importance of STI has been emerging in the Sustainable Development Goals (SDGs) newly agreed upon at the 70th UN General Assembly in September 2015. Accordingly, more discussions on increasing the share of STI ODA are underway [23].

The SDGs, following the MDGs, refer to 17 goals that all countries worldwide must make efforts together to achieve from 2016 to 2030, and STI capacity has been emphasized as key means to achieve them. The MDGs promoted by the UN from 2000 to 2015 have focused on receiving higher inputs of international aid to eradicate absolute poverty globally. In contrast, the SDGs, which are being promoted from 2016 to 2030, have focused on supporting the development capacity of developing countries to enable them to become self-supporting. This can be considered an important paradigm shift in development cooperation. In a world where STI are becoming crucial drivers of socio-economic growth, the evaluation of the effectiveness of STI ODA in developing countries has emerged as a critical research topic [9].

Among the SDGs, STI ODA is indicated in Goal 9: Industry, Innovation, and Infrastructure and targets 9-1: Develop Sustainable, Resilient, and Inclusive Infrastructures, 9-2: Promote Inclusive and Sustainable Industrialization, 9-3: Increase Access to Financial Services and Markets, and 9-4: Upgrade All Industries and Infrastructures for Sustainability. Furthermore, Goal 17: Partnerships for the Goals more clearly states the role of STI, compared to past MDGs [24,25].

In particular, studies that statistically organized STI ODA using the data from the OECD Development Assistance Committee (DAC) and empirically analyzed the impacts on the national innovative capacity as in this study are still rare. Therefore, the objectives of this study are as follows. First, by organizing STI ODA classification systems based on previous studies, it empirically analyzed the effectiveness and suggested a future direction for STI ODA. Second, it verified whether absorptive capacity moderated the relationship between STI ODA and innovative capacity. This study also aimed to determine how STI ODA affected the improvement of recipient countries' innovative capacity and whether there was a difference in the improvement of innovative capacity depending on the recipient countries' absorptive capacity. In addition, it clarified that absorptive capacity should be strengthened to increase the national innovative capacity. The study also empirically analyzed STI ODA and suggested the mechanisms of and conditions for absorptive capacity to boost the national innovative capacity of developing countries facing many challenges during the Fourth Industrial Revolution and to accelerate technological progress. Therefore, this study seeks to expand on previous research and uncover practical application strategies.

This study is structured as follows. Section 2 reviews previous studies on STI ODA. Section 3 explains the data structure, research model, and variables. Section 4 verifies models and an empirical analysis is conducted, while the effects of STI ODA and moderating effects of R&D investment are examined. Section 5 presents the value and limitations of this study and proposes suggestions for future research.

2. Literature Review

2.1. STI ODA and Innovative Capacity

ODA aims to eradicate poverty, promote the economic growth and welfare of developing countries, and provide support in all fields, including education, health, science, technology and innovation, and economic development [12]. Among them, STI ODA aims to support inclusive growth based on science and technology, by strengthening the innovation system of developing countries [26]. Major related programs encompass support on consultation to establish science and technology policy, support on fostering professionals/experts in science and technology, R&D infrastructure establishment, and support for capacity building [26]. Through this process, they aim to establish systems in science and technology sectors and achieve industrial development based on technology and innovation [26,27].

STI ODA refers to sectors related to science, technology, and innovation among ODA, and the ODA classification of the OECD DAC does not separate science and technology fields [28]. The DAC is a development assistance committee, one of the OECD's affiliated organizations which can be considered a meeting of OECD member countries to effectively promote development assistance.

Therefore, we collected data by extracting the sectors corresponding to education, training, and research in social infrastructure, economic infrastructure, production, and multi-sectors of the Creditor Reporting System (CRS) codes. An estimation of the volume of the STI ODA was first attempted by Song et al. (2008) [29], and related discussions on the methodology can be found in Lee (2010) [30].

The CRS codes for statistics, provided by OECD, have been subdivided and provided since 2002 and include multilateral and bilateral aids [22]. As shown in Figure 1, the volume of STI ODA was $2.799 billion in 2017, which nearly tripled compared to the ODA volume in 2003 ($1.047 billion). STI ODA from 2002 to 2018 accounted for 2.96% of total ODA on average.

As shown in Figure 2, data on STI ODA by sector (accumulated from 2002 to 2020) show that the production sector had the largest share (49%), followed by multisector (37%), social infrastructure (12%), and economic infrastructure (2%). The production sector includes agriculture, forestry, fishery, industry, mining, construction, trade, and tourism. The fact that the production sector had the largest proportion suggests that ODA support concentrated on R&D in each production sector. A multisector encompasses environmental education/training, environmental research, other education in multisector, and research/scientific institutions. Among them, other education in multisector accounted for 57%. Social infrastructure refers to research in the health and population sectors as well as support for human resource development. R&D in the health sector had a larger share. Finally, economic infrastructure refers to education in the transportation and warehouse sectors, as well as energy-related education and research. Among them, transportation and warehouse-related education had the largest proportion.

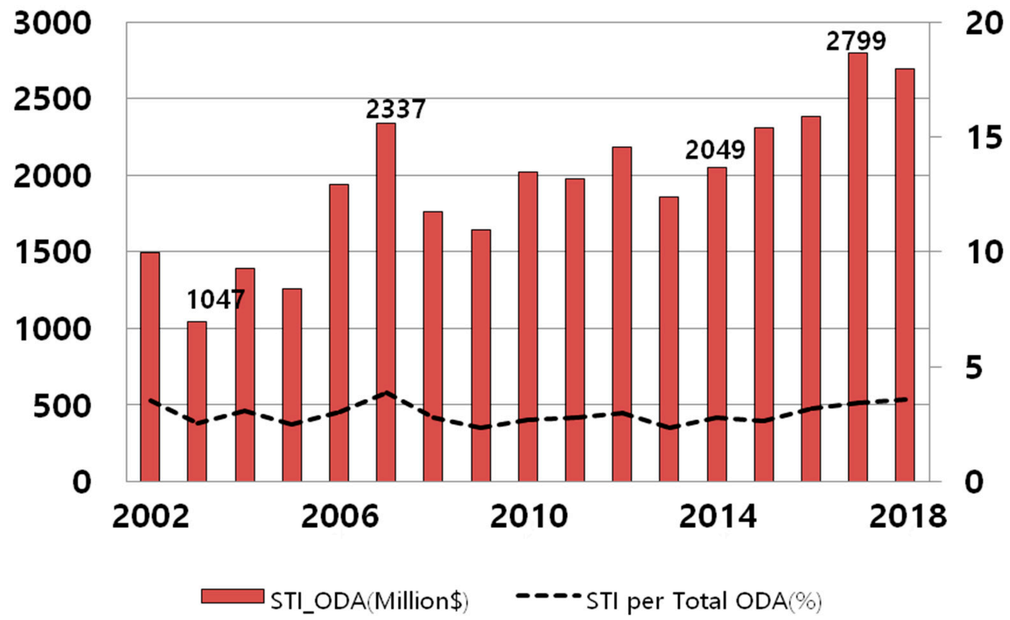

Figure 1. Trends in STI ODA support. Note: This graph was created by the author based on OECD data [31].

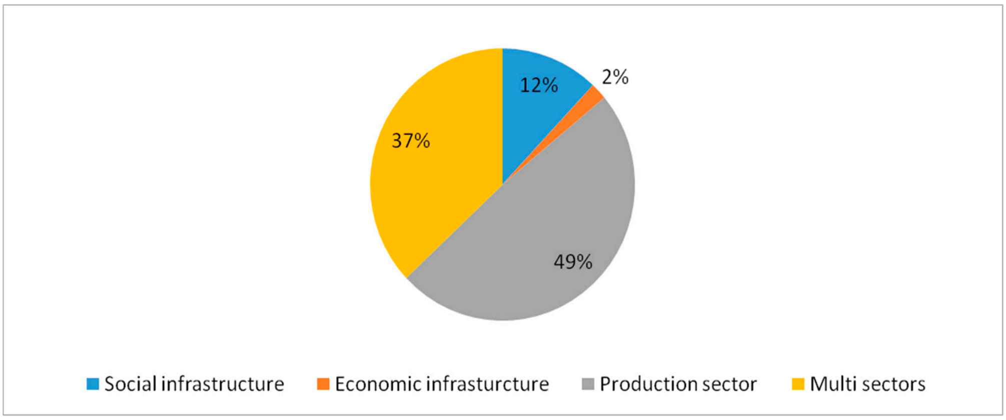

Figure 2. STI ODA support by sector (Accumulated from 2002 to 2018). Note: This graph was created by the author based on OECD data [31].

The main research agenda for STI ODA is to examine whether the STI ODA can improve the innovative capacity of developing countries. The effects of STI ODA have rarely been empirically studied because STI ODA has not been classified statistically.

Nadeem et al. (2020) [32] analyzed the effects of ODA on the improvement of innovative capacity. As a result of analyzing the mid-to-long-term effects of aid, political instability, and terrorism on innovation in Pakistan, by using autoregressive distributed lag (ARDL) methodology, it was found that all three variables had negative impacts on innovation in the mid-to-long term.

Byun et al. (2022) [33] found that Technology Cooperation ODA, which is similar to STI ODA and provides education, training, expert dispatches, and technical advice, had a positive impact on the export of intermediate goods at the manufacturing stage in South Korea.

Yun et al. (2013) [34] analyzed the effect of ODA on R&D. The number of domestic patent applications was set as a dependent variable, while recipient countries' R&D expenditure and R&D ODA were set as independent variables. The results of an empirical analysis revealed that recipient countries' R&D expenditure and R&D ODA had positive impacts on innovative capacity improvement.

Kang et al. (2019) [35] analyzed the impacts of STI ODA on recipient countries' economic growth using a panel vector autoregressive (VAR) model. It was found that ODA affected gross domestic product (GDP) growth in the short term, but the long-term effect was minimal, and the effect of STI ODA was greater than that of the education and health sectors.

Discussion on innovation begins with what Schumpeter mentioned the term "creative destruction" to describe the process by which innovation causes a free market economy to evolve [36] and is being discussed in various fields such as management, public administration, and economics. Innovative capacity is used as a term that indicates productivity (total factors) or relative efficiency, and sometimes it is interpreted as the same meaning as competitiveness in a broad sense, and there is no clear definition of the concept [37]. According to MetCalfe (1995) [38], 'innovation capacity' is defined as the relationship between input effort for innovation and innovation output. Lall (1992) [5] classifies three types of innovation capabilities at the corporate level as technological capabilities. They are investment capability, production capability, and inter-capability. Investment capability is the ability of a company to understand technology and use it efficiently. Production capacity is to develop technology and improve production facilities. Finally, linkage capabilities refer to procuring appropriate components, acquiring information, and transferring knowledge from the outside. In this study, the number of patents as an innovation output factor is considered as a major proxy for innovation capacity.

Based on the above studies, it can be inferred that STI ODA may have a positive impact on recipient countries' innovative capacity. Therefore, this study established the following hypothesis:

Hypothesis 1. *STI ODA will have a positive effect on recipient countries' innovative capacity.*

2.2. Absorptive Capacity and Innovative Capacity

Absorptive capacity is the ability to recognize and absorb new knowledge and utilize it to achieve project goals [39]. Furthermore, it is described as work methods and procedures, such as the potential capacity to acquire and assimilate new knowledge and the realization capacity to transform and utilize it, to build the dynamic capacity of organizations [40].

The concept of absorptive capability, which has been discussed at the corporate level, means that a company achieves its goals by effectively exploring, absorbing, and internalizing external information, knowledge, and capabilities [41]. Song et al. (2018) [42] classified absorption capacity into three categories: absorption effort, absorption knowledge base, and absorption process. Absorption effort is the investment that firms make to acquire knowledge; absorption knowledge base is the ability to understand and transform knowledge; and absorption process is the dissemination of absorbed knowledge [43]. Therefore, absorption capacity has been discussed to have a positive effect on technological innovation [44,45] and has been discussed to have a positive effect on financial and non-financial performance [46,47]. Variables to measure absorptive capacity include the number of researchers in the company, R&D intensity, knowledge sharing, and internal knowledge networks. When measuring national absorption capacity, R&D investment could be considered.

Govindaraju and Wong (2011) [48] reported that South Korea or Taiwan has focused on narrowing the technological gap with developed countries through high R&D investment, whereas Malaysia could not bridge the technological gap with developed countries due to low R&D investment and poor human resource development.

Countries with a low share of R&D investment, such as Vietnam, face difficulties in achieving a high level of industrialization due to a lack of national innovative capacity to utilize external resources, including ODA [49]. Furthermore, Thailand lacks the capacity required to absorb advanced technologies due to a very low share of R&D investment (0.2%) despite huge foreign direct investments (FDI) [50].

Park et al. (2021) [51] evaluated the innovation environments of eight Asian developing countries and found that countries with R&D investment in research institutes and active patent activities were transformed into high-income countries. However, in most developing countries, R&D investment is concentrated in universities or public research institutes, and private R&D investment is very low [52]. In other words, R&D investment, in both public and private sectors, is at a very low level.

In this sense, to increase the effectiveness of STI ODA in developing countries, more attention should be paid to the absorptive capacity that is closely related to the national innovation system [39,40,53–56].

In particular, for the industrialization of developing countries, absorptive and learning capacities are important for acquiring and absorbing existing technologies to bring about technological change. Developing countries have low absorptive capacities; thus, they do not have sufficient capacities to create technology markets by absorbing and utilizing scientific and technological knowledge [57]. In addition, from an innovation system perspective, developing countries may create insufficient innovation systems due to a lack of resources and capacity. Although they have systems, theirs may differ from those of developed countries in terms of maturity stages and characteristics [58].

From this point of view, Khan (2022) [59] found that the innovation system focuses on R&D investment in a narrow sense and follows a market-based approach. Thus, it is not suitable for low- and middle-income countries. In this regard, an inclusive and absorptive capacity-related perspective is necessary. In other words, preparation for innovation bases and the absorption and acquisition of external knowledge and skills require internal conditions (i.e., capacities). The internal conditions encompass manufacturing, policy, science and technology policy, infrastructure, business environment, finance, social welfare, and trust.

From the above discussion, it can be inferred that the absorptive capacity of developing countries would have a positive moderating effect on the effects of STI ODA on innovative capacity. Therefore, this study established the following hypothesis.

Hypothesis 2. *The absorptive capacity of developing countries will have a moderating effect on STI ODA and innovative capacity.*

Based on the above literature we propose the research model as shown in Figure 3.

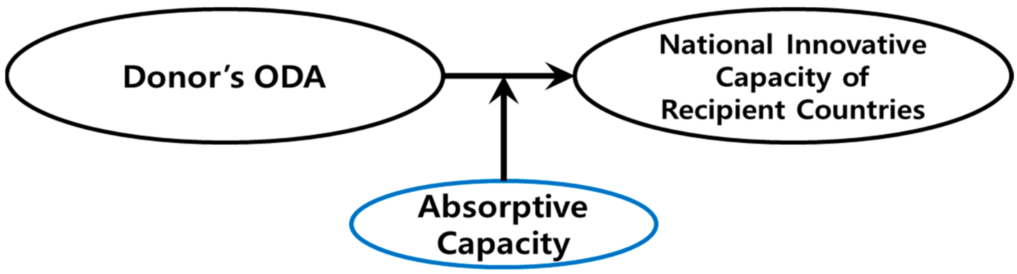

Figure 3. Research model.

3. Research Methods

3.1. Methodoloy

This study analyzed the effect of STI ODA on the improvement of the innovative capacity of developing countries and whether there is a difference in the improvement of the innovative capacity depending on the developing countries' absorptive capacity. To this end, we examined the theoretical background and previous studies on the effectiveness of aid and aid by sector.

This study was based on leading studies identifying the factors influencing national innovative capacity, such as Furman et al. (2004) [60] and Hu and Mathews (2005) [61]. Based on the knowledge production function of the endogenous growth theory, this study further elaborated the regression analysis model as follows:

$$\text{Patent}_{i,t} = \alpha + \beta_1 \text{stiper} + \beta_2 \text{rnd}_{i,t-3} + \beta_3 \left(\text{stiper}_{i,t} \times \text{rnd}_{i,t-3}\right) + \delta X_{i,t} + \lambda_t + \in_{i,t} \quad (1)$$

Where stiper, an independent variable, is the share of STI ODA to total ODA, and rnd is the share of R&D investment as a percentage of GDP. X denotes independent variables, including higher education enrollment rate, number of researchers, share of high-level technology export, per capita GDP, and government efficiency index. λ_t is time fixed effects, and $\in_{(i,t)}$ is an error term.

The number of patents is a dependent variable. As for rnd, we observed the number three years later, considering the time lag from R&D investment to its performance. R&D activities require a considerable amount of time, from basic research to commercialization and profit creation. Griliches (1984) [62] indicated that depending on the nature of R&D (basic research, applied research, development research, etc.), profits can be created at different times. Even for studies with similar characteristics, there may be time lag between those studies in terms of performance. Therefore, the R&D time lag varies depending on the country, industry or technology field, company, R&D characteristics, and R&D period and appears in a complex manner. The 3-year time lag suggested by Furman et al. (2002) [60] and Hu and Mathews (2005) [61], which are the most representative studies on national innovative capacity, was applied [63].

As the variables under moderation must be centered, this such transformation aims at reducing the correlation between the two variables [64,65] and the share of R&D investment used after the mean centering.

To analyze the effect of each country's STI ODA on innovative capacity, this study used a panel model. The panel model is appropriate for multivariate analysis of data that records several variables, while utilizing time information by repeatedly measuring panel objects. In addition, unlike the Ordinary Least Squares (OLS) model, the panel model can consider the heteroscedasticity of the residuals regarding the group or time of data. Furthermore, the panel model can measure unbiased coefficients by removing the endogeneity of the error term features of unobserved entities.

The panel model can be divided into a panel fixed effect and a panel random effect. The fixed effect considers the characteristics of targets and time, and the random effect is regarded as stochastic. Therefore, in this study, we used the Hausman Test among panel models to select and use appropriate models for innovative capacity analysis among fixed and random effect models [66].

3.2. Definition of Variables and Data Collection

3.2.1. Definition of Variables

(1) STI ODA share

The independent variable is the share of the volume of STI to the net ODA disbursements (volume in US dollars) received by recipient countries. This is the main variable of interest in this study; the amount of STI ODA was calculated in US dollars; we collected information on the volume for each recipient country. However, in OECD DAC, the data source, STI ODA is not suggested separately. Therefore, based on Kang et al. (2019) [35], we extracted the education, training, and research sectors from social infrastructure, economic infrastructure, the production sector, and multisector, calculated the total volume, and collected data. Table 1 indicates STI ODA fields organized per purpose-specific code provided by OECD DAC.

Table 1. STI ODA-related fields among the support sectors by DAC.

Support Sectors	Major Classification	Small and Medium Classification	CRS Code
Social infrastructure	Health	Medical education and training, and medical research	12181~2
		Health manpower development	12281
	Population policy and reproductive health	Human resource development for population policy and reproductive health	13081
Economic infrastructure	Transportation	Education in transportation and warehouse sectors	21081
	Energy	Energy development and supply	23181~2
Production sector	Agriculture	Agricultural education/training, and agricultural population	31181~2
	Forestry	Forestry education/training, and forestry research	31281~2
	Fishery	Fishery education/training, and fishery research	31381~2
	Industry	Industrial development, small business development, home industry, and handicraft industry	32120, 30, 40
		Agricultural and marine product processing, forest product processing, textile, leather, chemical, fertilizer, cement, energy processing, pharmaceutical production, and steel industry	32161~9
		Non-ferrous metal industry, engineering, and transportation and machinery industry	32170~2
		Technology research and development	32182
Multisector	Multisector	Environmental education/training, and environmental research	41081~2
		Other education in multisector, and research/scientific institutions	43081~2

Note: Re-classification based on the classification of Kang et al. [35].

(2) R&D share

As a moderating effect variable, the share/importance of R&D refers to the ratio of Gross Domestic Expenditure on R&D (GERD) in the national science and technology field (all natural science fields including science, engineering, agriculture, forestry, fisheries, pharmaceutical, and health science) as a percentage of GDP in a year. The corresponding data were obtained by accessing the UNESCO Data Portal.

(3) Number of patents

The national innovative capacity as a dependent variable in this study is the ability of a country as a political and economic entity to create and commercialize innovative technologies with long-term economic value [60]. It was measured by the number of patents as a proxy variable. The number of patent applications was obtained through the WIPO.

(4) Higher education enrollment rate

As a control variable, higher education refers to education provided by educational institutions such as universities and graduate schools, which students enter after successfully completed secondary education. The role of higher education, i.e., universities and graduate schools, is important in encouraging innovation [67,68].

(5) Number of researchers

As a control variable, the number of researchers, as human resources among R&D input resources, is the number of Full-Time Equivalent (FTE) researchers per million population. Researchers play an important role in creating new knowledge, performing research, creating theories and models, and improving software or operation methods. We obtained the data by accessing the UNESCO Data Portal.

(6) Share of high-level technology export

As a control variable, high-level technology export can be regarded as an indicator of a country's innovation capacity. The share of high-level technology exports to total manufacturing exports was selected as an indicator of the country's economic development level [69].

(7) Per capita GDP

As a control variable, GDP shows a country's economic performance and level of economic development, and it was measured assuming that there are differences in innovative capacity depending on the GDP level. The relevant data were obtained through the World Bank Indicator.

(8) Government efficiency index

Data related to the government efficiency index, a control variable, were obtained through the World Governance Indicator (WGI), which was established by Kaufman et al. (2010) based on data from the World bank. The WGI has released governance indicators for more than 200 countries and regions for the period 1996–2021. The WGI measures governments' governance capacity and consists of (1) citizen voice and accountability, (2) regulatory quality, (3) political stability and terrorism, (4) rule of law, (5) government efficiency, and (6) corruption control. Government efficiency evaluates the quality of public services, quality of civil servants, independence from political pressure, quality of policy establishment and implementation, and the credibility of the government's commitment to policy [70].

3.2.2. Data Collection

This study examined the effects of STI ODA on the improvement of recipient countries' innovative capacity. To this end, we selected 84 countries (see Appendix A) included in the list of ODA recipient countries of OECD DAC and constructed and analyzed panel data, which included cross-sectional data and time series data for 17 years (2002 to 2018). We collected the data from 2002 because the OECD has been providing OECD CRS detailed data since 2002. Thus, it was possible to collect the necessary STI ODA data for this study. The definition of variables and data sources per indicator are summarized in Table 2.

Table 2. Definition of variables and data source.

Variables	Name of Variables	Definition of Variables	Data Source
Independent variable	stiper (Share of STI ODA)	Share of STI ODA to ODA (%)	OECD [31]
Moderating variable	rnd (Share of R&D investment)	Share of R&D investment to GDP (%)	UNESCO [71]
Dependent variable	Patent (Number of patents)	Number of patent applications	WIPO [72]
Control variable	Edu (higher education enrollment rate)	Higher enrollment rates of colleges or graduate schools (%)	World Bank [73]
	Researcher (Number of researchers)	Number of full-time researchers per million population	UNESCO [71]
	hightec (Share of high-level technology export)	Share of high-level technology exports to total manufacturing exports (%)	World Bank [73]
	gdpper (Per capita GDP)	Per capita GDP	World Bank [73]
	ge (Government efficiency index)	Government efficiency index (-2.5 (minimum) ~ 2.5 (maximum)) including quality of public services	World Bank [73]

4. Results

4.1. Basic Statistics

Before the empirical analysis in this study, basic statistical analysis was conducted for each variable. Table 3 presents the descriptive statistics including the mean and standard deviation of independent, dependent, and control variables. Between 2002 and 2018, the mean number of patents in developing countries was 10,346.66. The mean stiper (STI ODA) was 0.03 ($million). The mean rnd (Share of R&D investment) was 0.39%. The mean edu (higher education enrollment rate) was 18.696. The mean researcher (number of researchers) was 485.01, and the mean hightec (share of high-level technology export) was 26.11%. Finally, the average of ge (government efficiency index) was −0.42.

Table 3. Descriptive statistics.

Name of Variables	Mean	Std.	Min	Max
stiper (Share of STI ODA)	0.03	0.04	0.00	0.49
rnd (Share of R&D investment)	0.39	0.35	0.01	2.14
Patent (Number of patents)	10,346.66	94,416.20	1.00	1,500,000
edu (higher education enrollment rate)	26.11	19.92	0.71	117.10
Researcher (number of researchers)	485.01	501.66	5.91	2396.54
hightec (share of high-level technology export)	10.82	81.60	0.00	61.35
gdpper (per capita GDP)	3246.43	2869.05	111.93	15,545
ge (government efficiency index)	−0.42	0.54	−1.95	1.27

Table 4 shows the result of verifying the correlation of variables and the multicollinearity. The variables with a positive correlation with patent, a dependent variable, were stiper, rnd, researcher, gdpper, and ge. In addition, rnd and stiper showed high positive correlations at 0.5478 and 0.2641, respectively. As a result of testing for multicollinearity between the independent variables using the Variance Inflation Factor (VIF), the VIF ranged from 1.18 to 2.54, which is <10. As a result, it was concluded that there was no multicollinearity [74].

Table 4. Correlations and multicollinearity test.

	Patent	Stiper	rnd	edu	Researcher	Hightec	Gdpper	ge	VIF	1/VIF
patent	1									
stiper	0.2641 ***	1							1.18	0.847862
rnd	0.5478 ***	0.1966 ***	1						1.85	0.54181
edu	0.0627	0.0924 **	0.2139 ***	1					1.75	0.572672
researcher	0.1799 **	0.0826	0.6259 ***	0.5628 ***	1				2.1	0.476921
hightec	0.0239	0.0018	0.0069	0.1631 **	0.3428 ***	1			1.95	0.513449
gdpper	0.1252 **	0.1527 ***	0.3350 ***	0.5682 ***	0.4039 ***	0.1734 ***	1		2.54	0.393521
ge	0.1207 **	0.1301 ***	0.4173 ***	0.2955 ***	0.4195 ***	0.0676	0.5381 ***	1	2.05	0.487712

Note: Asterisks indicate significance at *** $p < 0.01$, ** $p < 0.05$.

4.2. Empirical Analysis Results of Panel Model

Prior to data analysis, a Hausman test was conducted to select the final model between a fixed effect model and a random effect model. When patent was set as a dependent variable, the *p*-value for a Hausman test is <0.001. As a result, the hypothesis that there would be a correlation between the explanatory variable and the error term was rejected. Therefore, the estimator of the random effect model is not a consistent estimator, and the fixed effect model was found to be the most appropriate.

First, the results of analyzing the effect of STI ODA on the dependent variable, patent (innovative capacity), and the moderating effect of R&D investment (absorptive capacity) using a fixed-effect model are presented in Table 5.

Table 5. Result of stepwise regression analysis of panel fixed effect model for patent (innovative capacity).

Patent (log)	Model 1	Model 2	Model 3	Model 4
stiper	0.495 (0.692)		0.571 (0.647)	−0.250 (0.893)
rnd		−0.155 (0.660)	−0.163 (0.643)	−0.389 (0.289)
c.stiper X rnd				4.720 ** (0.042)
edu	0.022 (0.229)	0.023 (0.220)	0.022 (0.226)	0.018 (0.317)
Researcher (log)	0.188 ** (0.010)	0.184 ** (0.011)	0.183 ** (0.012)	0.182 ** (0.012)
hightec	−0.010 (0.667)	−0.009 (0.682)	−0.009 (0.684)	−0.009 (0.686)
gdpper (log)	−0.418 (0.419)	−0.403 (0.440)	−0.408 (0.431)	−0.459 (0.373)
ge	−0.165 (0.696)	−0.171 (0.692)	−0.176 (0.684)	−0.177 (0.684)
_cons	6.862 * (0.080)	6.740 * (0.089)	6.782 (0.085)	7.333 * (0.060)
Akaike crit. (AIC)	1754.642	1753.409	1755.291	1754.376
Bayesian crit. (BIC)	1779.545	1779.312	1785.512	1788.914
F-test	1.640	1.563	1.407	3.107 ***
R-square (overall)	0.027	0.027	0.027	0.032
Observation	554	554	554	554

Note: Robust p-values are given in parentheses. Asterisks indicate significance at *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

In Model 1, the influence of STI ODA on the dependent variable, patent (innovation capacity), was analyzed together with the control variable. From Model 1 to Model 4, the regression coefficient of STI ODA was found to be statistically insignificant ($p > 0.1$). Therefore, Hypothesis 1 that STI ODA will have a positive effect on innovative capacity was not supported.

So far, studies on ODA effectiveness have focused on whether ODA is effective in economic growth or not, and studies on its effects are often inconclusive, vast, and contradictory [75]. According to Quibria (2020) [76], it is difficult to draw one-sided conclusions because the research on aid effectiveness is vast and the results of empirical analysis are different. Similarly, the effectiveness of sectoral aid could be positive, negative, or mixed results depending on its efficacy [19]).

Next, the results of the analysis to verify the moderating effect of R&D investment (absorptive capacity) can be found in Model 4 in Table 5. To verify the moderating effect, the interaction terms of STI ODA and R&D investment were added to the model. As a result, the explanatory power of the model increased, and the interaction terms were found to be statistically significant in the positive direction (b = 4, $p < 0.05$). Therefore, Hypothesis 2 that the absorptive capacity of developing countries will have a moderating effect on STI ODA and innovative capacity was supported. The Table 6 shows the outcome of this hypotheses.

Table 6. Outcome of the hypotheses.

Hypothesis 1	Rejected
Hypothesis 2	Supported

Finally, among the control variables, the number of researchers was found to have a positive effect on innovative capacity (number of patents) across all models.

When these results are described using a graph, Figure 4 shows the average marginal effect of STI ODA and R&D investment. The estimation of the marginal effect enables us to examine interaction terms and main effects, and the effect of one-unit increase in R&D investment can be examined, while maintaining the average of other variables [77]. As for the effect of innovative capacity according to the increase or decrease in R&D investment, it can be seen that it has a negative effect when R&D investment is lower than approximately 5% but has a positive effect when it is higher than approximately 5%.

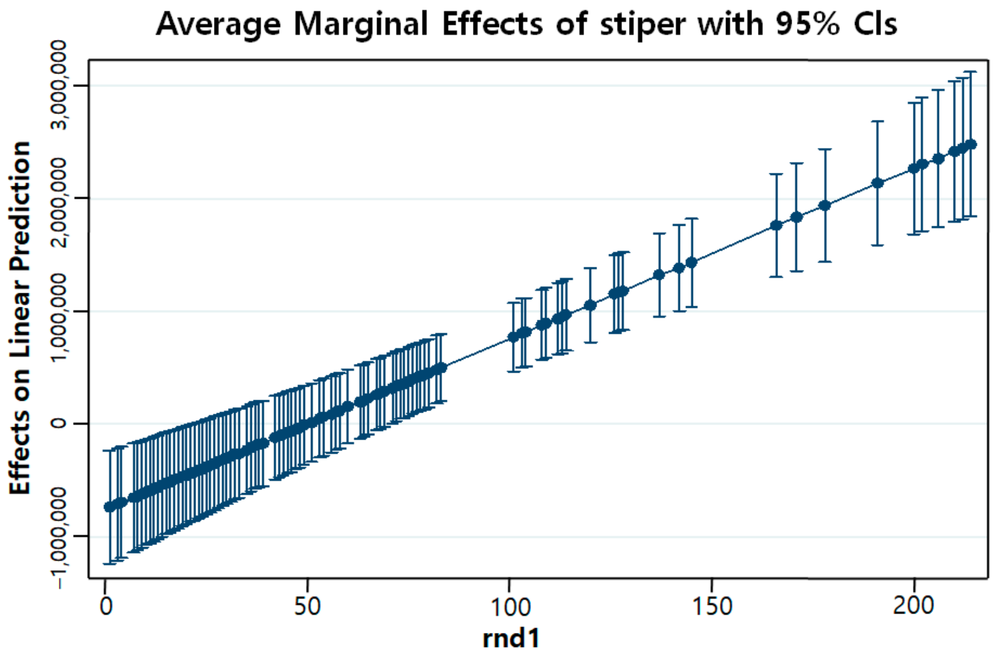

Figure 4. Average marginal effect of STI ODA according to R&D investment for patents (95% confidence). Note: rnd1 is 100 times rnd (share of R&D investment). For example, 50 means 0.5% of rnd (share of R&D investment).

5. Discussion

STI ODA is one of the most important tools for the economic and social development of developing countries. Nevertheless, there have been insufficient studies on the effectiveness of STI ODA, compared to education and health fields (Dreher et al., 2008; Doucouliagos, 2019). Therefore, this study attempted to empirically investigate the factors of STI ODA that influence the innovative capacity so as to evaluate the effectiveness of STI ODA. In particular, we attempted to study the moderating effects of R&D investment and the effect on innovative capacity. We utilized STI ODA-related data extracted from OECD DAC datasets, as well as variables such as the higher education enrollment rate, number of researchers, share of high-level technology export, per capita GDP, and government efficiency index, to control diverse factors affecting innovative capacity. A panel model was used for the empirical analysis, and a fixed-effect model was utilized for controlling differentiated characteristics temporally and regionally. We also confirmed through the Hausman test that the fixed-effect model was more appropriate than the random-effect model.

Our results can be summarized as follows. First, STI ODA did not directly increase innovative capacity. In other words, even if STI ODA was increased, it did not lead to an increase in the number of patents, which can be regarded as the innovative capacity of developing countries. It was found that STI had no direct positive effect on innovative capacity in developing countries.

Second, as the share of R&D investment increased, it showed a positive effect instead of a negative one on innovation capacity. R&D (absorptive capacity) had a moderating effect on STI ODA and innovative capacity. In other words, the effectiveness of STI ODA can be found in countries that invest in R&D expenditure above a certain level. From 2002 to 2019, the average R&D investment rate of developing countries was 0.38%, which was still significantly lower than that of developed countries. For instance, the average rate of R&D investment in 2018 was 0.386%. The highest R&D investment rate was found in China (2.14%), followed by Brazil (1.16%) and Malaysia (1.16%), whereas South Korea and other OECD member countries recorded 2.236%. The R&D investment rates of 60 countries were below a threshold of 0.5%, representing approximately 70% of the 84 countries targeted (see Appendix A) for this study. Among the collected data, if the 10 countries with the lowest share of R&D expenditures increase their R&D expenditures to the level of the 10 highest, the number of patents increase by 41 times. In other words, there is still plenty of room for STI ODA to improve its effectiveness along with R&D investment.

In this study, we have some policy implications and theoretical implications for the followings.

5.1. Policy Implications

Despite the continuous increase in STI ODA since 2002, the failure to directly affect the innovation capacity of developing countries provides important policy implications for policy makers implementing ODA. As development cooperation went through the MDG and SDG paradigms, more ODA and development cooperation were urged so that developing countries could overcome poverty and achieve the sustainable economic growth. However, simply increasing the amount of ODA cannot be expected to achieve better science and technology development in the developing countries. Again, in order to use STI ODA effectively and achieve its purpose, it is necessary to think about how STI ODA should be used and implemented.

5.2. Theoretical Implications

A lot of research on absorption capacity has been conducted using corporate data, but few have been studied using national level data. In addition, many studies on innovation capabilities have been conducted mainly in OECD and emerging countries. This study contributes to the study by expanding the scope of the concept of absorptive capacity within a company to the level of developing countries. In theory and practice, there has been little research on the relationship between the absorptive capacity and national innovative capacity by examining its moderating effect. It can be said that the contribution is meaningful because this study empirically analyzed that absorption capacity can be applied not only to the improvement of the innovation capacity of companies but also to the nation's innovation capacity.

Developing countries face many challenges with respect to eradicating poverty and achieving sustainable development. Among them, low innovative capacity has caused low innovation performance among companies, and they have been lagging behind on a global scale. As mentioned several times in the UN SDGs, STI is an important means of economic development in developing countries and requires continuous attention in the future.

6. Conclusions

The aim of this study is to investigate the effects of Science, Technology, and Innovation ODA on innovative capacity in developing countries. The direct effect of STI ODA on innovative capacity and moderating effect of R&D investment were investigated via the panel fixed effect model. The findings revealed that there is no direct effect on innovative capacity from STI ODA, and the moderating effect of R&D investment on innovative capacity is significant.

This study proposes that policy makers and practitioners should pay attention to recognize the effect of STI ODA on innovative capacity. In order for STI ODA to be effective, R&D investments must be considered together with STI ODA. In other words, when efforts to increase R&D investment on their own in developing countries along with STI ODA are accompanied, innovation capacity will be enhanced.

Although this study derived meaningful results and implications, it also has some limitations. First, since this study only analyzed data for the period between 2002 and 2018, it is difficult to generalize the results of this study. The detailed data provided by the OECD DAC started from 2002. Hence, we conducted an analysis from 2002. However, in the future, it will be necessary to devise measures for including data before 2002. Second, this study selected 84 developing countries (see Appendix A). Because there are many missing values for the variables in the study about developing countries, it will be necessary to solve the problem of these missing values and include more countries in future studies. Finally, in addition to the variables considered in this study, there are several factors that affect innovative capacity, such as the degree of protection of intellectual property rights and the financial accessibility of private companies. However, this study was unable to include these factors due to the limitations of data availability for developing countries. More useful and meaningful results may be derived if the abovementioned variables are included in the innovation capacity analysis.

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Appendix A

The lists of countries for this study are as follows: Albania, Algeria, Angola, Armenia, Azerbaijan, Belarus, Bolivia, Bosnia and Herzegovina, Botswana, Brazil, Burkina Faso, Burundi, Cabo Verde, Cambodia, Chad, China (People's Republic of), Colombia, Costa Rica, Côte d'Ivoire, Cuba, Democratic Republic of the Congo, Ecuador, Egypt, El Salvador, Ethiopia, Gabon, Gambia, Georgia, Ghana, Guatemala, Honduras, India, Indonesia, Iran, Iraq, Jamaica, Jordan, Kazakhstan, Kenya, Kyrgyzstan, Lao People's Democratic Republic, Lesotho, Madagascar, Malaysia, Mali, Mauritania, Mauritius, Mexico, Moldova, Mongolia, Montenegro, Morocco, Mozambique, Myanmar, Namibia, Nepal, Nicaragua, Nigeria, North Macedonia, Pakistan, Panama, Papua New Guinea, Paraguay, Peru, Philippines, Rwanda, Saint Vincent and the Grenadines, Senegal, Serbia, South Africa, Sri Lanka, Sudan, Syrian Arab Republic, Tajikistan, Tanzania, Thailand, Togo, Tunisia, Turkey, Uganda, Ukraine, Uzbekistan, Viet Nam, and Zambia.

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