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Do government subsidies promote green R&D efficiency? Empirical evidence from China

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I hereby declare that this dissertation is my original work and it has been written by me in its entirety. I have duly acknowledged all the sources of information which have been used in this dissertation.

This dissertation has also not been submitted for any degree in any university previously.

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Abstract

How to evaluate the effects of government policy on encouraging innovations? Existing studies strongly argue to reduce subsidies compared to indirect policy tools, such as tax rebate. However, direct government grants are popular and keep gaining momentum in China. Such a discrepancy between academic research and common practice is interesting and calls for further investigations. In the meantime, is there any difference for this issue if considering green attributes? In this article, we use data from Chinese A-share listed companies to study the effect of government subsidies on R&D activities, with a special focus on comparing green and non-green inventions. Our result shows that green attributes of innovation bring in heterogeneity in R&D intentions, market competition effects, and government subsidy incentives. Specifically, first, companies are less willing to pursue green innovations due to positive environmental externalities. Second, while market competition substantially stimulates non-green innovations, it does not have a positive effect on the efficiency of green R&D activity, or, even worse, inhibits it. Third, government subsidies are more effective in spurring green R&Ds, compared to non-green ones. A closer look at the above results demonstrates that official

green performance evaluation in China may play an important role. Green innovations are subject to more monitoring efforts by the government, which dissuades R&D manipulation by firms. Our study emphasizes the necessity of government policies as well as their combination with market competition. Specifically, we recommend the adoption of generous and comprehensive subsidy policy with rigorous supervision for green ones. We strongly suggest future research consider the possible heterogeneity of green attributes in R&D to avoid omitted variable bias.

Table of Contents

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1. Introduction

Global warming and extreme weather conditions have drawn a lot of public attention around the world. According to the Book “Guidebook to Carbon Neutrality in China”, innovation will play a vital role for the achievement of green society. In the meantime, green innovations have an important impact on business operations, resource utilization, public lives, and national development. Previous research has demonstrated that exogenous intervention is necessary for innovation incentives. For instance, Arrow (1962) discussed a possible failure of market competition to achieve an optimal resource allocation for inventions. In the case of green innovation, Porter and Linde (1995) first proposed Porter-hypothesis. Following that, existing studies mainly investigate two factors that drive green innovations, which are environmental regulation (Li and Xiao, 2020; Tao et al., 2021; Liu and Xiao, 2022) and green premium (Liu and Xie, 2016; Fang and Na 2020).

However, the role of government subsidies in green R&D incentives is rarely discussed in such emerging economies as China, where governments often lack a good understanding of technology and firms may be motivated to take advantage of policy benefits. This information asymmetry induces adverse selection, such as rent-seeking and R&D manipulation, and therefore harms the effectiveness of the policy (Zhang et al., 2016; Li and Zheng, 2016). In particular, a large body of literature argues that indirect policies, such as tax breaks, should be increased, while gradually reducing the direct ones (Gill, 2007; An et al., 2009; Li and Zheng, 2016; Zhang and Zheng, 2018; Zhang, 2021). In contrast, the direct subsidies from the Chinese government increased substantially after 2007 and have remained high since 2017. So, it is worth investigating why the actual scale of subsidies contradicts the suggestion from academic research. This paper discusses the discrepancy from a lens of green innovation. We investigate whether green and non-green innovations are different in R&D intentions, market competition effects, and government subsidy incentives.

Our data sample comes from the CSMAR and CCER databases, including all A-share listed companies in China, ranging from 2007 to 2021. Following the prior research method, we take patent information as the dependent variable, government subsidies received by the company as independent variable, and an R&D efficiency equation is estimated to examine the effect of government grants on invention incentives.

Our empirical study finds that companies are less willing to pursue green innovations than non-green ones. A reasonable explanation is that the environmental externalities of green innovations (Rennings, 1998) do not necessarily bring economic benefits to the firm. In specific, under the creative destruction channel (Schumpeter, 1943), market competition (Aghion et al., 2005; Zhang and Zheng, 2018) may have little impact on green innovation. A basic premise for the channel is that innovative products have to be profitable in the market. Since the current market premium is not enough to compensate for all the environmental externalities of green innovations, creative destruction theory could be invalid. Our empirical study supports the above arguments. It shows that market competition significantly promotes the efficiency of non-green innovations. In contrast, it does not have a positive effect on the efficiency of green R&D activity, or, even worse, inhibits it. Surprisingly, our result implies a positive relationship between monopoly and the efficiency of green innovation. Empirically, stronger market power is more likely to attract social scrutiny and face higher risk of public protest. In light of this, companies may pay more attention to factors such as reputation and environmental regulation. They tend to hedge these risks by increasing ESG investment. Notably, green innovation is an important part of these efforts.

To address the question why academic research diverges from practice on government subsidies, we discuss the different effect of subsidies on green and non-green R&D intentions. Our research shows that government grants enhance the R&D efficiency of green innovations, but have limited impact on that of non-green ones. This contradicts the popular opinion that government direct subsidies are inefficient in promoting R&D activities (Zhang and Zheng, 2018; Li and Zheng, 2016). We propose a novel mechanism to interpret our new findings. It should be emphasized that China's economic growth comes from a special incentive mechanism known as political tournaments (Li and Zhou, 2005; Qiao, 2013; Yang and Zheng, 2013; Luo et al., 2015; Chen and Zhu, 2018). It turns out that incentives from political promotions do affect company operations (Zhang et al., 2020; Pang, 2021). In this regard, as China places increasing emphasis on sustainable development, the government's influence on green innovations cannot be ignored, the Green GDP may be more essential to evaluate the officials' performance instead of traditional GDP. Since green innovations have the potential to drive sustainable economic development and also meets the political requirements of ecological civilization construction, they have gained more and more attention from the Chinese government.

We believe that the political performance appraisal mechanism in China helps to internalize the environmental externalities of green innovations. In specific, government officials conduct stricter supervision over green innovation in order to gain their political promotion. We infer from existing research that the government may have more incentives and capabilities to limit rent-seeking and R&D manipulation. For example, the regulatory review determines the quality of corporate innovations (Zhang et al., 2016). The policy performance indirectly affects corporate behaviors (Pang et al., 2021). To illustrate that the government conduct stricter oversight of green R&D activities, we identify the companies with R&D manipulation motives. Borrows from Yang et al. (2017) and Chen et al. (2021), we divide the sample by the ratio of R&D expenditure to sales revenue. Our subsample regressions show that subsidies have no significant impact on non-green innovations for companies with motives of R&D manipulation, but can significantly improve their green innovation efficiency. This demonstrates that R&D manipulation in green innovations is prohibited. In this regard, government's efforts in green R&D incentives do work.

Since green innovations differ significantly from non-green ones with respect to R&D intentions, competitive market drivers, and government subsidy incentives, heterogeneity should be taken seriously. In this regard, we further explore whether they also differ between SMEs and large ones, as well as between low-polluting and high-polluting firms. Specifically, we look into two plausible channels through which government subsidies affect innovations, namely by alleviating financing constraints and in conjunction with environmental penalties on high-polluting firms. Generally, SMEs face severer financing constraints (Palangkaraya, 2012; Zhang et al., 2017), which is the main impediment to innovations (Brown et al., 2009; Hall and Lerner, 2010; Hall and Harhoff, 2012). In this regard, the incentive effect depends on the extent to which the policy plays a role in alleviating financing constraints. If this is true, the role of subsidies in promoting R&D activities in SMEs will be stronger than that in large ones. Our empirical results support this conjecture in non-green innovations and suggest that SMEs should be the primary beneficiaries of subsidies. In contrast, with regard to green innovations, for both SMEs and large companies, government subsidies have a significant impact on improving R&D efficiency, and the magnitude of the impact is quite similar between the two groups. This further proves that alleviating financing constraints is not the only channel for subsidies to promote green innovations. In addition, our study found that government subsidies significantly promote green innovations for both low- and high-polluting firms, but have limited effects on non-green innovations. This further excludes the impact of penalties in "carrot-and-stick policies" on green R&D incentives.

Overall, this paper answers three main questions. First, what drives the discrepancy between academic research and common practice on innovation policies? Specifically, previous studies strongly argued to reduce direct subsidies, but government direct grants are popular around the world and still gaining momentum. Second, whether green and non-green innovations are different in R&D intentions, market competition effects, and government subsidy incentives? Third, does green performance evaluation in China help understand the potential incentives of government subsidy? The findings indicate that, although subsidies have a limited impact on non-green innovations, they do significantly improve the efficiency of green ones. The environmental externalities of green R&D activities produce significant heterogeneity in R&D activities.

The policy implications of this article are as follows. First, the performance assessment-oriented mechanism of green innovations can be improved, and the government can play a more important role as "gatekeeper" and "goalkeeper" to deter rent-seeking or R&D manipulation behaviors, thereby accelerating sustainable development with green inventions. The government should pay more attention to a combination of policy and market competition in improving the S&T innovation system and accelerating the implementation of the innovation-driven development strategy. From the perspective of providing incentives, it is necessary to balance the mixed effects of direct and indirect subsidies, and to promote the cooperation between the government, industry and academia. Second, direct subsidies should not be simply viewed as invalid. The government should maintain a considerable involvement in green innovations. This is because environmental externalities of green innovations are not adequately priced in, and companies lack incentives to engage in green innovations. Therefore, the government can play an important role in monitoring, supervising, and penalizing pollution emissions, as well as providing compensation for R&D activities through subsidies. Third, the size of companies should be taken into consideration in making policies. For non-green innovations, government grants should focus on supporting SMEs in alleviating their financing constraints. While for green innovations, more comprehensive subsidy policies that cover all kinds of companies should be adopted. It is particularly valuable to strengthen monitoring in order to improve the overall innovation quality. At last, Aghion (2015) suggests that future innovation-related academic research should address the importance of heterogeneity. Similarly, our study shows that the research in this regard should pay attention to the potential heterogeneity of R&D activities, such as green versus non-green ones, otherwise the researchers may bring in omitted variable bias.

The remainder of this paper is organized as follows. Chapter 2 reviews relevant literature and the policy before formulating research hypotheses. Chapter 3 presents the research design and the data used in this paper. Chapter 4 reports regression results, followed by Chapter 5, which provides further discussions, such as heterogeneity studies and robustness tests. Chapter 6 draws conclusions.

2. Literature Review, Political Policy Background, and Hypothesis

2.1 Literature Review

This paper is related to three strands of literature. First, our research sheds light on the literature on green innovation incentives inspired by Porter and Linde (1995). One of the mechanisms is the government's environmental regulations, such as environmental protection tax, pollution control fees, pollutant discharge standards, and green technology R&D subsidies, etc. (Popp, 2002, 2006; Lovely and Popp, 2011; Jing and Zhang, 2014; Qi et al., 2018; Li and Xiao, 2020; Tao et al., 2021; Liu and Xiao, 2022). The other is the green reward from the market, such as the profits from the trading of carbon emission quota and the green equity premium. (Tu and Chen, 2015; Calel and Dechezleprêtre, 2016; Liu and Xie, 2016; Fang and Na, 2020). For one thing, the existing literature about green R&D activities in China mainly focuses on taxes and fees but lacks relevant discussions on subsidy incentives. And for another, there are insufficient comparisons between the impact of innovation policies and market competition.

Previous studies hold different views on whether innovation subsidy policies can promote R&D expenditures and patent grants. In specific, 63% of the empirical literature holds a positive attitude, while 33% of the studies believe that government subsidies have no impact on corporate R&D expenditure and inventions, or even crowd out existing ones (Zúniga-Vicente et al., 2014). In this regard, Aghion (2015) pointed out that the discussion on heterogeneity is more important than arguing "yes" or "no". Subsequent studies have found that government monitoring is of great significance (Zhang and Zheng, 2018). Specifically, the government plays a key role as the last "gatekeeper" and "goalkeeper" for the quality of corporate innovations (Zhang et al., 2016). A lack of government monitoring may encourage companies to disguise innovations in search of subsidies. For example, these firms tend to undertake utility- and design-type innovations with lower technologies rather than substantial innovations. In this regard, the number of invention-type patents is also used as an indicator of corporate innovation intensity (Tong et al., 2014; Li and Zheng, 2016). In terms of government supervision, however, few studies have focused on whether the government adopts different attitudes toward green and non-green innovations.

When discussing China's economic development, there is an interesting and unique mechanism known as the “political turnover”, or the “political promotion tournament”, which describes the phenomenon that the likelihood of promotion increases with economic performance (Li and Zhou, 2005; Qiao, 2013; Yang and Zheng, 2013; Luo et al., 2015; Chen and Zhu, 2018). In this respect, political performance appraisal is inextricably linked with corporate social responsibility. Pang et al. (2021) found that political promotion incentives can effectively promote the pollution reduction of companies within the jurisdiction. Moreover, this impact grows stronger for young officials who are highly likely to be motivated to get promotions. It is worth noticing the potential effort of officials when their promotion chances are linked to the construction of ecological civilization. Through empirical tests, Zhang et al. (2020) showed that China’s official assessment mechanism has undergone a systematic change around 2013. After that, the promotion depends not only on the traditional GDP growth rate, but also on environmental protection. This raises an intriguing question: is there a stronger incentive for the government to monitor green innovations? However, there is currently a paucity of relevant empirical literature that investigates this issue.

To sum up, existing research has shortcomings in three aspects. First, green innovations have not been sufficiently studied in the literature regarding their impacts on R&D efficiency. Compared with non-green innovations, green ones have a positive environmental externality (Rennings, 1998) and are more requested by officials (Zhang et al., 2020), so green attributes may produce different policy effects. Second, there is little comparison between the mechanisms of government subsidies and market competition in stimulating innovations, as well as the question of which one is more effective. Third, existing literature lacks consideration of how the political tournament stimulates monitoring efforts on green innovations in China.

2.2 Policy Background

As Chinese President Xi Jinping announced that China aims to have CO2 emissions peak before 2030 and achieve carbon neutrality before 2060, the whole country has taken quick action to explore the path to materialize it.

Actually, since the 17th National Congress of the Communist Party of China in 2007, the construction of ecological civilization has become more and more prominent in government work. Specifically, the report of the 17th National Congress clearly put forward the idea of ecological civilization construction, including the classification of its principles, concepts and goals. This is an unprecedented new requirement for the goal of building a well-off society in an all-round way, emphasizing the firm establishment of the ecological civilization concept. Afterward, the report to the 18th National Congress put the construction of ecological civilization in a prominent position and incorporated it into the general layout of the “Five in One” cause of socialism with Chinese characteristics. In addition, “Green” and “Innovation” were also included in the country’s Five Major Development Visions. The report of the 19th National Congress proposed to “accelerate the reform of the ecological civilization system and build a beautiful China". Once again, it emphasized "building a market-oriented green technology innovation system, developing green finance, and strengthening energy-saving and environmental protection, clean production, and clean energy industries." The long-term goal of socialist modernization is to fundamentally improve the ecological environment and basically realize the goal of building a beautiful China.

From another perspective, there is huge uncertainty after covid-19 period and to be green is one of the few areas that the world can work together as we live on the same earth. To achieve green development is not only domestic target but also with global expectation.

How to achieve the green target? According to the Book "Guidebook to Carbon Neutrality in China", to achieve carbon neutrality from global experience, there are three key factors: carbon pricing, technological advancement and social governance. For carbon pricing, through internalizing the carbon cost to push the corporates reduce the carbon emission, it's easy to do, but cannot solve the issues from the fundamental. While social governance is a long way to go, the green innovation becomes an important pillar of the government objective.

However, when talking about the technological innovation promotion mechanism in China, we cannot ignore the unique nationwide innovation system. As innovation always needs huge capital investment in the early period and faces big uncertainty and risks, the government policy support will be very important, such as through tax rebate and direct subsidies to solve the financial problem of innovation firms. These policies are quite helpful to promote corporate innovation in the past. The development of new-energy related industry is a good example. Now China owns the most advanced technology in solar power and new-energy vehicles industries. Hence, we would like to focus on the government policy effects on green R&D, especially from the subsidies perspective.

2.3 Research Hypothesis

A large number of existing studies have found that direct financial subsidies failed to efficiently stimulate innovations. In this regard, they suggested increasing indirect subsidies and general industrial policies, such as tax reduction for high-tech enterprises (the InnoCom Program henceforth), talent introduction, etc., while reducing direct subsidies (Gill, 2007; An et al., 2009; Li and Zheng, 2016; Zhang and Zheng, 2018; Zhang, 2021). However, Figure 2.1 shows that the size of both indirect and direct government subsidies in China has increased steadily since 2007, especially from 2014 to 2021, when direct subsidies remained at a high level. This brings up a puzzle. The existing studies strongly advocate reducing R&D subsidies from the government. In contrast, these direct grants from the government keep gaining momentum. Notably, in 2013, the political performance assessment underwent a systematic change towards green and sustainable development (Zhang et al., 2020), and at the meantime, the size of direct subsidies also rose sharply. This offers a new lens for explaining the discrepancy between academic advice and policy practice.

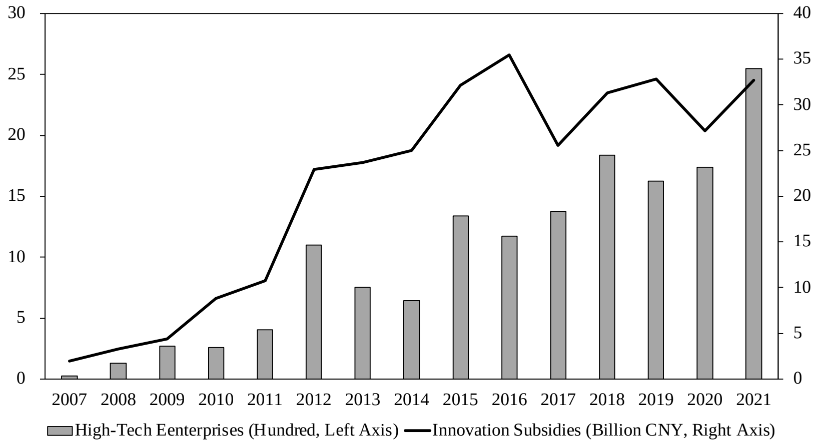

Figure 2.1: Trends in the Intensity of Government Innovation Policies

An important question is whether green attributes lead to different R&D intensities. Although green innovation is of great significance to combating global warming and achieving sustainable development, it lacks sufficient incentives. Arrow (1962) believed that due to spill-over effects and externalities, it would be hard to optimize R&D investment by solely relying on the market competition. Rennings (1998) pointed out that in addition to normal external benefits, products and services developed in the process of ecological innovation will generate additional external benefits, so there is a double externality. It implies that the willingness of companies to pursue green inventions will be further impeded. In addition, Aghion (2015) emphasized that researchers should pay attention to heterogenous R&D activities when discussing innovation policy incentives. In this regard, attention should be paid to the R&D heterogeneity which may arise from green attributes. To begin with, we put forward the following hypothesis.

Hypothesis 1: Companies are less willing to conduct R&D on green innovations than for non-green inventions. Specifically, when corporate R&D investment increases, the increment of green innovations is smaller than that of non-green ones.

Market competition provides a lens for discussing why companies may have different R&D intentions in green and non-green innovations. Intuitively, the intensity of market competition indeed affects corporate motivation to pursue innovations (Aghion et al., 2005; Zhang and Zheng, 2018). Yan and Gong (2009) distinguished between two mechanisms so-called vertical and horizontal patterns in Schumpeter's growth theory. In the vertical pattern, a company will crowd out its rivals and make monopoly profits if it succeeds in R&D activities. This is known as the creative destruction, by which market competition forces companies to constantly innovate. In the horizontal pattern, however, inventions increase the variety of production inputs, rather than crowd out existing ones. In this case, market competition has a relatively small contribution. Although most innovation process follow the creative destruction (Acemoglu, 2009), the green ones may have a different story. There are insufficient monopolistic profits for companies to take from green innovations because green products induce the environmental externality (Rennings, 1998) and their pricing mechanism is not yet fully developed in China. Green inventions thus have less power to crowd out traditional technologies and products. In this regard, the creative destruction theory is invalidated. Based on this argument, the following hypothesis is proposed.

Hypothesis 2.a: Market competition promotes R&D efficiency of non-green innovations, but has limited impacts on green ones. In specific, when the market competition is fierce, companies are more willing to engage in non-green R&D activities while less willing to engage in green ones.

To address the question why academic research diverges from practice on government subsidies, we discuss the different effect of subsidies on green and non-green R&D intentions. From a lens of economic growth, innovation promotes factor productivity and creates new products (Romer, 1990; Aghion and Howitt, 1992). In specific terms of sustainable development, green innovations reduce pollution emissions in the production process and fundamentally alleviate air and water pollution. They also directly participate in environmental governance by improving the efficiency of pollutant absorption, degradation and recycling. Interestingly, green innovation is also related to political performance in China. Sustainable development and GDP growth together constitute two KPIs for the evaluation of the Chinese government officials. For example, since 2007, the construction of ecological civilization has gradually become an important part of government work. After 2013, environmental protection has become one of the core indicators in the political evaluation of Chinese officials (Zhang et al., 2020), and thereby, local governments may have a more positive attitude towards green innovations. In addition, Pang et al. (2021) found that government performance incentives effectively promote the pollution reduction of companies in the jurisdiction. This means that green attributes may force the government to influence corporate ESG decision-making due to requirements from the political performance appraisal. In this regard, we continue to put forward the following hypothesis.

Hypothesis 2.b: Subsidies have a greater impact on green R&D efficiency. Specifically, when government grants increase, per unit of R&D input generates more green patents than non-green ones.

If the above two assumptions are true, we are curious about the channels through which the innovation policies stimulate the efficiency of green innovations. We further discuss the impact of government monitoring on R&D activities. Existing studies have found that the lack of government review and insufficient supervision may lead to rent-seeking (Zhang et al., 2017), and R&D manipulation (Li and Zheng, 2016). Specifically, companies may use accounting manipulation to decorate other expenditures as R&D investments, and thus to meet the criteria of the InnoCom Program in order to benefit from tax deductions (Yang et al., 2017; Chen et al., 2021). Then the R&D expenditure of these enterprises is inflated on the books, but the actual intensity is far less, resulting in weak innovation efficiency. However, some research believes that the government is capable to restrict strategic innovation through regulation. Zhang and Zheng (2018) likened the government to a final “gatekeeper” and ultimate “goalkeeper” who is responsible for reviewing the quality of corporate patent applications. To a certain extent, it determines the overall patent quality and development potential for future innovations. Since the construction of ecological civilization has strengthened the urgent need for green products, the government has the ability as well as the incentive to strictly scrutinize corporate green R&D activities. In this regard, if the government curbs corporate R&D manipulation through surveillance review, it will improve the efficiency of innovations. We further put forward the following hypothesis.

Hypothesis 3: The government improves the efficiency of green innovation by prohibiting R&D manipulation. Specifically, for the companies with R&D manipulation motives that receive innovation subsidies from the government, the efficiency of green R&D increases more.

3. Data, Measurement, and Sample Characteristics

3.1 Model and Method

3.1.1 R&D Intention of Green and Non-Green Inventions

Our independent variables are designed to capture green and non-green innovation of firms separately. We employ the equations proposed by Pakes and Griliches (1984), Griliches (1998), Hu and Jefferson (2009) and Zhang and Zheng (2018). Specifically, we estimate and compare two separate regression equations as follows.

$$lnPatent_{i,t} = \alpha + \beta_1 lnR\&D_{i,t-1} + \gamma X_{i,t-1} + \delta_i + \delta_{ind} + \delta_t + \epsilon_{i,t} \qquad (1.\text{A})$$

$$lnGreenPatent_{i,t} = \alpha + \beta_1 lnR\&D_{i,t-1} + \gamma X_{i,t-1} + \delta_i + \delta_{ind} + \delta_t + \epsilon_{i,t} \qquad (1.\text{B})$$

Equation (1.A) and (1.B) describe the input-output relationship for innovations. The dependent variable $lnPatent_{i,t}$ in (1.A) is measured by the log number of *non-green patents* granted to company i in year t. In contrast, the dependent variable $lnGreenPatent_{i,t}$ in (1.B) is measured by the log number of *green patents* granted to company i in year t. We add 1 to the variable value and take the natural logarithm to represent the percentage change in patent applications, referring to the data processing method in Tan et al. (2014) and Li and Zheng (2016). Previous empirical research has documented the effect of R&D expenditures on patent authorizations as indicated by (1.A). However, R&D efficiency of green innovation as indicated by (1.B) is less studied. Notably, we have not combined the two equations into one by using dummy variables as the research aims to emphasize the difference in R&D efficiency, rather than substitution between the two types of innovation.

The independent variable $lnR\&D_{i,t-1}$ is measured by the logarithm R&D investment of company i in year $t-1$. The logarithmic form allows us to study the output elasticity of patents. The variable is lagged by one period because Wang and Hagedoorn (2014) believed that corporate R&D expenditures are reflected in the next period of granted patents. In addition, firm size has a significant impact on R&D activities. To address this question, we include log firm size as a control variable in the regression equation. In the further heterogeneity discussion, we also regress with subsamples based on different firm size. Our model is consistent with existing studies. Zhang and Zheng (2018) also use the lagged log R&D expenditures as their independent variable.

We denote a series of control variables by vector $X_{i,t-1}$. Borrowing from studies of Tong et al. (2014), Zhou et al. (2012), Li and Zheng (2016) and Zhang and Zheng (2018), our regression model controls the capability factors of financing, research, and knowledge acquisition. Specifically, $X_{i,t-1}$ includes companies' log total assets denoted by lnTA; log age denoted by lnAge; a cash flow factor calculated by the ratio of cash flow from operating activities to total assets denoted by CF; the leverage expressed as the ratio of total liabilities to total assets, LEV; the liquidity factor calculated from the ratio of current assets to current liabilities (LIQ); the retained earnings constructed by the ratio of surplus reserves and undistributed earnings to total assets (RE);

the fixed asset ratio denoted by TAN, and the return on assets denoted as ROA. We also apply a dummy variable STA to distinguish whether the company is state-owned, and a dummy variable EXP to identify whether the company is a foreign trade company. In addition, we also introduce dummy variables δ_i, δ_{ind} and δ_t to control for fixed and time effects.

3.1.2 Effect of Market Competition on Green and Non-Green R&D Motivations

Different R&D intentions are possibly due to different market competition incentives. To demonstrate this channel, we add an interaction term of market competition and R&D expenditures to our base regressions above and create equations (2.A) and (2.B).

$$lnPatent_{i,t} = \alpha + \beta_1 lnR\&D_{i,t-1} \times HHI_{ind,t-1} + \beta_2 lnR\&D_{i,t-1} + \beta_3 HHI_{ind,t-1} + \beta_4 Subsidy_{i,\tau} + \gamma X_{i,t-1} + \delta_i + \delta_{ind} + \delta_t + \epsilon_{i,t} \quad (2.A)$$

$$lnGreenPatent_{i,t} = \alpha + \beta_1 lnR\&D_{i,t-1} \times HHI_{ind,t-1} + \beta_2 lnR\&D_{i,t-1} + \beta_3 HHI_{ind,t-1} + \beta_4 Subsidy_{i,\tau} + \gamma X_{i,t-1} + \delta_i + \delta_{ind} + \delta_t + \epsilon_{i,t} \quad (2.B)$$

The interaction term $lnR\&D_{i,t-1} \times HHI_{ind,t-1}$ is used to identify the elevating effect of market competition on the motivation of non-green (2.A) and green (2.B) innovations. In specific, variable HHI is the Herfindahl-Hirschman index calculated using two-digit industry codes. We use it to portray the degree of competition, with higher variable values implying a stronger monopoly in the industry and vice versa, meaning a more competitive environment in the market. In addition, variable $Subsidy_{i,\tau}$ controls for the effect of government subsidies on innovation. We will describe its construction method in detail below. The independent variables, other control variables, and fixed effects are consistent with (1.A) and (1.B).

3.1.3 Effect of Government Subsidies on Green and Non-Green R&D Motivations

In order to further study the effect of government direct subsidies on the efficiency of corporate green and non-green innovations, an interaction term of R&D expenditure and government subsidy is added to the base regressions. By doing so, we establish the following equations (3.A) and (3.B).

$$lnPatent_{i,t} = \alpha + \beta_1 lnR\&D_{i,t-1} \times Subsidy_{i,\tau} + \beta_2 lnR\&D_{i,t-1} + \beta_3 Subsidy_{i,\tau} + HHI_{ind,t-1} + \gamma X_{i,t-1} + \delta_i + \delta_{ind} + \delta_t + \epsilon_{i,t} \quad (3.A)$$

$$lnGreenPatent_{i,t} = \alpha + \beta_1 lnR\&D_{i,t-1} \times Subsidy_{i,\tau} + \beta_2 lnR\&D_{i,t-1} + \beta_3 Subsidy_{i,\tau} + HHI_{ind,t-1} + \gamma X_{i,t-1} + \delta_i + \delta_{ind} + \delta_t + \epsilon_{i,t} \quad (3.B)$$

The variable $Subsidy_{i,\tau}$ is measured by the ratio of the innovation subsidies that company i receives to its total asset in year τ, where τ is in a range of $t-1$, t and $t+1$, indicating the policy timing. We consider three periods of subsidy to capture the government policy incentives, which is in line with academic research. Yu et al. (2010) argued that the government does not provide subsidies until the company releases a signal of innovations. The impact of subsidies on innovation in this regard may be reflected in the relationship between the next period of subsidies and the current number of patents. That is to say, if one only considers the subsidies received in the lagged or current period, it may not be able to accurately identify the real effects of government subsidies. To further discuss the government subsidy channel, we adopt the research method of Li and Zheng (2016) by using the lagged, current, and leading terms of the subsidy, which improves the reliability of the regression results.

For the measurement of the government subsidies, it is worth noting that their raw values fail to meet the uniform sampling assumption due to uneven distribution. The sample with a value of 0 accounts for 31% of all observations, so it is necessary to make a distinction on whether the firm enjoys the policy benefits. Common methods in previous literature are roughly divided into two categories, one of which is utilizing the raw subsidy amount scaled by total assets (Li and Zheng, 2016), while the other is to take the natural logarithm after adding 1. (He et al., 2022). We finally adopted the former one due to two reasons. Firstly, the second method has the disadvantage of being sensitive to unit changes. Adjusting units may affect the data distribution. For example, the original data from the CSMAR database has the unit yuan, but He (2022) used 100 million yuan as the unit, the operation of adding 1 has quite different meanings for these two units. Secondly, it should be noted that the same subsidy amount has different impacts on companies with different assets, which is ignored by the second method. As a result, it makes more sense for us to use subsidy amounts scaled by total assets.

Furthermore, in dealing with the observations of $Subsidy_{i,\tau}$ that have 0 values, we also construct a dummy variable $DummyS_{i,\tau}$ which takes a value of 1 if $Subsidy_{i,\tau}$ is larger than 0, and a value of 0, otherwise. This newly formed $DummyS_{i,\tau}$ represents whether company i receives government subsidies in year τ so as to improve the robustness of our analysis.

3.1.4 R&D Manipulation Motives and the Efficiency

To further explore the effects of government subsidies on R&D activities, we concentrate on the agency problem of policies. The InnoCom Program in China provides tax breaks to high-tech companies based primarily on the intensity of R&D expenditures. For the purpose of spurring more investments in innovations, the Administrative Measures for the Recognition of High-tech Enterprises sets a series of thresholds that companies must meet to be qualified for tax reductions. Specifically, for companies with sales revenue of less than 50 million yuan in the past year, ratio of R&D investment to sales revenue shall not be less than 6%. For companies with sales revenue of 50 million to 200 million yuan in the latest year, the ratio is not lower than 4%. And for companies with sales revenue of more than 200 million yuan in the latest year, the ratio is not lower than 3%.

However, corporate R&D may be distorted by government incentives.

Previous studies have found that some companies may engage in R&D manipulation in order to obtain benefits such as tax breaks. For example, they tend to include non-R&D project expenses as innovation expenses to meet the R&D investment criteria recognized by the InnoCom Program (Yang et al., 2017). Consequently, R&D manipulation hinders the implementation of innovation policies and makes it difficult to stimulate enterprises to carry out substantive innovations.

Figure 3.1 presents a histogram of R&D investment scaled by sales revenue to illustrate this adverse selection. Panel A shows that the full-sample distribution is denser near the percentage of 3 and 4, which are the qualification thresholds for high-tech enterprises. For subsamples, Panel C uses medium-sized enterprises whose sales revenue is more than 50 million yuan and less than 200 million yuan, corresponding to the 4% identification threshold. It shows that the number of samples on the right side of 4% does increase sharply. Panel D finds that the distribution on the right side of 3% jumps upwards for the subsamples containing large enterprises with sales greater than 200 million yuan associated with a threshold of 3%. Panel B catches the small enterprises with sales revenue less than 50 million yuan, but only 51 samples were obtained, so they were excluded from our further research. Chen et al. (2021) believed that these discontinuous changes in data distribution are due to R&D manipulations. In this regard, it provides some side evidence for identifying the agency problem.

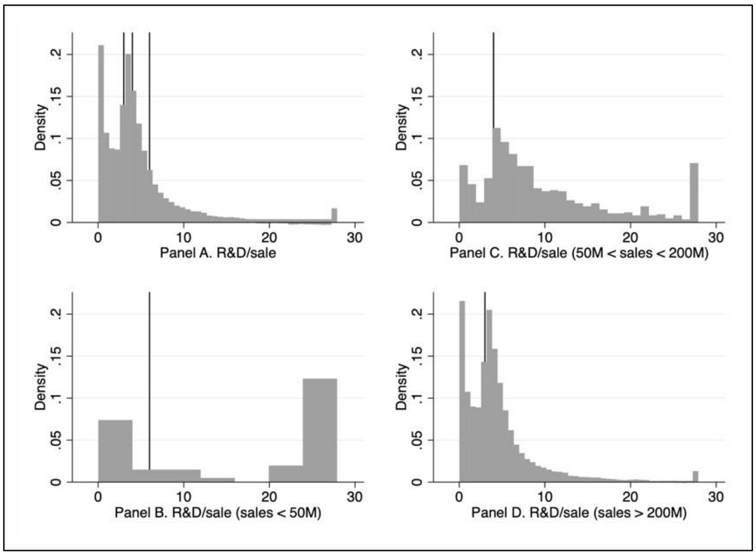

Figure 3.1: Frequency Distribution of R&D Expenditure/Sales Revenue (%)

We refer to the research of Yang et al. (2017) and Chen et al. (2021), using sales revenue and R&D expenditure to identify the motives of R&D manipulation for corporate i in year t. The classification is shown in Table 3.1. Specifically, Group 1 identifies the companies that are excluded by the InnoCom Program. Their low R&D intensity fails to meet the high-tech enterprise certification possibly due to their industry characteristics, financing constraints, or inadequate R&D conditions. Group 2 clusters firms with strategic innovation motives whose R&D intensity is only slightly above the criteria, namely just over the tax reduction threshold. It should be noted that this type of company is the main focus of our investigations. Yang et al. (2017) and Chen et al. (2021) believe that companies may use accounting manipulations to decorate non-R&D projects as R&D ones on their expenditure books, so as to meet the high-tech enterprise criterion and take advantage of policy benefits. However, their R&D efficiency may increase if the government implements stricter supervision and scrutiny of the R&D process (Zhang and Zheng, 2018). Group 3 presents companies that carry out substantial innovations. The R&D investment intensity for those companies is much higher than the threshold of tax reduction, implying that they engage in R&D activities not just for obtaining policy benefits. There are strong reasons to believe that Group 3 contains more companies that have a stronger intention to conduct high-quality innovations than the other two groups. Based on the classification, we divide the companies into three subgroups and perform regressions on each group by using Equation (3.A) and (3.B).

Since 2007, the prominence of ecological civilization in the efforts of the Chinese government has become apparent. However, it is worth noting that around 2013, there was a systematic change in the appraisal mechanism of Chinese officials (Zhang et al., 2020). Hence, the government's attitude towards green innovation may be different before and after 2013. In our robustness tests in Chapter 5, we divide the sample into two groups temporally and examine whether there is a significant increase in the effect of government subsidies on green innovation after 2013.

Table 3.1: Classification for Motives to Manipulate R&D

Classification	Group1 Firms without InnoCom support	Group2 Strategic innovation firms	Group3 Substantial innovation firms
If Sale < 200M CNY	R&D/Sale < 4%	4.0% ≤ R&D/Sale < 5.0%	5% ≤ R&D/Sale
If Sale ≥ 200M CNY	R&D/Sale < 3%	3.0% ≤ R&D/Sale < 4.0%	4% ≤ R&D/Sale

Notes: According to the "Administrative Measures for the Identification of High-tech Companies", the identification standard is that for companies with sales revenue of 50 million to 200 million yuan, the proportion must be at least 4%; for companies with sales revenue of more than 200 million yuan, the proportion must be at least 3%.

3.2 Patent and Innovation Subsidy Data

We obtain our patent authorization data of Chinese A-share listed companies in 2007–2021 from CCER databases, and green patent data from CSMAR database. Borrowing the methods of Tong et al. (2014) and Li and Zheng (2016), data for companies with no record of patent grants in the entire sample interval are removed. As a result, 4067 observations involving 692 companies are excluded. There are two possible reasons why these companies do not have patents. First, innovation has less impact on corporate profits. For example, the top three industries to which the excluded companies belong are real estate, retail and wholesale industries, accounting for a total of more than 20%. Second, some companies do not disclose patent licensing information for certain reasons, such as defense and military industry. In addition, to focus on substantive innovations, we follow Li and Zheng (2016) and exclude utility patents and design patents which are usually considered as strategic innovations. Finally, only invention-type patents are retained[1].

Our subsidy data come from the CSMAR database as well, including policy titles, brief descriptions, and fund amount. Text analysis is applied to divide them into three categories: general subsidies for non-innovation activities, functional industrial policies to stimulate social innovations, and selective industrial policies for particular types of inventions. This text analysis approach is borrowed from Chen et al. (2010), Song and Wang (2013), Li and

[1] We also regress the whole patent data and get consistent conclusions.

Li (2014), Han and Hong (2014) and Li and Zheng (2016). However, our keywords are more comprehensive, which are taken from the innovation incentive policies published on the Chinese government website [2] (see Appendix). We then sum up the finds of the functional industrial policies and the selective industrial policies, to get our independent variable of the government innovation subsidies.

In addition, financial information containing R&D expenditure, sales revenue and the other control variables also come from the CSMAR database. After merging all these data, we exclude financial and ST companies and winsorize the 1% and 99% percentiles of continuous variables. Finally, a total of 21704 observations are collected, involving 4070 listed companies. The descriptive statistics are as follows.

Table 3.2: Descriptive Statistics

Variable	Description	Observation	Mean	S.T.D.	Min	Max
lnPatent	Log of patent numbers	21704	1.37	1.35	0.00	5.26
lnGreenPatent	Log of green patents	21704	0.26	0.62	0.00	3.09
lnRD	Log of R&D expenditure	21704	-0.59	1.43	-5.05	3.35
RDSubsidy	R&D incentive subsidies	21704	0.24	0.42	0.00	2.44
HHI	Market competition index	21704	0.08	0.09	0.01	0.58
lnTA	Log of total assets	21704	3.65	1.25	1.36	7.77
lnage	Log of firm age	21704	2.85	0.33	1.61	3.50
CF	Cash flow ratio	21704	0.05	0.07	-0.15	0.25
Lev	Debt ratio	21704	0.40	0.20	0.05	0.93
LIQ	Liquidity ratio	21704	2.68	2.74	0.36	18.49
RE	Retained earnings	21704	0.17	0.20	-0.99	0.56
rTAN	Tangible Assets Ratio	21704	0.21	0.14	0.00	0.65
ROA	Return on net assets	21704	0.04	0.07	-0.33	0.21

[2] Relevant policy documents include: “Overall Plan for Systematically Promoting Comprehensive Innovation Reform Experiments in Some Regions”, “National Innovation-Driven Development Strategy Outline” and “Notice of the State Council on Printing and Distributing China’s Implementation of the 2030 Agenda for Sustainable Development Innovation Demonstration Zone Construction Plan”

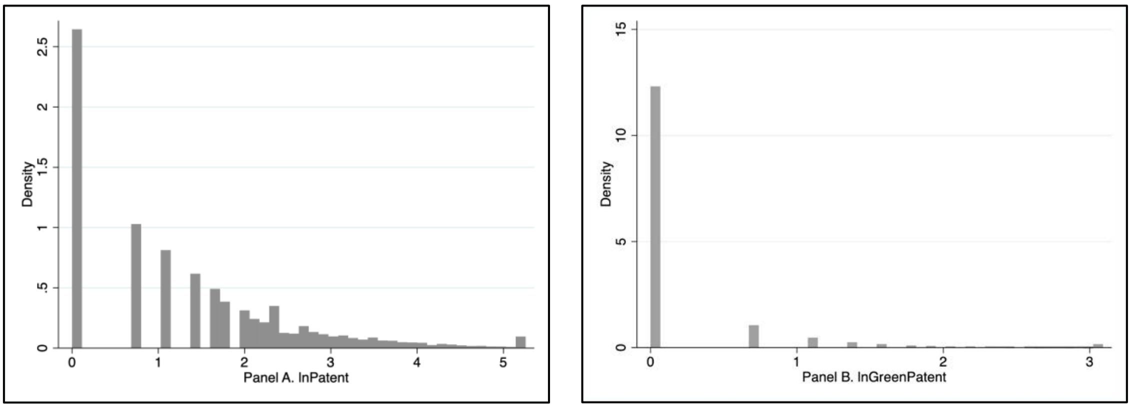

Figure 3.2：Data Distribution of lnPatent (Panel A) and lnGreenPatent (Panel B)

4. Empirical Results

4.1 Corporate R&D Intention on Green and Non-Green Innovations

4.1.1 Intention on Green Innovation Is Insignificant and Lower than Non-Green Ones.

Model (1), (2) and (3) in Table 4.1A report the R&D efficiency of non-green innovations, while Model (4), (5) and (6) report that of green innovations. The coefficient of the variable *lnRD* captures the increase in granted patents when increasing R&D expenditures. The coefficient of Model (3) shows that for every 1% increase in R&D investment, non-green patents will rise by 0.0429%, while in Model (6), green patents increase by 0.0072%, which is only about 1/6 of the former. In addition, R&D investment has a significant effect on non-green innovations, but it does not stimulate green innovations significantly.

It shows that although the Chinese central government requires vigorous development of the green economy, corporate willingness of green innovations is still lower than that of non-green ones. Rennings (1998) pointed out that green innovations have a positive environmental externality, resulting in a weak incentive for market competition. That is to say, although green product reduces emissions, degrades pollution, improves the natural environment, and increase the well-being of the inhabitants, the benefits that companies derive from them do not fully compensate for the opportunity costs. Therefore, the R&D intentions for non-green innovations are stronger. In this regard, the core of green innovation incentives lies in how to internalize these positive environmental externalities into corporate profits.

In terms of the policy recommendations, Fang and Na (2020) suggested strengthening market incentives and government guidance. Although research believed that market competition can promote non-green innovations (Aghion et al., 2005), green attributes may weaken this channel. We address this question by introducing market competition into the innovation efficiency equations.

4.1.2 Market Competition Promotes Non-Green Innovation, but Does Not Promote, or Even Discourages Green Innovation.

Table 4.1B reports the effects of market competition on R&D efficiency. Model (1)-Model (3) capture the impact of market competition on the efficiency of non-green innovations. The coefficients of the interaction term are -0.1912, -0.1913 and -0.2671, for controlling government subsidies in the lagged, current and forward periods, respectively. All of them are significant. The negative values for all these three models show that when the HHI becomes smaller, i.e., a fiercer market competition, corporate R&D intentions for non-green innovations will be accelerated. According to the creative destruction theory, the competitive market has a weak entry barrier. This increases the probability of crowding out rivals to earn a monopoly profit. Companies then will have a strong intention to engage in R&D activities. In addition, Aghion et al. (2005) and Zhang and Zheng (2018) both consider market competition as an important way to stimulate R&D efficiency. Consequently, the competition-based mechanism may induce a weaker agency problem than the government-intervention mechanism for non-green innovations. We draw a policy recommendation that, on the one hand, the government should lower the grants criterion to attract competitors. On the other hand, it is necessary to regulate the market mechanism, improve the protection of IPR, and enhance competition with the purpose of innovation incentives.

Model (4)-Model (6) shows the effect of market competition on green innovations. We also control the government subsidies in the lagged, current and forward periods, respectively. The coefficients of the interaction term are 0.2301 in Model (4), 0.2296 in Model (5), and 0.1174 in Model (6). The first two of them are significant. Although the third one is insignificant, its sign remains positive and has a t-statistic of 1.488. Notably, a key difference compared to the previous set of regressions is that the market competition cannot promote the R&D intentions. Specifically, the coefficients of the interaction terms of the green innovations are all positive, implying that market competition has a limited or even negative impact on green R&D efficiency. This suggests that green innovations are also different from non-green ones in terms of market competition incentives. Moreover, Schumpeter's theory of creative destruction becomes invalid probably because of the imperfect market pricing mechanism and the positive environmental externality from the green attributes. In addition, there is another aspect to understand the results that monopolies increase the efficiency of green innovations. A greater risk of public protest faced by monopoly companies forces them to invest more efforts in social reputation and environmental regulation. Meanwhile, they tend to hedge these risks by increasing ESG investments, to which green innovation is an important approach.

Overall, our further research finds that green attributes create different competition incentives for innovations. When the market power increases, the efficiency of non-green R&D activities is significantly diminished, but the intentions to innovate in a green way do not decline, or even increase. Intuitively, a basic premise for the creative destruction theory, that is, innovative products have to be profitable in the market, is violated. The pricing mechanism for the environmental externalities of green innovations is not yet in place. Society needs green inventions, but no one pays for it. In this circumstance, market competition incentives are less effective than government intervention. What's worse, fierce market competition may even inhibit the R&D efficiency of green innovations. Our empirical results have important implications for practice. In the absence of a complete pricing mechanism for green products, market competition and government subsidies need to work together. In order to achieve technological upgrades and product iterations, it is necessary to sensibly and carefully leverage the competitive system.

Table 4.1A: Regression Results of Differences in Green and Non-Green R&D Intentions

Dependent	*lnPatent*			*lnGreenPatent*		
	(1)	(2)	(3)	(4)	(5)	(6)
lnRD	**0.0394*** **	**0.0640*** **	**0.0429*** **	**-0.1202*** **	**0.0103**	**0.0072**
	(3.099)	(4.459)	(2.832)	(-16.024)	(1.356)	(0.832)
_cons	1.3960***	1.4754***	1.7487***	0.1874***	0.4715***	0.0893
	(187.348)	(4.527)	(2.961)	(42.669)	(6.479)	(0.277)
CONTROL	No	No	Yes	No	No	Yes
YEAR	No	Yes	Yes	No	Yes	Yes
INDUSTRY	No	Yes	Yes	No	Yes	Yes
COMPANY	Yes	Yes	Yes	Yes	Yes	Yes
N	21704	21704	21704	21704	21704	21704
R2	0.00	0.05	0.05	0.03	0.14	0.15

Note: *, ** and *** indicate significance levels of 10%, 5% and 1%, respectively. Values in parentheses represent t values, all regressions are cluster adjusted.

Table 4.1B: Regression Results of Market Competition Affecting R&D Efficiency

Dependent $\tau(Subsidy)$	*lnPatent* $t-1$	t	$t+1$	*lnGreenPatent* $t-1$	t	$t+1$
	(1)	(2)	(3)	(4)	(5)	(6)
lnRD x HHI	**-0.1912****	**-0.1913****	**-0.2671*****	**0.2301*****	**0.2296*****	**0.1174**
	(-2.062)	(-2.064)	(-2.601)	(2.860)	(2.854)	(1.488)
lnRD	0.0629***	0.0629***	0.0688***	-0.0173	-0.0172	0.0000
	(3.371)	(3.372)	(3.326)	(-1.545)	(-1.537)	(0.003)
HHI	-0.6887***	-0.6888***	-0.9916***	0.5486***	0.5479***	0.2320
	(-2.835)	(-2.836)	(-3.716)	(2.875)	(2.872)	(1.140)
Subsidy	0.0026	0.0020	-0.0435*	0.0122	0.0164	0.0078
	(0.124)	(0.084)	(-1.651)	(0.891)	(1.075)	(0.488)
_cons	1.8739***	1.8745***	1.6238**	-0.0049	-0.0056	-0.0489
	(3.191)	(3.192)	(2.562)	(-0.015)	(-0.017)	(-0.149)
CONTROL	Yes	Yes	Yes	Yes	Yes	Yes
YEAR	Yes	Yes	Yes	Yes	Yes	Yes
INDUSTRY	Yes	Yes	Yes	Yes	Yes	Yes
COMPANY	Yes	Yes	Yes	Yes	Yes	Yes
N	21416	21416	17730	21416	21416	17730
R2	0.06	0.06	0.04	0.15	0.15	0.12

Note: *, ** and *** indicate significance levels of 10%, 5% and 1%, respectively. Values in parentheses represent t values, all regressions are cluster adjusted.

4.2 Effects of Subsidies on Corporate Green and Non-Green R&D Efficiency

4.2.1 Subsidies significantly improve the efficiency of green R&D activities, but do not have a significant effect on that of non-green innovations.

In Table 4.2A, Model (1), (2), and (3) report the impact of lagged, current, and forward period subsidies, respectively, on non-green innovations. Likewise, Model (4), (5) and (6) report the impact of government grants during these three periods on green innovations, accordingly. Specifically, the coefficient of *Subsidy* is used to represent the direct policy on innovations, and the interaction term *lnRDxSubsidy* indicates its promotion effects on R&D

efficiency.

The coefficients of *Subsidy* and *lnRDxSubsidy* are 0.0060 and 0.0059 in Model (1) for the lagged period subsidies; -0.0001 and -0.0025 in Model (2) for the current subsidies; and -0.0476 and -0.0041 in Model (3) for the forward subsidies, respectively. These coefficients are insignificant in all periods. It shows that government grants have no significant impact on R&D efficiency for non-green inventions, whether in the lagged, current, or leading period. Consistent with our results, the existing literature also argue that the government subsidy cannot be considered an effective way to stimulate non-green innovations. Li and Zheng (2016) noted that in order to “seek allowance”, companies may increase the “quantity” of innovations while forgoing their “quality”. Zhang (2021) also criticized that the innovation subsidy policies implemented by the government at all levels fail to be effective tools for promoting R&D activities. But in reality, the persistent high subsidy level found in Figure 2.1 contradicts the existing research and policy recommendations. To explore the anomaly, we investigate the effects of government subsidies on green innovations.

Model (4) uses the patent of green innovations as the independent variable and reports the coefficients of the lagged policy intensity *Subsidy*, and its interaction with R&D investment *lnRDxSubsidy*. It shows that, for each 1% increase in the subsidy-to-asset ratio, there will be a significant 0.0546% increase in green inventions and the R&D efficiency will be promoted by

0.0676%. In addition, for the current and the forward periods, the coefficients of *Subsidy* are 0.0617 and 0.0678, and those of *lnRDxSubsidy* are 0.0391 and 0.0458, respectively. All of these interactions are significant and more substantial than those of non-green R&D activities.

Notably, we find a new result that contrasts with existing views, and this challenges the idea that government subsidies are always ineffective for R&D efficiency. Surprisingly, for green innovations, government subsidies do significantly increase the granted patents and stimulate R&D efficiency. The policy impacts are also larger than those of the non-green innovations. In addition, the huge difference in the effects of the subsidies on the green and non-green R&D efficiency highlights that the heterogeneity in green attributes is not only in R&D intentions but also in the policy incentives. This further leads to a new question. How do government subsidies significantly improve the R&D efficiency of green innovations? We discuss the question in Section 4.3.

4.2.2 The availability of subsidies to companies has a significant impact on green innovations.

To address the uneven distribution of the subsidy intensity, we replace *RDSubsidy* with the dummy variable *DummyS* and Table 4.2B presents the regression results. Model (1), (2) and (3) present the impact of the lagged, current, and forward period subsidies received, respectively, on non-green innovations. The result shows that all the interaction coefficients are insignificant. Model (4), (5) and (6) report the impact of subsidies on green innovations. This time, the coefficients of the interaction are all significantly positive, and the values are larger than those in regressions of the non-green ones. This is consistent with the regression results of Table 4.2A, revealing that the government subsidy promotes the R&D efficiency significantly in green innovations, while insignificantly in non-green ones.

To sum up, the findings shown in Table 4.1 and Table 4.2 are as follows. In terms of R&D intentions, corporate R&D expenditure does significantly increase non-green innovations, but it has insignificant and lower impact on green ones. This is because the pricing mechanism for the environmental externalities of green innovations is not yet in place. Society needs green inventions, but no one pays for it. From the perspective of government intervention, the subsidies significantly improve the R&D efficiency of green innovations, but their effect on non-green ones is insignificant. These results have three implications. First, compared to non-green innovations, green inventions contain positive environmental externalities, leading to a reduction in corporate willingness to engage in R&D activities. Second, green attributes lead to the heterogeneity of innovation incentives. Market competition does not have a positive effect on green R&D efficiency, or, even worse, inhibits it. However, government subsidies strongly stimulate it. Third, the subsidy policy is reasonable and valid under certain circumstances.

Table 4.2A: Regression Results of Subsidies Affecting R&D Efficiency

Dependent	*lnPatent*			*lnGreenPatent*		
$\tau(Subsidy)$	$t-1$	t	$t+1$	$t-1$	t	$t+1$
	(1)	(2)	(3)	(4)	(5)	(6)
lnRD x Subsidy	**0.0059**	**-0.0025**	**-0.0041**	**0.0676*** **	**0.0678*** **	**0.0458*** **
	(0.441)	(-0.145)	(-0.217)	(5.521)	(5.139)	(3.716)
lnRD	0.0419***	0.0433***	0.0415**	-0.0050	-0.0023	0.0049
	(2.735)	(2.817)	(2.453)	(-0.564)	(-0.260)	(0.515)
Subsidy	**0.0060**	**-0.0001**	**-0.0476**	**0.0546*** **	**0.0617*** **	**0.0391***
	(0.258)	(-0.004)	(-1.489)	(2.936)	(2.923)	(1.844)
_cons	1.8505***	1.8523***	1.5900**	0.0146	0.0132	-0.0622
	(3.118)	(3.119)	(2.469)	(0.045)	(0.041)	(-0.191)
CONTROL	Yes	Yes	Yes	Yes	Yes	Yes
YEAR	Yes	Yes	Yes	Yes	Yes	Yes
INDUSTRY	Yes	Yes	Yes	Yes	Yes	Yes
COMPANY	Yes	Yes	Yes	Yes	Yes	Yes
N	21704	21704	17991	21704	21704	17991
R2	0.05	0.05	0.04	0.15	0.15	0.12

Note: *, ** and *** indicate significance levels of 10%, 5% and 1%, respectively. Values in parentheses represent t values, all regressions are cluster adjusted.

Table 4.2B: Regression Results of Dummy Subsidies Affecting R&D Efficiency

Dependent	*lnPatent*			*lnGreenPatent*		
$\tau(Subsidy)$	$t-1$	t	$t+1$	$t-1$	t	$t+1$
	(1)	(2)	(3)	(4)	(5)	(6)
lnRD x DummyS	**0.0106**	**-0.0145**	**-0.0219***	**0.0645*** **	**0.0601*** **	**0.0396*** **
	(0.839)	(-1.116)	(-1.683)	(6.504)	(6.075)	(4.161)
lnRD	0.0357**	0.0500***	0.0544***	-0.0347***	-0.0281***	-0.0129
	(2.020)	(2.945)	(2.992)	(-3.175)	(-2.686)	(-1.197)
DummyS	0.0177	0.0491**	0.0417*	0.0100	0.0063	0.0021
	(0.817)	(2.190)	(1.789)	(0.631)	(0.394)	(0.127)
_cons	1.8187***	1.8333***	1.5535**	-0.0674	-0.0897	-0.0961
	(3.057)	(3.086)	(2.411)	(-0.207)	(-0.278)	(-0.293)
CONTROL	Yes	Yes	Yes	Yes	Yes	Yes
YEAR	Yes	Yes	Yes	Yes	Yes	Yes
INDUSTRY	Yes	Yes	Yes	Yes	Yes	Yes
COMPANY	Yes	Yes	Yes	Yes	Yes	Yes
N	21704	21704	17991	21704	21704	17991
R2	0.05	0.06	0.04	0.15	0.15	0.12

Note: *, ** and *** indicate significance levels of 10%, 5% and 1%, respectively. Values in parentheses represent t values, all regressions are cluster adjusted.

4.3 Effects of Subsidies on Innovation When Considering R&D Manipulation Motives

In order to further explore the mechanism by which the government grants promote the R&D efficiency of green innovations, we then apply subsample regressions. Our following study divides the full sample into three subgroups, labeled as Group1, Group2, and Group3, depending on whether the companies have not met, just met, or exceeded the thresholds in the InnoCom Program[3]. Specifically, these three groups represent companies that “do not enjoy R&D policy benefits”, “have R&D manipulation motives” and “pursue substantial innovations”, respectively. Table 4.3 reports the results of subsample regressions about how subsidies affect R&D efficiency. The key independent variable in Table A is the corporate R&D investment *lnRD*, while the key independent variables in Table B, Table C, and Table D are the interaction item *lnRDxSubsidy*. The control variables and fixed effects are incorporated in all regressions.

4.3.1 For firms that “do not enjoy R&D benefits”, R&D efficiency of green inventions is lower than that of non-green ones. However, for firms of “strategic innovations” and “substantial innovations”, R&D efficiency of green and non-green inventions has no significant differences.

For firms that “do not enjoy R&D benefits”, the intention of taking non-

[3] See the research method for the classification process for details.

green R&D activities is stronger than that of green ones. The regression coefficient of R&D investment *lnRD* shown in Table A is 0.0317 for Model (1) regarding non-green innovations and -0.0275 for Model (4) with respect to green inventions, both being significant. The discrepancy demonstrates that the R&D efficiency of green inventions is significantly lower than that of non-green ones, indicating that without policy benefits, firms would have weaker incentives to conduct green R&D activities. Intuitively, high uncertainties and inadequate rewards discourage corporate R&D intentions. In specific, high risks do reduce R&D expenditures in the early R&D phase (He et al., 2022). This leads to a vicious circle. If firms fail to meet the policy criterion, they get no subsidy and are stuck in financing constraints. Consequently, the intensity of their R&D expenditure is weak, which makes it even more difficult to reach the policy criterion. Worse yet, the benefits of green attributes cannot be converted into corporate profits through market competition. Together, these two factors reduce corporate willingness to conduct green R&D activities and may even squeeze them out if firms urgently need non-green innovations to make profits. In policy recommendations, alleviating R&D risks is an important task to stimulate green innovations. Moreover, enhancing policy stability and sustainability is fundamental to long-term sustainable development.

For firms that happen to meet the threshold of policy criterion, the motives of “R&D manipulation” close the intentional gap between green and non-green

R&D activities. The regression coefficient of R&D expenditure *lnRD* shown by Table A is 0.0601 in Model (2) regarding non-green innovations and 0.0627 in Model (5) with regard to green ones. It shows that the efficiency between green and non-green R&D is quite close. This is because when firms are going to take advantage of policy benefits, green and non-green R&D activities actually make no differences. In addition, the R&D efficiency for “substantive innovation” companies is 0.0600 in Model (3) and 0.0632 in Model (6), with regard to non-green and green innovations, respectively. The two coefficient values are very close. This is because high R&D expenditure means that the firms are more likely to face less uncertainty in later stages of development.

To sum up, the risks and profits provide a lens for explaining different green R&D efficiency in three groups. When non-green R&D intensity has not reached a bottleneck, as in Model (1) with a value of 0.0317, it is less costly than green innovation due to fewer externalities. However, with a diminishing marginal output of R&D investment, green innovations become relatively more profitable, and the uncertainty is mitigated in later R&D phases. As a result, companies with higher R&D expenditure are more willing to conduct green innovations, as in Models (5) and (6) with an efficiency of approximately 0.06. From this point of view, a conclusion is drawn that although we are in a trend of shifting from non-green to green innovations, non-green innovation still plays an important role in the development of SMEs.

4.3.2 For firms of "strategic innovations", government subsidies significantly inspire the R&D efficiency of green inventions, but have an insignificant impact on that of the non-green ones.

The interaction term in Model (2) captures the contribution of the lagged, current and forward period subsidies to non-green R&D efficiency for firms taking "strategic innovations", as shown in Table 4.3B, C and D with the values of -0.0257, 0.0094 and -0.0159, respectively. None of them is significant and, notably, they are smaller than that of the firms taking "substantial innovations" as shown in Model (3). It indicates that for the companies taking "strategic innovations", the effect of the government grants on non-green R&D activities is limited, or even crowds out the existing ones. In this regard, Yang et al. (2017) believed that although these policies are intended to promote innovations, they instead ultimately incentivize firms to engage in R&D manipulation, leading to a decline in innovation performance. Mainstream literature also advocates replacing direct subsidies with tax breaks or talent acquisition while reducing governments' direct involvement to avoid R&D manipulations (Gill, 2007; An et al., 2009; Li and Zheng, 2016; Zhang and Zheng, 2018; Zhang, 2021). However, some studies argued that the role of the government in spurring innovations should not be underestimated. The government plays an important part as a gatekeeper whose surveillance review determines the overall quality of innovations (Zhang et al., 2016).

Our regression results for green innovations are in line with the second view above. The interaction term in Model (5) captures the contribution of the lagged, current and forward period subsidies to green R&D efficiency among the R&D-manipulation firms, as shown in Table 4.3B, C and D with the values of 0.1016, 0.1156 and 0.0709, respectively. An inter-group comparison demonstrates sufficient differences between the non-green and green innovations. Specifically, the coefficients are all significant in Model (5) regarding the green inventions and larger than that in Model (2) with respect to the non-green ones. Moreover, the inner-group comparison finds that the impact of the subsidies on green R&D activities among the R&D-manipulation firms is larger than that among the substantively innovative firms, as shown in Model (5) versus Model (6). It suggests that government incentive policies improve the efficiency of green innovations not only by alleviating the financing constraints discovered by existing studies, but also by inhibiting motives to manipulate R&D. Chinese political evaluation (Li and Zhou, 2005; Zhang et al., 2020; Pang et al., 2021) provides a possible mechanism that the assessment in sustainability performance inspires the government to monitor and review green innovations. In this regard, the adverse selection between R&D encouragement and corporate benefits is mitigated under government scrutiny (Zhang et al., 2016).

Overall, the regression results drawn from Table 4.3 are as follows. First, firms in the early R&D phase are less willing to innovate in a green way. But as the entire R&D expenditure increases, the willingness of green and non-green innovations converges. Second, in terms of non-green R&D activities, the subsidy effects on companies that pursue "R&D manipulation" are insignificant and weaker than that on substantively innovative firms. However, in the case of green innovations, government grants significantly improve the R&D efficiency of companies that pursue "strategic innovations" and have a greater impact than that on substantively innovative firms. Our findings demonstrate a possible explanation for the question of why subsidies significantly increase the efficiency of green R&D activities but have only a modest impact on the non-green ones. That is, strategic R&D motives are inhibited in green R&D activities. Specifically, firms that innovate for the sake of funding will face a moral hazard after receiving subsidies, leading to a lack of substantive innovations. But relatively stricter surveillance review from the government mitigates the adverse selection between R&D encouragement and corporate benefits. Referring to existing literature, we infer that the political competition and the evaluation of ecological civilization stimulate official scrutiny through their political promotion incentives.

Table 4.3：Heterogenous Impact of Green Attributes on R&D Manipulation

Dependent	$lnPatent$			$lnGreenPatent$		
Subsample	Group1	Group2	Group3	Group1	Group2	Group3
	(1)	(2)	(3)	(4)	(5)	(6)
A：R&D Efficiency						
lnRD	**0.0317***	**0.0601**	**0.0600***	**-0.0275*****	**0.0627**	**0.0632*****
	(1.727)	(1.447)	(1.762)	(-2.599)	(1.272)	(3.373)
_cons	1.4997	1.2900	1.8049**	-0.0158	0.6431	-0.6011
	(1.605)	(1.129)	(2.226)	(-0.025)	(0.948)	(-0.991)
N	7292	4176	10220	7292	4176	10220
R2	0.05	0.08	0.08	0.11	0.14	0.17

B：Effect of Subsidies (Period $t-1$) on R&D Efficiency						
lnRD x Subsidy	**-0.0081**	**-0.0257**	**0.0025**	**0.0318****	**0.1016*****	**0.0726*****
	(-0.354)	(-0.430)	(0.115)	(2.256)	(2.724)	(3.854)
lnRD	0.0325*	0.0605	0.0607*	-0.0309***	0.0504	0.0387*
	(1.742)	(1.445)	(1.764)	(-2.865)	(1.025)	(1.899)
Subsidy	-0.0033	0.1149	-0.0162	0.0158	0.0797	0.0299
	(-0.056)	(1.510)	(-0.549)	(0.427)	(1.527)	(1.410)
_cons	1.5359	1.5404	1.8325**	-0.0904	0.6049	-0.6407
	(1.632)	(1.355)	(2.254)	(-0.141)	(0.894)	(-1.085)
N	7292	4176	10220	7292	4176	10220
R2	0.05	0.08	0.08	0.11	0.14	0.18
C：Effect of Subsidies (Period t) on R&D Efficiency						
lnRD x Subsidy	**-0.0354**	**0.0094**	**0.0047**	**0.0329****	**0.1156*****	**0.0752*****
	(-1.327)	(0.165)	(0.181)	(2.045)	(3.178)	(3.904)
lnRD	0.0346*	0.0595	0.0613*	-0.0299***	0.0509	0.0441**
	(1.850)	(1.414)	(1.766)	(-2.813)	(1.044)	(2.267)
Subsidy	-0.0578	0.1518**	-0.0465	0.0414	0.1314**	0.0271
	(-0.842)	(2.156)	(-1.278)	(0.998)	(2.264)	(1.121)
_cons	-0.0354	0.0094	0.0047	0.0329**	0.1156***	0.0752***
	(-1.327)	(0.165)	(0.181)	(2.045)	(3.178)	(3.904)
N	7292	4176	10220	7292	4176	10220
R2	0.05	0.08	0.08	0.11	0.14	0.18
D：Effect of Subsidies (Period $t+1$) on R&D Efficiency						
lnRD x Subsidy	**-0.0529****	**-0.0159**	**0.0093**	**0.0468*****	**0.0709***	**0.0398****
	(-2.072)	(-0.301)	(0.297)	(2.745)	(1.941)	(2.100)
lnRD	0.0309	0.0606	0.0569	-0.0272**	0.0508	0.0458**
	(1.444)	(1.362)	(1.498)	(-2.395)	(1.015)	(2.254)
Subsidy	-0.1325**	-0.0480	-0.0308	0.0239	0.1289**	0.0194
	(-2.160)	(-0.583)	(-0.789)	(0.601)	(2.074)	(0.770)
_cons	-0.0529**	-0.0159	0.0093	0.0468***	0.0709*	0.0398**
	(-2.072)	(-0.301)	(0.297)	(2.745)	(1.941)	(2.100)
N	6146	3571	8259	6146	3571	8259
R2	0.05	0.05	0.04	0.09	0.12	0.14
Control Variables and Fixed Effects for Table A - Table D						
CONTROL	Yes	Yes	Yes	Yes	Yes	Yes
YEAR	Yes	Yes	Yes	Yes	Yes	Yes
INDUSTRY	Yes	Yes	Yes	Yes	Yes	Yes
COMPANY	Yes	Yes	Yes	Yes	Yes	Yes

Note: *, ** and *** indicate significance levels of 10%, 5% and 1%, respectively. Values in parentheses represent t values, all regressions are cluster adjusted.

5. Further Discussions

Our regression results have demonstrated that, first, companies have lower R&D willingness to take green innovations than non-green ones. Second, although market competition does promote non-green innovations, green attributes weaken this channel. Third, government subsidies have limited effects on non-green innovations, which is consistent with the academic research findings. In contrast, government subsidies do significantly promote green innovations. That is, green innovations differ significantly from non-green ones with respect to R&D intentions, competitive market drivers, and government subsidy incentives. In this regard, we further explore whether they also differ between SMEs and large ones, as well as between low-polluting and high-polluting firms.

5.1 Discussions on Heterogeneity

5.1.1 Heterogeneity in Firm Sizes

The firm sizes are strongly correlated with the financing constraints and may bring in different R&D intensities. Previous literature believed that financing constraints do suppress R&D investment (Arrow, 1962; Hall and Lerner, 2010; Gorodnichenko and Schnitzer, 2013; Zhang et al., 2016). To make an intuitive identification of corporate financial condition, Zhang et al. (2017) pointed out that the firm size is a useful index. This is because it's hard for SMEs have qualified collateral assets and their default rates are too high

(Palangkaraya, 2012), resulting in asymmetric information and adverse selection. In this regard, it is costly for investors to evaluate and monitor their innovative projects. SMEs have to pay more risk premiums and their R&D intentions are consequently discouraged. Our study above has demonstrated that companies in less market competition are more motivated to engage in green R&D activities. In this point of view, firm sizes provide a possible lens for understanding our results. Green innovations may be clustered in emerging SMEs with weaker monopoly power. Their innovative projects are risky and trap them in severe financing constraints. As a result, these companies are more reluctant to engage in green R&D activities. In this regard, government subsidies stimulate R&D efficiency by the alleviating financing constraints channel. To explore this plausible conjecture, we propose the following hypothesis.

Hypothesis 4: Alleviating financing constraints are the main mechanism by which government grants significantly enhance the R&D intentions. Specifically, the effects of subsidies on R&D efficiency are stronger among SMEs with severe financing constraints.

To investigate the hypothesis above, we refer to Zhang et al. (2017), using the number of employees to classify firms. Firstly, based on the number of employees at the year-industry level, companies below the median are classified as SMEs and vice versa as large ones. Subsequently, the regression equations (1) and (3) are re-estimated with regard to these two subgroups. Table 5.1 reports the findings and draws our point of view as follows.

Regarding the intention of non-green R&D activities, there is a disparity between SMEs and large ones. The regression coefficient values with respect to non-green R&D intention, *lnRD*, are 0.0626 for the SMEs shown in Model (1) of Table A, and 0.0175 for the large firms shown in Model (1) of Table B. Notably, the latter is only a quarter of the former, suggesting that SMEs are more effective in terms of the non-green R&D activities. This is because in an economy of diminishing marginal returns, most SMEs are startups. Their total R&D investments are low and more concentrated. In this regard, their innovative projects are more growth-oriented. However, severe financing constraints impede the development of good projects, which have the higher R&D efficiency but lower expenditure levels.

In contrast, for green R&D activities, the discrepancy of the intention is small. The regression coefficient values in terms of the green R&D intention, *lnRD*, are 0.0143 for the SMEs shown in Model (5) of Table A, and 0.0162 for the large firms shown in Model (5) of Table B. Both of them are insignificant and their discrepancy is small, indicating that green R&D demonstrates no difference in terms of the firm sizes. Intuitively, the benefits of green innovations mainly come from government subsidies. Unlike the capital market, the government is more concerned with whether the companies meet the subsidy criterion, rather than their profits. As a result, the adverse selection is mitigated and leads to a weaker contribution of firm sizes.

Next, we investigate the incentive effects of government subsidies on different firm sizes. For non-green R&D efficiency, government subsidies are significantly effective for SMEs, but invalid for large ones. The coefficient values of the interaction term between the R&D investment and the lagged period subsidies, *lnRDxSubsidy*, are 0.0772 for the SMEs shown in Model (2) of Table A, and -0.0163 for the large firms shown in Model (2) of Table B. The effects of current period subsidies on SMEs and large firms are shown in Model (3) of Table A and Table B, respectively. The effects of the forward period subsidies are shown in Model (4). The comparison demonstrates that government grants do significantly improve the efficiency of non-green innovations for SMEs but not for large ones. In this regard, Hypothesis 4 is accepted for non-green innovations and draws a policy implication that the government needs to adopt subsidy policies for SMEs with the primary goal of alleviating financing constraints.

For green innovations, government subsidies significantly stimulate the R&D efficiency of both SMEs and large ones. The coefficients of the interaction term between the R&D investment and the lagged period subsidies, *lnRDxSubsidy*, are 0.0379 for the SMEs shown in Model (6) of Table A and 0.0532 for the large firms in Model (6) of Table B. Those interactions are 0.0444 and 0.0604 in Model (7) for the current period subsidies, and 0.0255 and 0.0456 in Model (8) for the forward period subsidies. Notably, all these coefficients are significantly positive with regard to large firms. Hypothesis 4 is rejected for green innovations because government subsidies are not found to have a greater impact on the R&D efficiency of SMEs that are stuck in financing constraints. Consequently, alleviating financing constraints is not the main mechanism by which government subsidies stimulate the efficiency of green R&D activities.

Overall, the research in this section shows that the effects of government subsidies on non-green R&D efficiency vary significantly depending on the size of the firms involved. However, this difference disappears in a discussion about green R&D activities. It demonstrates that the differences in green and non-green innovations are not caused by firm sizes. In this regard, we suggest future research could take into account of the possible heterogeneity of green attributes in R&D to avoid omitted variable bias. In terms of policy recommendations, for non-green innovations, government grants should focus on supporting SMEs from the perspective of alleviating financing constraints. For green innovations, a generous and comprehensive subsidy policy with more rigorous supervision should be adopted.

Table 5.1: Firm Size Heterogeneity in Innovation Policy Incentives

Dependent	*lnPatent*				*lnGreenPatent*			
$\tau(Subsidy)$		$t-1$	t	$t+1$		$t-1$	t	$t+1$
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
A: Subsample of SMEs								

lnRD	**0.0626*** **	0.0469**	0.0497**	0.0708***	**0.0143**	0.0071	0.0064	0.0059
	(3.190)	(2.327)	(2.487)	(2.977)	(1.410)	(0.701)	(0.628)	(0.489)
lnRD x Subsidy		**0.0772*** **	**0.0741*** **	**0.0950*** **		**0.0379*** **	**0.0444*** **	**0.0255**
		(3.209)	(2.590)	(3.154)		(2.838)	(3.039)	(1.426)
Subsidy		0.1032**	0.0878*	0.0796		0.0374	0.0641**	0.0503
		(2.380)	(1.747)	(1.482)		(1.511)	(2.275)	(1.577)
_cons	2.8565***	2.8909***	2.8897***	2.6681***	-0.2141	-0.2422	-0.2671	-0.3006
	(4.227)	(4.254)	(4.200)	(3.496)	(-0.718)	(-0.825)	(-0.888)	(-0.883)
N	10435	10435	10435	8648	10435	10435	10435	8648
R2	0.06	0.07	0.07	0.03	0.08	0.08	0.08	0.06
B: Subsample of Large Firms								
lnRD	**0.0175**	0.0200	0.0201	0.0129	**0.0162**	0.0058	0.0084	0.0124
	(0.787)	(0.885)	(0.892)	(0.547)	(1.210)	(0.420)	(0.621)	(0.877)
lnRD x Subsidy		**-0.0163**	**-0.0220**	**-0.0366***		**0.0532*** **	**0.0604*** **	**0.0456*** **
		(-0.954)	(-1.016)	(-1.665)		(2.904)	(3.024)	(2.627)
Subsidy		0.0160	0.0113	-0.0390		0.0532**	0.0481*	0.0183
		(0.527)	(0.313)	(-1.003)		(2.097)	(1.676)	(0.609)
_cons	1.5042*	1.5179*	1.5032*	1.3809*	0.3689	0.3051	0.3283	0.3288
	(1.917)	(1.928)	(1.905)	(1.659)	(0.624)	(0.516)	(0.557)	(0.572)
N	11262	11262	11262	9336	11262	11262	11262	9336
R2	0.07	0.07	0.07	0.06	0.21	0.21	0.21	0.17
Control Variables and Fixed Effects for Table A and Table B								
CONTROL	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
YEAR	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
INDUSTRY	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
COMPANY	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Note: *, ** and *** indicate significance levels of 10%, 5% and 1%, respectively. Values in parentheses represent t values, all regressions are cluster adjusted.

5.1.2 Differences in High- and Low- Polluting Firms

Industry heterogeneity may lead to different intentions of R&D activities. Qi et al. (2018) pointed out that high-polluting firms are more willing to pursue green innovations as sustainable development becomes universally acknowledged in China. This is because dirty companies are more likely to bear penalties for pollution emissions (Hsu et al., 2022) and environmental regulations will force them into green transitions. For these considerations, it is also plausible that non-green companies have stronger incentives to innovate green products under the intimidation of pollution penalties. To exclude the mechanism of avoiding pollution penalties, we refer to the studies of Tanaka et al. (2014) and Qi et al. (2018) and explore the different impacts of government subsidies on the R&D efficiency between polluting and non-polluting firms. In specific, we first obtained the annual SO_2 emissions of listed companies from the CSMAR database. Subsequently, we take the average value at the industry-year level by weighting the total assets. Thirdly, the full sample is divided into high- and low- polluting subgroups based on the median of all industries by year. We use these two subsamples to regress the equations (1) and (3) respectively and obtain four sets of results. Table 5.2 reports our findings.

Our regressions demonstrate that only high-polluting firms have significant intentions to innovate non-green products. The coefficient values of non-green innovations are significantly positive in high-polluting firms but insignificant in low-polluting ones. Moreover, the green R&D efficiency is insignificant for both types of firms. In more detail, the coefficient of non-green R&D input, *lnRD*, is 0.0579 and significant for high-polluting firms shown in Model (1) of Table A, and 0.0184 but insignificant for low-polluting firms shown in Model (1) of Table B. In addition, the green R&D efficiency are 0.0045 and -0.0061 and none of them are significant for high- and low-polluting firms, respectively. It shows that these high-polluting firms are more capable of R&D activities, indicating that we have to be adequately careful when making environmental regulations. This is in line with our point of view that the incentives of the market competition are insufficient and the green transition for polluting companies is of great importance.

Our further investigation rules out the mechanisms that companies pursue green innovations just for avoiding pollution penalties. The interaction analysis shows that government subsidies significantly contribute to green R&D efficiency for both high- and low- polluting firms. In specific, the coefficient values of the interaction term between the R&D investment and the lagged period subsidies, *lnRDxSubsidy*, are 0.0750 in Model (6) of Table A for high-polluting firms and 0.0500 in Model (6) of Table B for low-polluting ones. The effects of the current period subsidies on the efficiency of R&D activities are 0.0787 and 0.0395 for high- and low- polluting firms. And that of the forward period subsidies are 0.0511 and 0.0674 for high- and low- polluting firms, respectively. The interaction terms in all these three models are significantly positive, indicating that government subsidies promote the R&D efficiency not only for high-polluting firms but also for low-polluting ones that have weaker intentions to avoid pollution penalties.

To sum up, our findings exclude the impact of penalties intimidation on green R&D intentions. The regression results show that government subsidies do significantly and substantially stimulate the R&D efficiency of green innovations, especially for companies that are exposed to a lower risk of pollution penalties. In addition, a cross-sectional comparison of non-green and green innovations reveals that the main findings of this paper are robust across high- and low- polluting firms. That is, government subsidies significantly increase the efficiency of green innovations. In contrast, they have an insignificant impact on the efficiency of non-green innovations. This is consistent with our previous conclusions.

Table 5.2: Subsidy Effects on R&D Efficiency for High- and Low- Polluting Firms

Dependent	*lnPatent*				*lnGreenPatent*			
$\tau(Subsidy)$		$t-1$	t	$t+1$		$t-1$	t	$t+1$
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
A: Subsamples from High Polluting Firms								
lnRD	**0.0579****	0.0591**	0.0568**	0.0535*	**0.0045**	-0.0190	-0.0166	-0.0182
	(2.056)	(2.086)	(2.009)	(1.795)	(0.368)	(-1.075)	(-0.961)	(-1.014)
lnRD x Subsidy		**-0.0219**	**-0.0052**	**-0.0068**		**0.0750*****	**0.0787*****	**0.0511****
		(-0.945)	(-0.175)	(-0.215)		(3.180)	(3.057)	(2.179)
Subsidy		0.0476	0.0539	0.0099		0.0321	0.0834***	0.0521
		(1.438)	(1.349)	(0.211)		(1.111)	(2.708)	(1.581)
_cons	2.2096**	2.2375**	2.2489**	0.7077	0.0045	-0.4625	-0.4377	-1.0150*
	(2.137)	(2.172)	(2.182)	(0.786)	(0.368)	(-0.703)	(-0.659)	(-1.726)
N	8449	8449	8449	6802	13102	8449	8449	6802
R2	0.07	0.07	0.07	0.04	0.19	0.22	0.22	0.18
B: Subsamples from Low Polluting Firms								
lnRD	**0.0184**	0.0198	0.0193	0.0264	**-0.0061**	-0.0130	-0.0106	-0.0099
	(0.661)	(0.716)	(0.688)	(0.832)	(-0.368)	(-0.773)	(-0.634)	(-0.521)
lnRD x Subsidy		**-0.0012**	**-0.0055**	**-0.0318**		**0.0500*****	**0.0395****	**0.0674*****
		(-0.037)	(-0.145)	(-0.775)		(2.697)	(2.135)	(3.362)
Subsidy		-0.0906	-0.0774	-0.1221*		-0.0022	-0.0054	0.0494
		(-1.622)	(-1.315)	(-1.653)		(-0.072)	(-0.171)	(1.229)
_cons	4.3646***	4.4741***	4.4702***	4.1857***	-0.5824	-0.4651	-0.4861	-0.2137
	(4.168)	(4.334)	(4.314)	(3.481)	(-0.974)	(-0.792)	(-0.827)	(-0.320)
N	6430	6430	6430	5175	6430	6430	6430	5175
R2	0.07	0.07	0.07	0.04	0.13	0.13	0.13	0.11
Control Variables and Fixed Effects for Table A and Table B								
CONTROL	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
YEAR	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
INDUSTRY	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

COMPANY	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Note: *, ** and *** indicate significance levels of 10%, 5% and 1%, respectively. Values in parentheses represent t values, all regressions are cluster adjusted.

5.2 Robustness Tests

The regression results in this paper are robust. First, we refer to the studies of Zhu and Xu (2003), Yu et al. (2010) and Li and Zheng (2016), using the lagged, current, and forward period subsidies to regress the equations, and obtain robust results. Second, the subsample regressions regarding corporate motives on R&D manipulation have found that government subsidies are more likely to enhance the R&D efficiency of green innovations than non-green ones in all subsamples. Thirdly, we also investigate the mechanisms of financing constraints and penalty intimidation. The results show that the impact of government subsidies on R&D efficiency is not significantly different between SMEs and large ones, or between high- and low- polluting firms. The next section presents more robustness tests with regard to the type of government incentives and time intervals.

5.2.1 Types of Innovation Subsidy Policies

Now we investigate the effects of two types of innovation policies separately. In our above discussions, government incentives are measured according to Li and Zheng (2016). Specifically, we treat both functional and selective industrial policies as government subsidies. The method for selecting keywords is detailed in the Appendix. In this section, the robustness tests distinguish between these two types of industrial policies by measuring the total subsidies separately. The regression results shown in Table 5.3 are consistent with our conclusions drawn from Table 4.2A, demonstrating the robustness of our results.

Table 5.3: Robustness Testing of Innovation Policy Subsidy Types

Dependent	*lnPatent*				*lnGreenPatent*			
$\tau(Subsidy)$		$t-1$	t	$t+1$		$t-1$	t	$t+1$
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
A: Subsidy Measured Using Functional Industrial Policy								
lnRD	0.0429***	0.0436***	0.0434***	0.0413**	0.0072	0.0010	0.0018	0.0076
	(2.832)	(2.833)	(2.814)	(2.427)	(0.832)	(0.115)	(0.207)	(0.800)
lnRD x Subsidy		**-0.0075**	**-0.0134**	**-0.0067**		**0.0861*** **	**0.0866*** **	**0.0609** **
		(-0.245)	(-0.395)	(-0.196)		(3.952)	(3.547)	(2.317)
Subsidy		-0.0074	0.0320	-0.0147		0.0303	0.0435	0.0791*
		(-0.145)	(0.521)	(-0.225)		(0.916)	(1.121)	(1.885)
_cons	1.7487***	1.8545***	1.8404***	1.5764**	0.0893	0.0308	0.0330	-0.0491
	(2.961)	(3.123)	(3.091)	(2.437)	(0.277)	(0.095)	(0.102)	(-0.150)
N	21704	21704	21704	17991	21704	21704	21704	17991
R2	0.05	0.05	0.05	0.04	0.15	0.15	0.15	0.12
B: Subsidy Measured Using Selective Industrial Policy								
lnRD	0.0429***	0.0419***	0.0433***	0.0415**	0.0072	-0.0050	-0.0023	0.0049
	(2.832)	(2.735)	(2.817)	(2.453)	(0.832)	(-0.564)	(-0.260)	(0.515)
lnRD x Subsidy		**0.0059**	**-0.0025**	**-0.0041**		**0.0676*** **	**0.0678*** **	**0.0458*** **
		(0.441)	(-0.145)	(-0.217)		(5.521)	(5.139)	(3.716)
Subsidy		0.0060	-0.0001	-0.0476		0.0546***	0.0617***	0.0391*
		(0.258)	(-0.004)	(-1.489)		(2.936)	(2.923)	(1.844)
_cons	1.7487***	1.8505***	1.8523***	1.5900**	0.0893	0.0146	0.0132	-0.0622
	(2.961)	(3.118)	(3.119)	(2.469)	(0.277)	(0.045)	(0.041)	(-0.191)
N	21704	21704	21704	17991	21704	21704	21704	17991
R2	0.05	0.05	0.05	0.04	0.15	0.15	0.15	0.12
Control Variables and Fixed Effects for Table A and Table B								
CONTROL	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
YEAR	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
INDUSTRY	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
COMPANY	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Note: *, ** and *** indicate significance levels of 10%, 5% and 1%, respectively. Values in parentheses represent t values, all regressions are cluster adjusted.

5.2.2 Time Interval

We then explore the different effects of government subsidies before and after 2012. In 2007, the 17th National Congress of the Communist Party of China clearly put forward the concept of ecological civilization construction. In 2012, the 18th National Congress of the CPC proposed the requirements to vigorously strengthen the construction of eco-civilization and incorporate it into the general layout of the “Five in One” cause with Chinese characteristics. This indicates that eco-civilization has become an important part of the government’s work since 2012.

Through empirical tests, Zhang et al. (2020) showed that China’s official assessment mechanism has undergone a systematic change around 2013. After that, promotions depend not only on the GDP growth rate, but also on environmental protection. Meanwhile, the intensity of direct subsidies increased sharply during this period, suggesting that government subsidies may stimulate more R&D efficiency in green innovations in this political context. If the green appraisal drives the government to enforce stricter supervision of corporate innovations, the effects of subsidies on promoting green innovations will be more significant after 2012.

The robustness test in this section divides the full sample into two subsamples based on time, in particular, the subgroup from 2007 to 2013 and that from 2014 to 2021. Table 5.4 reports the regression results. It shows that the effect of government grants on green R&D efficiency is insignificant in the time interval from 2007 to 2013. However, the government subsidies do significantly stimulate the R&D efficiency of green innovation in the time interval from 2014 to 2021. This is consistent with our discussion above and demonstrates robustness.

Table 5.4: Robustness Testing of Time Interval

Dependent	*lnPatent*				*lnGreenPatent*			
$\tau(Subsidy)$		$t-1$	t	$t+1$		$t-1$	t	$t+1$
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
A: Subsamples in 2007-2013 Interval								
lnRD	0.0322	0.0282	0.0367	0.0109	0.0348	0.0355	0.0293	0.0337
	(0.814)	(0.694)	(0.920)	(0.262)	(1.080)	(1.070)	(0.897)	(1.014)
lnRD x Subsidy		**0.0101**	**-0.0234**	**0.0607****		**-0.0004**	**0.0341**	**-0.0019**
		(0.312)	(-0.937)	(2.329)		(-0.017)	(0.923)	(-0.081)
Subsidy		0.1030**	0.0012	-0.0370		-0.0285	0.0605	-0.0377
		(2.010)	(0.027)	(-0.796)		(-0.604)	(0.883)	(-0.733)
_cons	1.9221	1.9714	1.9244	2.4227	1.5970	1.6256	1.7207	1.6912
	(1.084)	(1.106)	(1.084)	(1.389)	(1.250)	(1.271)	(1.335)	(1.306)
N	3453	3453	3453	3389	3453	3453	3453	3389
R2	0.02	0.02	0.02	0.02	0.03	0.03	0.03	0.03
B: Subsamples in 2014-2020 Interval								
lnRD	0.0228	0.0241	0.0234	0.0279	0.0035	-0.0070	-0.0048	-0.0031
	(1.415)	(1.480)	(1.418)	(1.625)	(0.374)	(-0.725)	(-0.509)	(-0.310)
lnRD x Subsidy		**-0.0016**	**-0.0034**	**-0.0163**		**0.0553*****	**0.0586*****	**0.0476*****
		(-0.111)	(-0.173)	(-0.825)		(4.092)	(4.528)	(3.556)
Subsidy		-0.0283	-0.0052	-0.0484		0.0479**	0.0514**	0.0350*
		(-1.167)	(-0.156)	(-1.480)		(2.401)	(2.432)	(1.664)
_cons	1.4390**	1.5907**	1.5719**	1.5265**	0.0889	0.0575	0.0528	0.0364
	(2.060)	(2.283)	(2.250)	(2.166)	(0.205)	(0.133)	(0.123)	(0.084)
N	16509	16509	16509	16331	16509	16509	16509	16331
R2	0.03	0.03	0.03	0.03	0.12	0.13	0.13	0.13
Control Variables and Fixed Effects for Table A and Table B								
CONTROL	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
YEAR	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
INDUSTRY	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
COMPANY	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Note: *, ** and *** indicate significance levels of 10%, 5% and 1%, respectively. Values in parentheses represent t values, all regressions are cluster adjusted.

6. Conclusion

Based on patent authorizations and innovation incentives data of more than 4000 Chinese A-share listed companies during 2007–2021, we investigate the differences in the impact of government subsidies on green and non-green R&D activities. Specifically, we investigate whether there are differences between green and non-green innovations stimulated by the market competition and government subsidy. Within the framework of the research on green innovations, we introduce political performance incentives to demonstrate a novel explanation. This complements existing mechanisms which are government environmental regulation and green premiums. Our study provides empirical evidence and policy recommendations for sustainable economic development in China.

The findings of this paper indicate that green attributes lead to corporate innovations different from non-green innovations regarding R&D intentions, market-driven force and government policy incentives. First, companies are more willing to take R&D activities for non-green innovations than for green ones due to the double externality (Rennings, 1998). For example, green attributes may raise the opportunity cost of green innovation. Second, in line with the existing points, market competition significantly drives non-green R&D activity. However, it fails to promote the efficiency of green R&D activity, or, even worse, significantly inhibits it. Intuitively, the lack of potential monopoly profits from eco-inventions depresses corporate willingness to pursue green innovations. Third, government subsidies substantially stimulate green R&D efficiency, but the effects on non-green R&D activities are not significant. Our subgroup regressions illustrate that there is less motive to manipulate R&D in green innovation. In this regard, the government does conduct stricter surveillance review on green innovations. In further discussions, subsidy incentives significantly vary between SMEs and large ones in terms of non-green R&D activities. In contrast, this difference is not significant with respect to green innovations. This demonstrates that financing constraints are not the only channel through which the government promotes green R&D activities. In addition, no significant effect of subsidies on non-green innovations is found for either low- or high- polluting firms, yet they significantly promote green innovations in both industries. This further excludes the impact of penalties on green R&D intentions.

The policy implications of this article are as follows. First, the performance assessment-oriented mechanism for green innovations can be improved, and the government can play a more important role as a "gatekeeper" and "goalkeeper" to deter rent-seeking or R&D manipulation behaviors, thus accelerating sustainable developments through green inventions. The government should pay more attention to a combination of policy and market competition in improving the S&T innovation system and accelerating the implementation of the innovation-driven development strategy. From a perspective of delivering incentives, it is necessary to balance the mixed effects of direct and indirect subsidies, and to promote the cooperation between the government, industry and academia. In terms of monitoring, it is not only essential to prevent power-for-money transactions, but also important to encourage local governments and officials to promote green innovations by adjusting appraisal indexes of political performance properly. Second, direct subsidies should not be seen as invalid. The government should maintain a considerable involvement in green innovations. This is because the environmental externalities of green innovations are not adequately priced in, and companies lack incentives to pursue green innovations. As a result, the government can play an important role in monitoring, supervising and penalizing pollution emissions and providing compensation for R&D activities through subsidies. Third, the size of the companies should be taken into consideration when making policies. For non-green innovations, government grants should focus on supporting SMEs in alleviating their financing constraints. While for green innovations, more comprehensive subsidy policies that cover more companies should be adopted. It is particularly valuable to strengthen monitoring in order to improve the overall innovative quality. Finally, Aghion (2015) suggests future innovation-related academic research should address the importance of heterogeneity. Similarly, our study shows that the research in this regard should pay attention to the potential heterogeneity of R&D activities, such as green versus non-green ones, otherwise the researchers may bring in omitted variable bias.

Appendix

A. Identification of Innovation Subsidy Policy and Selection of Keywords

A1. Functional Industrial Policy

In 2015, the Central Committee of the CPC and the State Council issued the "General Program on Systematically Promoting Comprehensive Innovation Reform Experiment in Some Regions". The "main tasks" of the document pointed out some requirements to spur innovations. For example, it is necessary to establish the indicators of S&T innovations and complete the evaluation system of innovation-driven development. The government must focus on the protection of intellectual property rights to promote industrial development…... It is essential to accelerate industrialization and capitalization for the realization of high-tech achievements. We have to enhance the support and leading role of S&T in economic and social development. It is important to make government, industry, academia, and research work together. The government should fully stimulate the inherent power of corporate innovations. It is vital to make full use of global S&T achievements and high-level talents in order to carry out the cooperation of innovations on the international stage. The government must accelerate the establishment of a deeply integrated open innovation mechanism. It is recommended to deeply reform foreign investment by completing the management system of FDI. In addition, it is also necessary to promote the opening of S&T projects to the world and encourage overseas-funded companies to introduce more innovation achievements for Chinese industrialization.

The documents above are recognized as functional industrial policies. This is because Li and Zheng (2016) pointed out that functional industrial policies mainly refer to science and technology investment, infrastructure development and talent cultivation. In this regard, we classify them into this category and the following keywords are extracted: *science, technology, research, chemical, development, patent, subject, industry-university-research, automatic, integration, joint, laboratory, innovation, development, knowledge, education, training, campus, university, talent, academician, PhD, graduate, introduce, two new products, triple one innovation*. Finally, the percentage of the policies containing any of the above keywords is 36%.

A2. Selective Industrial Policy

In 2016, the Central Committee of the CPC and the State Council announced “the Outline of National Innovation-driven Development Strategy”. In the same year, the State Council released the “Notice of the State Council on the Issuance of the ‘Construction Program of the Innovation Demonstration Zone for the Implementation of the 2030 Agenda for Sustainable Development in China’”. The “strategic tasks” in these documents stressed some key points. For example, it is important to develop a new generation of information network technology. We must develop intelligent and green manufacturing technologies, and then promote the manufacturing industry to a high level of the value chain. It is necessary to develop ecological, green, efficient, safe as well as modern agricultural technologies to ensure the security and safety of food. In addition, we have to develop safe, clean and efficient energy technologies in order to promote the revolution in energy, production and consumption. The government should develop marine and space advanced and applicable technologies……

In addition, in 2016, the Notice of the State Council on "the Issuance of the General Plan for Strengthening the Construction of National Science and Technology Innovation Center in Beijing" pointed out that we have to focus on some specific industries, such as smart manufacturing, biomedicine, integrated circuits, new displays, modern seed, mobile Internet, aerospace and green manufacturing. It requires building a number of national technology support centers that play a core leading role in the innovation of priority areas…… In specific, the government must focus on breakthroughs in high-performance computing, graphene materials, intelligent robotics and a number of key common technologies. It is necessary to promote the transformation of the energy mix to clean and low-carbon patterns……

The policies above point to some specific industries, such as energy, information technology, and ecological and environmental protection. According to Li and Zheng (2016), we classify them into "selective industrial policies". The keywords are extracted from their descriptions, including: *two-wheel drive, intelligent, manufacturing, aviation, aerospace, equipment, high-tech, high-efficiency, high-end, high-performance, new, modern, materials, vanadium, titanium, lithium, nickel, laser, precision, core, crystal, graphene, biological, medical, cancer, blood, medicine, toxin, extract, mobile, Internet, information, software, digital, AI cloud computing, big data, GIS, Beidou, circuit, robot, energy, pioneer, ocean, space, green manufacturing, greening, re-greening, environment, carbon, waste, sludge, clean, environmental, smokeless, energy saving, new energy, sun, atmosphere, photovoltaic, photoelectric, wind, water, soil, ecology, organics, industrial restructuring*. Ultimately, the percentage of the policies containing any of the above keywords is 22%.

A3. General Subsidy Policy

In order to have a comprehensive understanding of our classification results, we also extract the keywords that are unrelated to innovation incentives and name them as general government subsidies. Specifically, the keywords are as follows: *renovation, expansion, listing, transformation, industry, projects, capitalization, export, going out, abroad, international, foreign trade, open, disease, health, pension, beneficiary, township, village, poverty alleviation, remediation, pollution, emission reduction, emission, shipbuilding, rail, transportation, smart city, party, tax reform, interest discount, amortization, processing fee, deferred revenue, loan, income related, total, operation, operating, sales, import, outsourcing, market development, line subsidy, unemployment, employment, post, preservation, support, micro, zombie enterprises, social welfare, disability, elderly, social security, employee training, vocational training, occupation, human society, freight subsidy, resettlement, demolition, relocation, land acquisition, compensation, reimbursement, disaster, flood, epidemic, hardship, special hardship, fire, military, strategy, central, infrastructure, old cars, scrapped, obsolete, trade-in, daily activities, food, agriculture, meat, milk, fish, heating, natural gas, oil price, coal storage, coal mine, fuel, electricity, boiler, public transportation, Spring Festival, culture, literature, economy, finance, bank, civilization, labor, electronics, business, service industry, hotel, tourism, cinema, movie, house, road, logistics, local financial subsidy income, Henan Province famous brand industry*. The general subsidy policies containing these keywords is 33%.

Notably, the percentage of unclassified policies is less than 9%.

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