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CAN GOVERNMENT R&D EXPENDITURE PROMOTE INNOVATION? NEW EVIDENCE FROM 37 OECD COUNTRIES

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Abstract. This research employs a fixed effect model to empirically estimate panel data from 37 OECD countries spanning 2000 to 2021, revisiting the influence of government R&D expenditure on innovation within the theory of marginal diminishing effect. Results reveal a significant positive effect of government R&D expenditure on national innovation capacity, and this influence remains robust under robustness checks. Then, quantile regression uncovers a nuanced pattern, indicating that as a country's innovation capacity strengthens, the stimulative effect of government R&D expenditure initially rises and subsequently declines. Additionally, incorporating lags of the independent variable at different periods affirms the time lag effect of government R&D expenditure on national innovation capacity. Deeper scrutiny using two fixed effect models including interaction terms reveals a multifaceted mechanism, where government R&D expenditure fosters innovation by promoting bank credit, yet simultaneously suppresses innovation by hindering non-governmental R&D intensity. Lastly, heterogeneity analysis affirms that government efficiency, democracy, ruling party ideology, political stability, and economic freedom moderate the link between government R&D expenditure and national innovation capacity. These insights offer new references for governments to promote innovation.

Keywords: government R&D expenditure, innovation, OECD, bank credit, government efficiency.

JEL Classification: H50, O30, O32.

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1. Introduction

As indicated by endogenous growth theory, technological innovation is the determining factor for sustained regional economic growth (Ding et al., 2023). Furman et al. (2002) also found that countries with prosperous innovation activities have more significant latecomer advantages in economic development. Furthermore, innovation is an important means to attain sustainable development in light of global issues such as climate change, resource scarcity, and environmental pollution (Omri, 2020). As such, since this century, innovation, as a key factor to achieve sustainable economic growth, has been increasingly concerned by countries (Wen et al., 2021). However, the substantial investment, cycle length, and risk that characterize innovation endeavors can inhibit their prosperity (Castellion & Markham, 2013); at the same time, the favorable externalities of innovation output can distort the price and allocation of innovation factors, and lead to the inability to achieve Pareto optimality in the allocation of innovation factors (Wang et al., 2023). Therefore, it is essential for governments to fully play the positive role of macro-control and effectively promote the vigorous development of innovation activities.

As a commonly used macro-control means of governments, the role of fiscal policies in innovation has been widely discussed. Fiscal policies that can affect innovation mainly include government subsidies (Xu et al., 2023), government procurement (Bruce et al., 2019), government investment (Zheng et al., 2018) and tax incentives (Dai & Chapman, 2022), of which the first three can be covered in the scope of government R&D expenditure. As such, fiscal policies affecting innovation can be classified into two types: government R&D expenditure and tax incentives (Tang et al., 2022). Due to the sensitivity of tax incentives to innovation output and the high discretion of enterprises in using such incentives, government R&D expenditure can have a stronger impact on innovation than tax incentives (Nakano & Nguyen, 2012; Tang et al., 2022). As such, this study focuses on the relationship between government R&D expenditure and innovation.

Regarding this relationship, different conclusions have been drawn from previous studies. Audretsch et al. (2002) found that the Small Business Innovation Research (SBIR) Program in the United States effectively stimulated the innovation vitality of assisted enterprises. Supporting this finding, Boeing et al. (2022), Ren (2022), and Tang et al. (2022) empirically confirmed that government R&D spending significantly promotes innovation in China. Similarly, the positive impact of government R&D expenditure in innovation was also found in Sweden (Lööf & Heshmati, 2007) and Germany (Czarnitzki & Licht, 2006). However, some studies came to the opposite conclusion. For example, Wallsten (2000) found that in the context of the SBIR program, assisted enterprises in the United States actually reduced their innovation investment, meaning that the US government's R&D spending crowded out innovation activities. This crowding out effect was also confirmed to exist in Israel (Lach, 2002) and China (Zhao et al., 2018).

Although the influence of government R&D expenditure on innovation has been investigated in some studies, it is still necessary to further explore this impact. First, as indicated earlier, existing literature on this relationship has not reached a consistent conclusion. Second, to our knowledge, existing literature all focused on a particular country as a research sample, which makes their research conclusions not universally applicable to other countries. Third, marginal diminishing effect argues that the marginal production of variable factors will decrease, which means that when a country's innovation capacity is at different stages, government R&D expenditure will have a different impact on it. Unfortunately, as of now, we have not found any literature that has empirically explored this. Fourth, innovation is not instantaneous, and it takes a certain amount of time from the initial innovation inspiration to the final innovation output. This means that government R&D input could not immediately generate an impact on national innovation capacity, suggesting a potential time lag effect. However, this time lag effect has not been explored in previous studies. Fifth, few studies have explored the mechanisms through which government R&D expenditure affects innovation. To our knowledge, only Tang et al. (2022) examined the indirect impact of government R&D expenditure on innovation from the three perspectives of financing constraints, employee creativity, and the institutional environment. In addition, government R&D expenditure could also affect innovation by influencing bank credit and the R&D intensity of non-governmental sectors[1]. However, no research has explored these two factors as mechanisms in this relationship, which leaves room for further research on the indirect impacts of government R&D expenditure on innovation in this study. Finally, a country's government R&D expenditure, innovation input, and innovation output could be influenced by its political and economic context. As such, it is necessary to investigate the relationship between government R&D expenditure and innovation in some specific political or economic environment. In other words, it is necessary to examine the moderating effects of some political and economic variables on this relationship, which has not been implemented in existing literature.

This study made the following improvements to fill the aforementioned gaps, which are also the study's possible marginal contributions. First, unlike previous studies that only used data from one country up to 2018 for empirical testing, we used panel data from 37 OECD countries[2] from 2000 to 2021 to retest the link between government R&D expenditure and innovation. This not only helps researchers obtain more current findings, but also makes these findings more universal. Second, more in-depth than existing literature, we used quantile regression to examine the different impacts of government R&D expenditure on national innovation capacity at different stages. Third, beyond existing literature, we attempted to examine the time lag effect of government R&D expenditure on national innovation capacity. Fourth, this study attempted to examine the indirect effects of government R&D expenditure on innovation from the two perspectives of bank credit and the R&D intensity of non-governmental sectors, in order to discover some mechanisms that have not been empirically confirmed. Finally, more in-depth than existing literature, this study incorporated several political or economic variables (e.g. government efficiency, democracy, ruling party ideology, political stability, and economic freedom) into the research framework to investigate their moderating effects on the relationship between government R&D expenditure and innovation. In doing so, we are able to offer governments more specific policy insights towards enhancing innovation from these five perspectives.

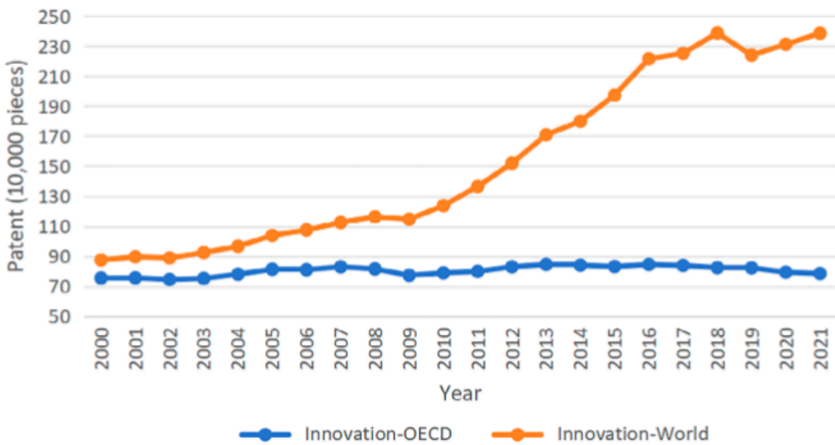
Figure 1 visually illustrates the innovation trends in OECD countries and globally since the beginning of this century. It can be observed that, unlike the significant leap trend in global innovation, innovation in OECD countries did not seem to experience substantial development during this period. An objective fact is that the majority of OECD countries are developed countries. Developed countries encounter higher production factor costs compared to developing countries. As a result, developed countries require innovations that can enhance production efficiency even more, to reduce average production costs and thereby increase economic efficiency. Hence, we conducted this study in the context of 37 OECD countries[3].

The remaining of this paper is arranged as follows. Section 2 reviews the existing literature related to this study. Section 3 introduces the data and methods used in this study. The empirical results are reported and discussed in Section 4. Section 5 summarizes the main research findings, puts forward policy implications, and recognizes the study's limitations that cannot be solved at present.

[1] The two mechanisms will be further discussed in Section 2.3.

[2] The country list is provided in List A1 of the Appendix.

[3] The reasons for selecting 37 OECD countries as research samples will be further discussed in Section 3.



Note: Following Ding et al. (2023), the number of patent applications is used to measure innovation.

Figure 1. Innovation trend during the period of 2000–2021 (source: the World Development Indicator (WDI) database)

2. Literature review

2.1. The influencing factors of innovation

The factors that were confirmed to affect innovation can generally be divided into three categories: human capital, physical capital, and institutional environment (Anokhin & Wincent, 2012). As far as human capital is concerned, it can be divided into two schools: quantity and quality. The quantity school believes that the expansion of population size is a positive factor for boosting innovation, as population growth increases the likelihood of talented innovators appearing (Wen et al., 2021). In addition, increasing population will generate more diverse demands, which provides impetus for product innovation (Dong et al., 2016). Supporting quantity school, Wang et al. (2021) and Li et al. (2023) both provided empirical proof on the positive effect of population growth on innovation. However, the quality school has challenged the quantity school. The quality school believes that simple population growth cannot promote innovation, and may even inhibit it, because lower labor costs will inhibit the motivation of enterprises to pursue new technologies (Parrotta et al., 2014). Corroborating this, Ding's et al. (2023) empirical study validated the negative link between population growth and innovation. Unlike the quantity school that simply pursues population expansion, the quality school believes that higher levels of human capital investment (i.e. education) can provide support for the prosperity of innovation activities (Kaiser et al., 2015). Supporting this, Donou-Adonsou (2019) and Wang et al. (2019) both empirically confirmed the positive role of education in innovation.

In terms of physical capital, a large amount of literature has focused on the impact of foreign direct investment on innovation. On the one hand, the spillover effects of foreign direct investment can generate a positive impact on innovation in host countries, as foreign direct investment can bring advanced production technologies and management concepts to host countries (Morita & Nguyen, 2021). Supporting this, Li et al. (2021) and Tan et al. (2023) both empirically confirmed that foreign direct investment can produce more prosperous innovation. On the other hand, due to the existence of the "market plunder" effect, foreign direct investment can also inhibit innovation (García et al., 2013). Specifically, better-endowed foreign-funded enterprises can seize market share from local enterprises and thus force them to reduce production. This will reduce the profitability of local enterprises and thus force them to reduce their expenditure in innovation. Correspondingly, the empirical findings of both Wen et al. (2021) and Ding et al. (2023) support the inhibitory effect of foreign direct investment on innovation.

From the perspective of institutional environment, changes and implementation of industrial policies can to some extent determine the direction of innovation and have an impact on the innovation investment decisions of enterprises (Lovett, 2011). Especially, the industrial policy of advocating high-tech added value can stimulate the innovation enthusiasm of societies, thus creating a virtuous circle (Kuhn, 2012). As such, as empirically confirmed by Wen et al. (2021), an adaptable innovation environment can effectively boost innovation activities.

2.2. Impact of government R&D expenditure on innovation

The extant literature on the impact of government R&D expenditure on innovation can be broadly divided into two categories. One only explores the direct influence of government R&D expenditure on innovation, while the other examines both direct and indirect impacts. We first review the former category of literature. Some literature believes that government R&D expenditure can significantly improve innovation. For example, through extensive statistical analysis and case studies on SBIR recipients, Audretsch et al. (2002) confirmed that funding support for innovation activities in small businesses from US government can promote their innovation output. The relationship between government R&D expenditure and innovation had been also empirically examined using Swedish data (Lööf & Heshmati, 2007), German data (Czarnitzki & Licht, 2006), and Chinese data (Boeing et al., 2022; Ren, 2022), and positive conclusions were drawn. However, some literature challenges the positive relationship between government R&D expenditure and innovation. For example, Wallsten (2000) conducted a series of empirical estimates on the data of firms involved in the SBIR program and found that US government R&D expenditure generates a crowding out effect on innovation. This crowding out effect was also empirically confirmed in Israel (Lach, 2002) and China (Zhao et al., 2018). In addition to examining the direct impact of government R&D expenditure on innovation, Tang et al. (2022) also investigated the indirect effect of government R&D expenditure on innovation by adding the interaction terms containing intermediate variables to the regression model. They found that government R&D expenditure can promote innovation by alleviating financing constraints, enhancing employee creativity, and improving institutional environment.

A review of existing literature reveals that researchers have not reached a consensus on whether government R&D expenditure has a positive or negative impact on innovation. More importantly, the exploration of this impact in the existing literature remains quite limited. Specifically, most studies solely focused on examining the direct impact of government R&D expenditure on innovation, with only Tang et al. (2022) investigating the indirect effects from three perspectives. In other words, the complete exploration of the impact of government R&D expenditure on innovation across various levels of innovation and its time lag, indirect, and moderating effects have not been thoroughly examined yet. As such, this study will try to close these gaps[4].

2.3. Hypothesis development

Government R&D expenditure could affect innovation from the following perspectives. First, as elaborated and empirically confirmed by Tang et al. (2022), government R&D expenditure can promote innovation by alleviating financing constraints, enhancing the creativity of human capital, and optimizing institutional environment.[5] Second, government R&D expenditure could promote innovation by expanding the scale of bank credit. Specifically, government expenditure has a guiding role (Ding et al., 2023). The increase in government spending on R&D can deliver a positive signal to society that governments are encouraging innovation. This positive signal can reduce the risk perception of banks lending to innovation projects, as government funding for R&D can be seen as reducing the risk of innovation projects. As such, banks could expand their credit support for innovation projects and thus promote innovation output. Additionally, government R&D expenditure could affect innovation by influencing the R&D intensity of non-governmental sectors. On the one hand, government R&D expenditure has spillover effect on R&D in non-governmental sectors. More specifically, the increase in government R&D input can guide non-governmental sectors to pay more attention to the field of technological innovation and improve their expectation for the future development of the innovation market. This helps to increase the R&D intensity of non-governmental sectors and thus enhance innovation. Meanwhile, the increase in government R&D expenditure increases the demand for innovation factors, which will generate upward momentum on the prices of innovation factors. The rise in prices of innovation factors tends to suppress the R&D intensity of non-governmental sectors and thus generate a negative impact on innovation. In short, the impact of government R&D expenditure on innovation by influencing the R&D intensity of non-governmental sectors is not clear. Based on the analysis above, we put forward the following hypotheses.

Hypothesis A: *Government R&D expenditure could positively affect innovation.*

Hypothesis B: *Government R&D expenditure could negatively affect innovation.*

3. Data and methodology

3.1. Data

This study empirically examines the impact of government R&D expenditure on national innovation capacity by utilizing panel data from 37 OECD countries from 2000 to 2021. The usage of this dataset is mainly based on the following concerns. First, we have not found

[4] These literature gaps and how this study intends to close them have been discussed in more detail in Section

[5] More information related to the three mechanisms can be obtained by further reading: Tang et al. (2022). 0

any publicly available databases that disclose government R&D expenditure data for countries other than these 37 OECD countries. In other words, we can only obtain government R&D expenditure data for these 37 OECD countries at present. Second, OECD almost covers all developed countries around the world. The statistical agencies of developed countries have established strict data quality management systems and evaluation mechanisms, which makes the data of these countries usually more accurate, and thus improves the credibility of conclusions obtained from empirical analysis using these data. In addition, as mentioned earlier, compared to developing countries, developed countries have higher production factor costs. As such, developed countries require innovation that can improve production efficiency to reduce their average production costs, and thus raise their economic efficiency. Fourth, due to the fact that OECD almost encompasses all developed countries with top economic and technological levels, the innovation capacity of these countries have a more significant impact on global innovation development. As such, the findings of the empirical study using panel data of 37 OECD countries also have reference significance for non OECD countries.

The dependent variable of this study is national innovation capacity (*NIC*). Pradhan et al. (2016) claimed that patents can reveal something about the degree of regional innovation. While the quantity of patent authorizations (Guo & Zhong, 2022; Liu et al., 2020) and patent applications (Wen et al., 2021; Ding et al., 2023) were both used to gauge a region's capacity for innovation, the latter can identify innovation output more promptly than the former (Jalles, 2010). As a result, the number of national patent applications filed each year serves as the proxy variable for *NIC*. In this study, the key construct of interest is government R&D expenditure (*GRDE*). Additionally, referring to Wen et al. (2021), some indicators that could affect *NIC*, such as economic growth (*EG*), service industry cluster (*SIC*), Education (*Edu*), international trade (*IT*), population density (*PD*) and foreign direct investment (*FDI*) are included as control variables in the analysis framework. The proxies for these control variables are GDP per capita, the ratio of the service industry's output of GDP, gross secondary school enrollment rate, the ratio of total export-import volume to GDP, population per square kilometer of land area, and the ratio of foreign direct investment inflows to GDP, respectively. The data on these variables are accessible from World Intellectual Property Organization (WIPO) Patent Report, the World Development Indicator (WDI) database and OECD database.

The descriptive analysis results of the variables mentioned above are presented in Table 1. It can be observed that all variables except *FDI* have positive values. Importantly, the large standard deviations held by *NIC*, *GRDE* and *EG* indicate significant differences in innovation output, government R&D input and wealth among these 37 OECD countries. The standard deviations of the other variables, in comparison, are relatively modest, indicating that the data for those variables are not widely scattered. Additionally, the correlation matrix for all independent variables is displayed in Table A1 of the Appendix. In this study, estimate bias due to multicollinearity is eliminated as no two independent variables exhibit a substantial correlation.

Table 1. Descriptive statistics of full-sample

Category	Variable Name	Measurement	Mean	Standard Deviation	Min	Max
Dependent variable	NIC	Piece	26,362.08	72,319.69	13.00	3.87e+05
Independent variable	GRDE	US Dollar, Millions, 2015	9,152.401	23,027.67	47.95	1.45e+05
Control variables	EG	US Dollar, 2015	31,242.30	20,312.37	4,003.99	1.12e+05
	SIC	Ratio	0.62	0.06	0.50	0.80
	Edu	Ratio	1.06	0.14	0.71	1.64
	IT	Ratio	0.92	0.50	0.20	3.93
	PD	people per sq. km of land area	139.23	132.39	2.48	531.11
	FDI	Ratio	0.06	0.14	0.00	2.34

Note: *NIC* – National innovation capacity; *GRDE* – Government R&D expenditure; *EG* – Economic growth; *SIC* – Service industry cluster; *Edu* – Education; *IT* – International trade; *PD* – Population density; *FDI* – Foreign direct investment.

3.2. Methodology

3.2.1. Benchmark estimation and robustness checks

A number of empirical estimations will be carried out in order to verify the effect of government R&D expenditure on national innovation capacity. A fixed effect model is created as Equation (1) for benchmark regression. In this equation, Z stands for the control variables, μ_i and ν_t indicates the country and year fixed effects, respectively, α_0, α_1 and β are the estimation coefficients, and ε_{it} represents the error term. It is important to note that the variables called *NIC*, *GRDE*, *EG* and *PD* will be treated logarithmically in order to reduce the heteroscedasticity issue.

$$Ln(NIC_{it}) = \alpha_0 + \alpha_1 Ln(GRDE_{it}) + \beta Z_{it} + \mu_i + \nu_t + \varepsilon_{it}. \quad (1)$$

This study will also carry out a number of robustness checks to see if the results of the benchmark regression are reliable. A placebo test is the first robustness check that needs to be done. Ding et al. (2023) stated that the result of the *GRDE-NIC* link demonstrated in the benchmark estimation could just be a placebo outcome because of the constraints in the research methodology. In accordance with Cornaggia and Li (2019), a placebo test will be carried out to rule out this option. Specifically, we extract all of the *GRDE* data and reassign them randomly to every sample. We next re-estimate Equation (1). In the placebo test, the coefficient of *GRDE* should be significant and same in sign as the benchmark estimation if the *GRDE-NIC* link demonstrated by the latter is a placebo effect.

Changing the dependent variable's proxy is the second robustness check. The Global Innovation Index (GII), jointly developed by the World Intellectual Property Organization (WIPO), Cornell University, and Institut Européen d'Administration des Affaires, comprehensively measures the innovation performance of 131 countries or regions based on over 80 indicators (Zavale, 2023). As such, GII is also considered a suitable proxy for a country's innovation capacity (Asghar et al., 2024). As a robustness check, we will re-estimate Equation (1) after switching the proxy construct of *NIC* from patent application volume to GII. It should be noted that since only GII data after 2011 is available, the period for this robustness test is from 2011 to 2021. The data of GII can be obtained from WIPO official website[6].

System GMM estimation serves as the third robustness check. Although a fixed effect model can give solid static estimation findings for researchers, it may result in skewed estimations due to disregarding the possible endogeneity produced by dynamic panel deviation (Wen et al., 2021). To minimize the possibility of endogeneity, in accordance with Arellano and Bond (1991), we will use system GMM to perform a dynamic estimation of the effect of government R&D expenditure on national innovation capacity, as demonstrated by Equation (2), which adds the lag term of the dependent variable as an instrumental variable to Equation (1). In Equation (2), $NIC_{i,t-1}$ is the lag term of NIC_{it}, and other variables carry the same connotations as in Equation (1).

$$Ln(NIC_{it}) = \alpha_0 + \alpha_1 Ln(NIC_{i,t-1}) + \alpha_2 Ln(GRDE_{it}) + \beta Z_{it} + \varepsilon_{it}. \quad (2)$$

Lastly, according to Wen et al. (2018), a notable drawback of the generic panel fixed effect model is the need that variables have a normal distribution. Because of this, a Poisson regression will be carried out as a robustness check to ascertain whether the *GRDE-NIC* link holds true when a diversified distribution is present. Equation (3) displays the Poisson model, with all variables having the same meanings as in Equation (1).

$$NIC_{it} = \alpha_0 + \alpha_1 Ln(GRDE_{it}) + \beta Z_{it} + \mu_i + \nu_t + \varepsilon_{it}. \quad (3)$$

3.2.2. Quantile regression

As mentioned earlier, marginal diminishing effect reminds that the effect of government R&D expenditure on a country's innovation capacity could change depending on where the country's innovation capacity is at. Additionally, according to Syed et al. (2022), the sensitivity of OLS regression to outliers could result in biased estimates, while quantile regression can successfully alleviate this deficiency. As such, we will conduct quantile regression to examine the various effects of government R&D expenditure on the capacity for national innovation at various stages of the capacity. Following Zheng et al. (2021), five representative quantiles (i.e. 0.1, 0.25, 0.5, 0.75, and 0.9) will be selected for the quantile regression.

3.2.3. Time lag effect

In accordance with Wen et al. (2022), we will lag the independent variable called *GRDE* for periods 1, 3, 5, 7, and 9, then regress with the dependent variable to confirm the long-term influence of government R&D expenditure on national innovation capacity. In other words, we will estimate Equations (4) through (8). In Equations (4) to (8), *GRDE*'s lagged periods of 1, 3, 5, 7, and 9 are represented by $GRDE_{i,t-1}$, $GRDE_{i,t-3}$, $GRDE_{i,t-5}$, $GRDE_{i,t-7}$, and $GRDE_{i,t-9}$, respectively. The meanings of other variables in these five equations are identical to those in Equation (1).

[6] The website is https://www.wipo.int/global_innovation_index/en/.

$$Ln(NIC_{it}) = \alpha_0 + \alpha_1 Ln(GRDE_{i,t-1}) + \beta Z_{it} + \mu_i + \nu_t + \varepsilon_{it}; \quad (4)$$

$$Ln(NIC_{it}) = \alpha_0 + \alpha_1 Ln(GRDE_{i,t-3}) + \beta Z_{it} + \mu_i + \nu_t + \varepsilon_{it}; \quad (5)$$

$$Ln(NIC_{it}) = \alpha_0 + \alpha_1 Ln(GRDE_{i,t-5}) + \beta Z_{it} + \mu_i + \nu_t + \varepsilon_{it}; \quad (6)$$

$$Ln(NIC_{it}) = \alpha_0 + \alpha_1 Ln(GRDE_{i,t-7}) + \beta Z_{it} + \mu_i + \nu_t + \varepsilon_{it}; \quad (7)$$

$$Ln(NIC_{it}) = \alpha_0 + \alpha_1 Ln(GRDE_{i,t-9}) + \beta Z_{it} + \mu_i + \nu_t + \varepsilon_{it}. \quad (8)$$

3.2.4. Mechanism tests

As elaborated in Section 2.3, government R&D expenditure could affect national innovation capacity by influencing bank credit scale and R&D intensity of non-governmental sectors, which has not been empirically confirmed by existing literature. To fill this gap, referring to the method used by Wen et al. (2021), we will examine the two mechanisms empirically by including two additional independent variables to Equation (1). To determine if government R&D expenditure can influence national innovation capacity by influencing bank credit scale, as illustrated in Equation (9), we introduce bank credit (*BC*) and its interaction term with government R&D expenditure (*GRDE*BC*) to Equation (1). Following Gozgor et al. (2019), the proportion of domestic credit from banks to private sector to GDP is used to measure *BC*. To examine how government R&D expenditure affects national innovation capacity by influencing R&D intensity of non-governmental sectors, as shown in Equation (10), we add R&D intensity of non-governmental sectors (*RDI*) and its interaction term with government R&D expenditure (*GRDE*RDI*) to Equation (1). The data of *BC* and *RDI* can be obtained from the World Development Indicator (WDI) database and OECD database.

$$Ln(NIC_{it}) = \alpha_0 + \alpha_1 Ln(GRDE_{it}) + \alpha_2 Ln(BC_{it}) + \alpha_3 (Ln(GRDE_{it}) * Ln(BC_{it})) + \beta Z_{it} + \mu_i + \nu_t + \varepsilon_{it}; \quad (9)$$

$$Ln(NIC_{it}) = \alpha_0 + \alpha_1 Ln(GRDE_{it}) + \alpha_2 Ln(RDI_{it}) + \alpha_3 (Ln(GRDE_{it}) * Ln(RDI_{it})) + \beta Z_{it} + \mu_i + \nu_t + \varepsilon_{it}. \quad (10)$$

3.2.5. Moderating effects

In order to investigate the moderating effects of government efficiency (*GE*), democracy (*Dem*), political stability (*PS*), and economic freedom (*EF*) on the *GRDE-NIC* link, following the method used by Jadiyappa et al. (2021), we will divide the 37 sample countries involved in this study into 8 sub-samples based on the median values of these four moderating variables, and estimate these sub-samples separately using Equation (1). If the four variables do have moderating effects on the relationship between government R&D expenditure and national innovation capacity, the results obtained by the variable named *GRDE* should be different among the estimations. Following Wen et al. (2021), indicators of government effectiveness acquired from the Worldwide Governance Indicator (WGI) database is regarded as the proxy of *GE*. Following Neff and Pickard (2021), the democracy index published by the Economist Intelligence Unit is used to measure *Dem*. Following Yuliantini and Nurmandi (2023), we use the estimate of political stability and absence of violence/terrorism obtained from the World-wide Governance Indicator (WGI) database to measure *PS*. Following Harkati et al. (2020), the economic freedom index released by Heritage Foundation is used as the proxy of *EF*. Similarly, to examine whether ruling party ideology (*RPI*) moderates the *GRDE-NIC* link, the full-sample will be divided into two sub-samples – left- and right-wing governments – for separate estimations using Equation (1). As advised by Cotoc et al. (2021), we use the IDB's Database of Political Institutions (DPI) to gather details about the ruling party ideology.

4. Empirical findings and discussion

4.1. Benchmark estimation and robustness checks

The outcomes of benchmark estimation using Equation (1) are detailed in the first and second columns of Table 2, where Column I excludes the control variable and Column II includes them. The results show that immaterial of the inclusion of control variables, the coefficient obtained by *GRDE* is positive and significant at the 1% level. This indicates that the increase in government R&D expenditure can significantly promote a country's innovation capacity, verifying Hypothesis A. As for the control variables, first, a prosperous economy can not only provide more financial support for innovation activities, but also provide well-anticipated social atmosphere, which are conducive to the prosperity of innovation activities. As such, *EG* is predicted to yield a positive coefficient. Contrarily, *EG* presented a statistically significant negative coefficient, which is unexpected. Consistent with this, Wen et al. (2021) also obtained a significant negative coefficient for GDP per capita as a control variable when examining the impact of bureaucratic quality on innovation. This unexpected result could be related to the 2007 financial crisis. During the 2007–2009 financial crisis, developed economies such as the United States, the European Union, and Japan experienced a slowdown in growth, and even negative growth. This has led these economies to focus mainly on short term rapid economic recovery during this period, and could therefore neglected the investment in innovation that plays a crucial role in the long term economic development. Second, consistent with Ding et al. (2023), *SIC* exhibited a positive and significant coefficient at the 1% level. This indicates that a developed service industry cluster can effectively promote a country's innovation capacity, which could be due to the fact that professional services for innovation (e.g., legal, advisory, and financial) throughout the patent application procedure, can be obtained from a developed service industry cluster (Cai et al., 2021). Third, as Bianchi and Giorcelli (2020) have shown, the popularization of education can promote innovation by cultivating more innovative talents. As such, *Edu* obtained a statistically significant positive coefficient, confirming the positive relationship between education and national innovation output. Fourth, as stated by Cai et al. (2023), commerce between countries fosters the cross-border interchange of novel ideas and technological advancements, in turn stimulating innovation. *IT* is therefore anticipated to produce a statistically significant positive coefficient. Nonetheless, *IT* actually yielded a non-statistically significant coefficient, suggesting that international trade has no discernible effect on national innovation output. This unusual occurrence could be brought about by the fact that a significant portion of global commerce merely entails the traditional resource and product exchange, without fully involving the transfer of knowledge and technology across borders. This reminds countries to pay attention to international trade of knowledge intensive products. Fifth, Parrotta et al. (2014) argued that the expansion of population size is not conducive to the development of innovation, as population growth often accompanies a decrease in labor costs, which can suppress the drive to pursue new technologies. However, a statistically significant positive coefficient obtained by *PD* poses a challenge to Parrotta et al. (2014), which indicates that higher population density can lead to more innovation output. Supporting this, Wen et al. (2021) posited that the increase of population density is conducive to generating more innovative inspiration. Finally, Ding et al. (2023) argued that foreign direct investment enhances innovation in host countries by introducing advanced production technologies and management concepts. Notably, the coefficient of *FDI* is not statistically significant, which indicates that it does not affect the innovation output of the 37 OECD countries. This unexpected finding could be related to the selection of sample countries in this study. Specifically, the 37 countries covered in this study, except Turkey, Mexico and Poland, are almost all developed countries, and their production technologies and management concepts are very advanced. In other words, the marginal benefit of additional foreign direct investment in these already highly developed countries could be minimal, as they already possess cutting-edge technologies and management practices. Supporting this, Zakari et al. (2023) empirically confirmed that FDI can promote the innovation of non OECD countries, but has no significant impact on the innovation of OECD countries.

The estimated results of the robustness checks are presented in Column III to Column X of Table 2, wherein odd columns exclude the control variables and even columns include them. The third and fourth columns present the placebo test output. The coefficients obtained by *GRDE* in the two columns did not achieve significance, confirming that the positive impact of government R&D expenditure on national innovation output as per the benchmark estimation is not a placebo effect; that is, the benchmark estimation results are robust. In addition, after switching the proxy variable of *NIC* from the number of patent applications to GII (Columns V and VI), changing the estimation model from a fixed effect to a system GMM (Columns VII and VIII), and changing the estimation method from a fixed effect model to a Poisson model (Columns IX and X), *GRDE* still obtained statistically significant positive coefficients, which were consistent with the benchmark estimation results. This confirms the robustness of the benchmark estimation results.

4.2. Quantile regression

Table 3 reports the estimation results of using quantile regression to investigate the impact of government R&D expenditure on national innovation capacity. It can be seen from the results that *GRDE* obtained a statistically significant positive coefficient at all of the five quantiles, indicating that regardless of the stage of a country's innovation capacity, an increase in government R&D expenditure can improve the country's innovation capacity. This reiterates the robustness of the benchmark estimation results. Furthermore, it can be observed that both from the perspective of statistical significance and marginal effect, the positive role of government R&D expenditure in a country's innovation capacity shows a process of first increasing and then decreasing with the enhancement of the country's innovation capacity. This phenomenon can be explained by marginal diminishing effect, which believes that the marginal production of variable factors will decline after the production reaches a certain

Table 2. The impact of government R&D expenditure on national innovation capacity (fixed effect model, placebo test, variable replacement, system GMM and poisson model)

	Fixed Effect		Placebo Test		Variable Replacement		System GMM		Poisson Model	
	I	II	III	IV	V	VI	VII	VIII	IX	X
GRDE	0.651*** (12.26)	0.360*** (3.07)	0.019 (0.31)	0.002 (0.13)	0.174*** (7.80)	0.055*** (2.87)	0.279*** (15.17)	0.151** (2.13)	0.577*** (459.95)	0.279*** (63.77)
EG		–0.285* (–1.68)		0.548*** (3.87)		0.753*** (4.77)		0.092 (0.74)		0.586*** (58.55)
SIC		0.807*** (3.05)		1.848* (1.90)		–1.646* (–1.69)		–0.690 (–1.23)		–0.854*** (–17.85)
Edu		0.848*** (3.52)		1.017*** (4.01)		1.036*** (4.10)		–0.278 (–1.27)		–0.199*** (–15.36)
IT		–0.091 (–0.67)		0.099 (0.70)		0.105 (0.75)		–0.268** (–2.57)		–0.080*** (–18.15)
PD		0.699** (2.05)		1.661*** (4.95)		1.562*** (4.63)		0.159 (0.58)		0.644*** (27.91)
FDI		0.170 (1.58)		0.197* (1.72)		0.180 (1.58)		0.082*** (4.37)		0.398*** (33.12)
Constant	2.325*** (5.63)	2.049*** (3.06)	7.538*** (99.97)	–5.530*** (–3.14)	7.477*** (67.16)	–7.810*** (–4.12)	0.367*** (5.99)	–0.576 (–0.30)	4.176*** (17.32)	–1.530*** (–5.70)
Lagged dep. var							0.761*** (24.32)	0.822*** (14.13)		
R-squared	0.213	0.756	–0.057	0.715	0.138	0.701				
country FE	YES	YES	YES	YES	YES	YES				
year FE	YES	YES	YES	YES	YES	YES				
Sargan test							0.216	0.113		
AR(1)							0.000	0.000		
AR(2)							0.328	0.463		

Note: t-statistics are in parenthesis; ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

value. As such, if government R&D expenditure is continuously and equally increased, the increment of innovation output provided by the expenditure will decrease when the innovation output reaches a certain value. Correspondingly, the promoting impact of government R&D expenditure on national innovation capacity shows a trend of first increasing and then decreasing.

These findings reflect the diversity of the impact of government R&D expenditure on national innovation capacity at different stages of innovation capability. In countries with relatively weak innovation capability, governments could increase R&D input to guide and support innovation. However, in countries with strong innovation capability, governments could need to optimize their expenditure strategies and focus more on the accuracy and effectiveness of innovation policies, rather than just increasing the amount of R&D expenditure (Zang et al., 2019).

Table 3. The impact of government R&D expenditure on national innovation capacity (quantile regression)

	QR_10	QR_25	QR_50	QR_75	QR_90
	I	II	III	IV	V
GRDE	0.292** (2.39)	1.001*** (3.65)	0.407*** (3.93)	0.214** (2.41)	0.211** (2.34)
EG	0.569*** (5.42)	0.466*** (4.18)	0.400*** (3.47)	0.332*** (3.22)	–1.070* (–1.72)
SIC	–0.614* (–1.69)	–0.424* (–1.67)	0.785*** (3.19)	0.646* (1.93)	0.939*** (2.69)
Edu	0.605 (1.07)	–0.915 (–1.52)	–0.575 (–1.33)	0.525* (1.82)	1.359*** (2.88)
IT	–1.091*** (–8.40)	–0.770*** (–6.31)	–0.563*** (–4.31)	–0.626 (–0.68)	–0.479 (–0.62)
PD	0.440*** (4.75)	0.224*** (2.73)	0.171*** (4.79)	0.270*** (8.30)	0.629*** (4.88)
FDI	–0.101 (–0.26)	0.128 (0.53)	0.435 (1.03)	0.213 (0.80)	0.035 (0.08)
country FE	YES	YES	YES	YES	YES
year FE	YES	YES	YES	YES	YES

Note: t-statistics are in parenthesis; ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

4.3. Time lag effect

The estimation results of Equations (4) to (8) are presented in Column I to Column V of Table 4, respectively. The statistics confirmed the existence of the time lag effect of government R&D expenditure on national innovation output. Overall, over time, the promoting effect of government R&D expenditure on a country's innovation capacity has gone through a process of first increasing and then decreasing. More specifically, the promoting effect reaches its peak in the third year, then begins to weaken, and becomes insignificant from the ninth year onwards. The existence of the time lag effect is due to the time required to convert government R&D expenditure into innovation output. Initially, it takes time for government R&D expenditure to fully penetrate enterprises and research institutions, thus forming substantial innovation activities. Furthermore, the process from the initiation of innovation activities to the generation of innovation achievements also requires a period of time. Supporting this, Wen et al. (2022) confirmed that innovation activities cannot achieve immediate results because they require long-term investment.

This time lag effect reminds governments to have a long-term vision when formulating innovation policies, and deeply understand and accept the deferred effect brought by innovation investment. By more comprehensively and systematically considering the time lag during innovation activities, governments could more effectively guide and support innovation activities, and make it generate a lasting impact on the improvement of national innovation capacity.

Table 4. The time lag effect of government R&D expenditure on national innovation capacity

	Lag1	Lag3	Lag5	Lag7	Lag9
	I	II	III	IV	V
GRDE	0.411*** (5.32)	0.722*** (2.60)	0.499** (2.50)	0.203* (1.82)	0.102 (0.59)
EG	–0.002 (–0.01)	0.297 (1.25)	0.963*** (3.65)	1.589*** (5.40)	1.534*** (4.71)
SIC	0.265** (2.05)	0.163* (1.72)	0.876** (2.27)	–0.674 (–0.44)	0.064 (0.03)
Edu	0.963*** (3.24)	1.617*** (5.08)	1.510*** (4.91)	0.956*** (2.87)	0.623* (1.73)
IT	–0.110 (–0.59)	0.315* (1.67)	0.745*** (3.49)	0.648*** (3.08)	0.393* (1.70)
PD	1.431*** (3.34)	1.454*** (2.84)	1.370** (2.50)	1.284** (2.06)	2.042*** (2.84)
FDI	–0.102 (–0.54)	–0.227 (–1.21)	–0.068 (–0.40)	–0.099 (–0.88)	–0.004 (–0.03)
Constant	–3.170*** (–4.36)	–5.115* (–1.85)	–10.456*** (–3.38)	–15.494*** (–4.52)	–19.081*** (–5.07)
R-squared	0.749	0.737	0.731	0.709	0.617
country FE	YES	YES	YES	YES	YES
year FE	YES	YES	YES	YES	YES

Note: t-statistics are in parenthesis; ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

4.4. Mechanism tests

Table 5 depicts the results of the mechanism tests by estimating Equations (9) and (10). The estimation results of Equation (9) are shown in Column I and Column II. Consistent with Ding et al. (2023), *BC* in Column I yielded a positive coefficient with statistical significance, which indicates that the expansion of bank credit scale is a catalyst for prosperous innovation activities. Likewise, in Column II, *GRDE*BC* also produced a positive and significant coefficient, implying that government R&D expenditure can improve national innovation capacity by alleviating credit constraints. This finding emphasizes the synergistic effect of government R&D expenditure and bank credit scale in promoting innovation. Specifically, government R&D expenditure can play a guiding role in alleviating financing difficulties of innovators, and the expansion of bank credit scale can provide broader financial support for innovation activities, becoming a catalyst for the vigorous development of innovation activities. This synergy enables innovators to carry out innovation activities more flexibly and continuously while obtaining sufficient funds, so as to promote the improvement of national innovation capacity. This also means that governments and financial institutions need to coordinate and cooperate in formulating policies to create a more conducive environment for innovation and provide comprehensive support for innovation activities.

Table 5. Mechanism tests of the effect of government R&D expenditure on national innovation capacity

	Bank credit		R&D intensity	
	I	II	III	IV
GRDE		0.121** (2.45)		0.327*** (3.20)
EG	0.157*** (2.70)	0.301*** (2.84)	0.170 (1.13)	–0.343** (–2.10)
SIC	–1.341 (–0.87)	–1.186 (–0.81)	–1.911** (–2.12)	–0.054*** (–3.42)
Edu	0.802 (1.21)	0.029 (0.05)	1.000*** (4.06)	0.504** (2.10)
IT	1.042*** (4.09)	1.345*** (2.74)	–0.346*** (–2.58)	–0.139 (–1.06)
PD	0.972** (2.48)	0.464*** (3.02)	0.883*** (5.23)	1.252*** (3.69)
FDI	–1.643 (–1.11)	–1.834 (–1.37)	0.299*** (2.62)	0.196* (1.87)
BC	1.150*** (3.90)	2.086*** (4.53)		
GRDE*BC		0.010*** (3.29)		
RDI			0.724*** (7.41)	0.995*** (6.28)
GRDE*RDI				–0.005*** (–5.72)
Constant	1.982 (0.43)	–2.746 (–0.50)	–1.630** (–2.19)	–2.657** (–2.33)
R-squared	0.717	0.760	0.742	0.816
country FE	YES	YES	YES	YES
year FE	YES	YES	YES	YES

Note: t-statistics are in parenthesis; ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

Columns III and IV present the estimation results of Equation (10). *RDI* in Column III has a positive and statistically significant coefficient, showing that the R&D intensity of non-governmental sectors can improve national innovation capacity. Meanwhile, the coefficient of *GRDE*RDI* in Column IV was significant but negative, which indicates that government R&D expenditure can negatively influence national innovation capacity by inhibiting the R&D intensity of non-governmental sectors. This puzzling result actually makes sense. Although the increase of government R&D investment can guide non-governmental sectors to pay more attention to the field of technological innovation and thus promote innovation, at the same time, the increase of government R&D expenditure can also lead to greater demand for innovation factors, which can raise the price of innovation factors. This could make non-governmental sectors reduce their investment in R&D when facing higher innovation factor costs, and thereby hinder innovation. Consequently, while supporting the funding of innovation activities, governments could also need to pay attention to the regulation of innovation factor price.

4.5. Moderating effects

Table 6 details the estimated output of five moderating relationships. According to the median value of the moderating variable called *GE* (similarly hereinafter), the full-sample was divided into two sub-samples, that is countries with relatively low government efficiency and countries with relatively high government efficiency. Subsequently, both sub-samples were separately estimated using Equation (1), the results of which are reported in Columns I and II, respectively. The findings suggest that although *GRDE* in both columns produced significant positive coefficients, the coefficient in Column II is larger than that in Column I. This indicates that with the improvement of government efficiency, the promotion effect of government R&D expenditure on national innovation capacity is intensified, that is, government efficiency exerts a positive moderating effect on the *GRDE-NIC* link. The key role of government efficiency in the link between government R&D expenditure and national innovation capacity can be explained. As Ding et al. (2022) stated, efficient governments tend to be more executive. As such, an efficient government can often promote the optimal allocation of its R&D input more quickly and efficiently (Wen et al., 2021). On the contrary, an inefficient government is often associated with corruption, which has a destructive impact on the innovation ecology (Wen et al., 2022).

Table 6. Moderating effects of the impact of government R&D expenditure on national innovation capacity

	Government efficiency		Democracy		Ruling party ideology		Political stability		Economic freedom	
	I	II	III	IV	V	VI	VII	VIII	IX	X
GRDE	0.222*** (3.73)	0.534*** (7.34)	–0.079 (–0.57)	0.810*** (9.16)	0.329 (1.33)	0.287*** (2.94)	0.356*** (3.50)	0.543*** (5.97)	0.217*** (3.52)	0.505*** (7.67)
EG	0.003 (0.01)	–0.285 (–0.24)	–0.608* (–1.96)	–0.428* (–1.79)	0.087 (0.16)	0.262 (1.16)	0.231 (0.99)	0.958*** (8.76)	–0.067 (–0.27)	–0.348 (–1.34)
SIC	1.188 (0.82)	0.667*** (3.62)	1.014** (2.53)	0.604*** (4.30)	2.517 (1.31)	1.753*** (2.90)	0.259*** (3.80)	1.338*** (3.73)	1.542 (1.24)	0.960*** (4.38)
Edu	2.475*** (4.85)	–0.221 (–1.13)	0.933 (1.35)	0.397 (1.56)	0.010 (0.02)	1.646*** (5.15)	1.673*** (3.73)	0.289 (1.24)	2.118*** (5.42)	0.190 (0.64)
IT	–0.244 (–1.02)	0.425*** (3.36)	0.329 (1.10)	–0.236 (–1.45)	–0.700* (–1.92)	0.348 (1.50)	–0.415* (–1.76)	1.012*** (6.35)	–0.205 (–0.83)	–0.295* (–1.78)
PD	1.921*** (3.52)	1.071*** (2.69)	1.103*** (2.98)	0.239*** (3.48)	4.769*** (4.61)	0.504 (1.23)	2.298*** (4.56)	3.058*** (6.68)	0.303 (0.59)	1.330** (2.51)
FDI	–0.056 (–0.22)	0.224*** (2.72)	–0.037 (–0.20)	0.223* (1.92)	0.001 (0.00)	–0.015 (–0.12)	0.311 (1.04)	0.087 (0.94)	–0.015 (–0.07)	0.225* (1.88)
Constant	–8.754*** (–2.91)	19.492*** (9.52)	–0.303 (–0.08)	4.588* (1.79)	21.966*** (5.05)	0.389 (0.20)	–7.370*** (–2.92)	30.079*** (10.54)	–0.073 (–0.03)	0.679 (0.25)
R-squared	0.681	0.792	0.419	0.719	0.512	0.523	0.736	0.741	0.412	0.673
country FE	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
year FE	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES

Note: t-statistics are in parenthesis; ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

The third and fourth columns of Table 6 present the estimation findings of two sub-samples of relatively low and relatively high democratic countries, respectively. *GRDE* in Column III failed to show a significant coefficient, while the coefficient of *GRDE* in Column IV was positive and statistically significant. This suggests that government R&D expenditure can notably enhance the innovation capacity of countries with relatively high levels of democracy, while it does not have a similar impact on the innovation capacity of countries with relatively low levels of democracy. In other words, democracy has a positive moderating effect on the *GRDE-NIC* link, which can be explained. A higher degree of democratic system is often accompanied by more open information dissemination, more effective institutional supervision, and broader public participation. These characteristics enable government R&D expenditure to be more effectively translated into improved innovation capacity, as higher transparency and participation can increase the quality and quantity of innovation activities (Wang et al., 2021). On the contrary, countries with relatively low levels of democracy could be constrained by information blockades, inadequate systems, or a lack of widespread participation, which could weaken the positive impact of government R&D expenditure on innovation. This finding emphasizes the crucial role of institutional environment in the relationship between government R&D expenditure and national innovation capacity.

Column V and Column VI present the estimation results of two sub-samples – left-wing and right-wing governments – respectively. It can be observed that *GRDE* in Column V obtained a coefficient which is not statistically significant, while *GRDE* in Column VI produced a positive coefficient with statistical significance. This indicates that when left-wing parties are in power, government R&D expenditure cannot significantly influence national innovation capacity. However, when right-wing parties are in power, government R&D expenditure can enhance national innovation capacity. The difference in the *GRDE-NIC* link caused by the governance of different political parties confirms the moderating effect of ruling party ideology, which is logical. According to Ding et al.(2022), ruling party ideology can influence a government's priorities. Specifically, when left-wing parties are in power, governments could pay more attention to issues such as social equity and labor rights (Hevia-Pacheco & Vergara-Camus, 2013), resulting in relatively less resources being invested in the capital-intensive innovation area. Nevertheless, right-wing governments are more concerned about capital-intensive industries (Ding et al., 2022), and therefore more inclined to promote technological innovation and improve national innovation capacity by increasing R&D spending. In summary, the difference in the *GRDE-NIC* link between left-wing and right-wing governments highlights the importance of political factors in the effectiveness of innovation investment.

The seventh and eight columns report the estimation findings of two sub-samples of countries with relatively low political stability and countries with relatively high political stability, respectively. According to the result, although the coefficients of *GRDE* in both columns are significant and positive, the coefficient in Column VIII is larger than that in Column VII. This indicates that with the improvement of political stability, the positive influence of government R&D expenditure on national innovation capacity is stronger, meaning that political stability positively moderates the *GRDE-NIC* link. This moderating effect can be explained by the positive role played by political stability in the innovation environment. Specifically, with the improvement of political stability, national innovation environment tend to be more stable and predictable (Ege & Ege, 2019). The stable environment is crucial for the successful conversion of government R&D expenditure into innovation output, as this stability can provide a reliable foundation for R&D activities and help ensure the coherence and smooth progress of the entire innovation process.

Finally, Column IX and Column X present the output of the estimation of two sub-samples of countries with relatively low economic freedom and countries with relatively high economic freedom, respectively. It can be found that *GRDE* in both columns produced statistically significant positive coefficients, and the coefficient in Column X is greater than that in Column IX. This indicates that with the increase of economic freedom, the positive effect of government R&D expenditure on national innovation capacity tends to strengthen, that is, there is a positive moderating effect of economic freedom on the *GRDE-NIC* link. This positive moderating effect can be explained. Higher economic freedom means less market regulation and more corporate autonomy (Asteriou et al., 2021). In this market environment, innovators are more likely to flexibly utilize the R&D funds from governments for innovation activities based on actual market demands and changes. In other words, government R&D expenditure is more likely to match market demands in a market environment with higher freedom, thereby generating substantial innovation output required by the market.

5. Conclusions

5.1. Summary of findings and policy implications

The objective of this paper was to examine the influence of government R&D expenditure on national innovation capacity. First, we used a fixed effect model as the benchmark estimation method to empirically analyze panel data covering 37 OECD countries from 2000 to 2021. The estimation results reveal that government R&D expenditure has a substantial positive effect on a country's innovation capacity. Moreover, this positive impact withstands scrutiny through various robustness checks. Then, we used quantile regression to explore the variability of this impact across different stages of a country's innovation capacity. We found that as national innovation capacity strengthens, the stimulative effect of government R&D expenditure on national innovation capacity exhibits a pattern of initially increasing and subsequently decreasing. Third, we introduced lags of *GRDE* for periods 1, 3, 5, 7, and 9, and regressed them with the dependent variable to investigate the prolonged influence of government R&D expenditure on national innovation capacity. The findings affirmed the existence of a time lag effect of government R&D expenditure on national innovation capacity. Fourth, we employed two fixed effect models with interaction terms to examine the mechanisms of government R&D expenditure's influence on national innovation capacity. The findings suggest that, on the one hand, government R&D expenditure can enhance a country's innovation capacity by facilitating increased bank credit; On the other hand, government R&D expenditure can also inhibit a country's innovation capacity by dampening the R&D intensity of non-governmental sectors. Finally, we divided the full-sample and conducted heterogeneity analysis, which confirmed the moderating roles of government efficiency, democracy, ruling party ideology, political stability, and economic freedom on the *GRDE-NIC* link. Specifically, when a country has higher government efficiency, greater democracy, political stability, economic freedom, and is under the governance of a right-wing political party, the positive effect of government R&D expenditure on national innovation capacity tends to be more pronounced.

This study complements the previous literature from the following points. First, we placed the *GRDE-NIC* link under the theory of marginal diminishing effect, confirming the diversity of this link at different stages of innovation capacity. This not only provides important insights for a deeper understanding of the role of government intervention in the innovation process, but also enriches the application of marginal diminishing effect theory. Additionally, the examination of the time lag effect, mechanisms, and moderating effects in the *GRDE-NIC* link distinguishes our study from previous research, expanding the field's investigative scope and providing valuable insights for governments seeking to promote innovation. First, recognizing the positive influence of government R&D expenditure on national innovation capacity, policymakers could enhance the proportion of fiscal expenditure allocated to support research and development. This increased funding can drive innovation, support the development of new technologies, and ensure that countries remain competitive in the global market. Alongside direct government expenditure, offering grants and subsidies for private sectors' R&D are crucial. Supporting human capital development through education and training, promoting international R&D collaborations, and establishing mechanisms to monitor and evaluate R&D programme can further enhance national innovation capacity. Second, taking into account the observation that, with the strengthening of national innovation capacity, the positive effect of government R&D expenditure follows a trend of initial increase followed by a decrease, governments, when formulating R&D investment strategies, could precisely adjust fiscal support at different stages to ensure that R&D input maximizes value creation throughout the entire innovation process. In particular, governments can actively encourage high-risk projects and basic research in the early phases of innovation to set the groundwork for later technological advances; in the later stages, they can encourage applied research and market promotion to hasten the industrialization of innovative outcomes. Third, considering the time lag effect of government R&D expenditure on national innovation capacity, policymakers should avoid being short-sighted, and be more patient with innovation activities, providing sustained and stable fiscal support for innovation activities. The innovation process often requires years or even decades of accumulation, and governments should ensure the long-term sustainability of R&D funding, avoiding frequent budget adjustments that may interrupt or terminate innovation projects prematurely. At the same time, specialized evaluation agencies should be established to strengthen the mid-to-long-term evaluation of innovation projects, formulate multi-year R&D plans, specify R&D goals and priority areas for the coming years, and attract more enterprises and research institutions to participate. Fourth, considering that more government R&D expenditure can inhibit national innovation capacity by suppressing the R&D intensity of non-governmental sectors, policymakers, when increasing government R&D expenditure, need to carefully evaluate its potential negative impact on the innovation vitality of private sectors and consider implementing complementary incentives to avoid harming the innovation enthusiasm of private sectors. To balance public and private R&D spending, governments could implement a mixed funding model, acting as a catalyst by co-funding initiatives with private sectors. This reduces risks and costs for private organizations, boosting investment in innovation and thus fostering economic innovation. Finally, considering the roles of government efficiency, democracy, ruling party ideology, political stability, and economic freedom in moderating the *GRDE-NIC* link, governments should tailor their innovation investment strategies to local conditions, conducting in-depth research on the unique political and economic background of countries, and formulating more precise and targeted innovation policies.

5.2. Limitations of the study

Despite our diligent efforts to carry out this empirical research with precision, there remain certain limitations that currently remain unresolved. First, limited by the availability of data, this study only included 37 OECD countries. If more *GRDE* data from additional countries are released in the future, researchers can extend this study to obtain more universally applicable conclusions. Additionally, while this study delves into the mechanisms of the *GRDE-NIC* link through the lenses of bank credit scale and the R&D intensity of non-governmental sectors, there might be additional mechanisms yet to be uncovered, providing opportunities for further investigation.

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APPENDIX

List A1. The country list

Australia, Austria, Belgium, Canada, Chile, Colombia, Czechia, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Israel, Italy, Japan, Korea, Latvia, Lithuania, Luxembourg, Mexico, Netherlands, New Zealand, Norway, Poland, Portugal, Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Türkiye, United Kingdom, United States

Table A1. Correlation matrix

	GRDE	EG	SIC	Edu	IT	PD	FDI	VIF	1/VIF
GRDE	1							2.48	0.403689
EG	0.3601	1						2.46	0.40682
SIC	0.267	0.5645	1					2.03	0.493428
Edu	0.0272	0.4392	0.1458	1				1.68	0.59594
IT	–0.4384	0.1407	0.064	0.0324	1			1.56	0.639383
PD	0.3831	–0.0089	0.1674	–0.2364	0.1491	1		1.35	0.742989
FDI	–0.104	0.0587	0.0813	0.0132	0.3353	0.0602	1	1.14	0.880158