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# The effect of the policy mix of green credit and government subsidy on environmental innovation

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ABSTRACT

We examine to what extent ‘policy mix’ of green credit policy and government subsidy affects high-quality environmental innovation of high-polluting firms. The green credit policy is a special environmental regulation that guides the distribution of credit from banks. Using the difference-in-difference method, we find that Green Credit Guidelines (GCGs) have a negative impact on the high-quality environmental innovation of high-polluting firms in China. However, the negative relationship between GCGs and high-quality environmental innovation depends on the level of government subsidy. Subsidies can effectively correct the negative impact of GCGs. The mechanism analysis shows that GCGs hinder high-quality environmental innovation through two channels: (1) increase in compliance costs and (2) lack of long-term bank credit that supports environmental innovation. Government subsidies can play a moderating role in the second channel.

## 1. Introduction

A consequence of China’s tremendous economic development is the huge environmental costs. Environmental innovation is a cost-effective way to achieve the dual goals of economic development and environmental protection (Wurlod and Noailly, 2018; Rennings, 2000; Lv et al., 2021; Dorfleitner and Grebler, 2022). As a public interest representative, the government has social responsibilities committed to guiding firms to be more active in conducting high-quality environmental innovation through various regulatory and incentive measures (Ji et al., 2021a; Ji et al., 2021b). The Green Credit Guidelines (GCGs) were introduced in China in 2012 and require commercial banks to assess a firm’s environmental risks when granting credit. They aim to restrict the blind expansion of high-polluting industries and guide them to achieve a green transition through high-quality environmental innovation (Hu et al., 2021; Nesta et al., 2014). Additionally, the Chinese government offers extensive subsidies to support innovative activities (Bai et al., 2019). This study explored the impact of GCGs on firms’ high-quality environmental innovation and the moderating role of government subsidies.

This study focuses on high-quality environmental innovation embodied in environmental invention patents, which reflects a firm’s real innovation level (Hu et al., 2020). Using the difference-in-difference (DID) method, we find that GCGs have a negative effect on high-polluting firms’ high-quality environmental innovation. This result is counterintuitive and deviates from the initial intention of GCGs. Given the importance of policy mix in promoting innovation, Boekholt (2010) showed that the interaction of policy instruments significantly influence the quantity and quality of innovation. Therefore, we examine the interaction effect of GCGs and government subsidies on high-quality environmental innovations. We find that the policy mix of GCGs and government subsidies is positively related to high-quality environmental innovation. The effect of the policy mix is more pronounced for state-owned enterprises (SOEs), firms with political connections, firms in areas with low marketisation, and large firms. Our inferences remain the same after controlling for other firm-level determinants of high-quality environmental innovation, such as firm size, Tobin’s Q, leverage ratio, and cash holdings, as well as firm and year fixed effects. The result is

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robust to alternative definitions of treatment and control groups and alternative measures of high-quality environmental innovations.

Furthermore, we explore why GCGs hinder high-quality environmental innovation. High-polluting firms need to increase investment in pollution control measures to meet compliance requirements (Jorgenson and Wilcoxen, 1990), which may crowd out investment in environmental innovation. We show that compliance costs increase for high-polluting firms after the implementation of GCGs, and high compliance costs crowd out high-quality environmental innovation. Moreover, we examine the bank credit support channel for high-quality environmental innovation. We find that bank credit does not flow to high-polluting firms with high-quality environmental innovation, which creates credit allocation inefficiency after GCGs. Compliance with GCGs is mandatory for banks. Owing to information asymmetry, high uncertainty associated with innovation, and the tendency to avoid violating GCGs, banks tend to decline loans to high-polluting firms actively engaged in innovative activities. However, we show that government subsidies can act as certifications for firms with a high level of environmental innovation and help alleviate credit allocation inefficiency.

Our study contributes to the research in two ways. First, to the best of our knowledge, this study is the first to investigate the relationship between GCGs and high-quality environmental innovation. Existing literature explores the effect of GCGs on debt financing (Liu et al., 2019), firm performance (Zhang and Vigne, 2021; Yao et al., 2021), and total factor productivity (Wen et al., 2021). Hu et al. (2021) found a positive relationship between GCGs and environmental innovation. Different from them, this study investigates high-quality environmental innovation as measured by environmental invention patents. High-quality environmental innovation aims to promote technological progress and can be regarded as effective innovation (Du et al., 2022). This study finds a negative relationship between GCGs and high-quality environmental innovation. Additionally, we explicitly examine the channel by which GCGs affect high-quality environmental innovation — the compliance costs channel and bank credit channel.

Second, given that government subsidy is a commonly used policy instrument in China, our study is the first to empirically examine the effect of the policy mix of green credit policy and government subsidy. The lack of empirical studies on policy mix constitutes a remarkable gap because many countries have various policy instruments to promote environmental innovation. GCGs are used to regulate firm emissions, and subsidies are used to support environmental innovation. However, the interaction effect of joint policies (comprising both GCGs and subsidies) on the development of environmental innovation remains largely unverified. A comprehensive analysis of the effects and mechanisms can facilitate the design of environmental innovation incentives and maximise social welfare.

The remainder of this paper is organised as follows. Section 2 discusses the literature and hypotheses, and Section 3 describes the research design. Subsequently, Sections 4 and 5 present the main empirical and robustness test results, respectively. Finally, Section 6 concludes the paper.

## 2. Literature review and hypothesis development

The green credit policy is an innovative form of environmental regulation, and the existing literature shows concern for the effect of environmental regulations on firm innovation. According to Porter's hypothesis developed by Porter et al. (1995), properly crafted environmental regulations can effectively stimulate firm innovation. Using various environmental regulations in different countries, scholars have found that the Porter hypothesis holds in the environmental innovation field. Using US manufacturing industries as a research sample, Pickman (1998) found a statistically significant positive relationship between environmental innovation and environmental regulation as measured by pollution abatement and control expenditure (PACE). Based on a novel dataset of 1566 UK firms, Kesidou and Demirel (2012) provided evidence that stricter regulations are important drivers of eco-innovation. In particular, considering the quality of innovation, Nesta et al. (2014) indicated that environmental regulations contribute to the increase in high-quality environmental patents in OECD countries. Using data on listed firms in China from 2006 to 2020, Du et al. (2022) found a positive relationship between the establishment of monitoring stations and local firms' green innovation. To limit emissions, GCGs cause high-polluting firms to face stricter supervision from the government and greater pressure on credit restrictions from banks. According to the original design of GCGs, high-polluting firms can relieve regulatory pressure and obtain more bank credit through high-quality environmental innovation. Thus, firms are motivated to improve their energy efficiency and environmental protection capabilities in the pursuit of legitimacy (Li et al., 2017). In this regard, GCGs may guide high-polluting firms to conduct high-quality environmental innovation.

However, GCGs might become a paradox and deviate from the initial intention to encourage environmental innovation. According to neo-classical economic theory, environmental regulation increases compliance costs, squeezes out funds used for R&D, and limits firms' ability to innovate, which is a phenomenon known as the 'compliance cost' effect (Gollop and Roberts, 1983; Wagner, 2007). Compared to environmental innovation, investing in pollution abatement facilities has several advantages. Environmental investment can help achieve evident abatement effects in a short time and avoid excessive time input and R&D uncertainty. Chen et al. (2021) found that the carbon emission trading system in China is related to a significant decrease in environmental innovation. As a target of GCGs, high-polluting firms tend to increase investment in pollution control (Jorgenson and Wilcoxen, 1990; Yu et al., 2022), which may crowd out funds for environmental innovation. Owing to this crowding-out effect, the environmental innovation capability of high-polluting firms is weakened. Additionally, GCGs require banks to limit credit to firms with high environmental risks (Liu et al., 2019; Xu and Li, 2020). In practice, banks have difficulty identifying firms' environmental risks. In this case, given the pressure from the government, commercial banks choose to explicitly reduce all credit to high-polluting firms regardless of what the credit is used for (Wen et al., 2021). Innovation is associated with high uncertainty, and banks bear innovation risk but do not share innovation benefits (Stiglitz, 1985; Bhattacharya and Ritter, 1983; Freel, 2007). Therefore, banks impose stricter credit restrictions on high-polluting firms actively engaged in innovative activities. Thus, the innovation capability of high-polluting firms is further weakened. Hence, GCGs might hinder high-quality environmental innovations in high-polluting firms.

Thus, the impact of environmental regulations on environmental innovations may be positive or negative (Du et al., 2021). Whether the Porter hypothesis is true for GCGs depends on how the policy is implemented and how banks and high-polluting firms respond to it. Therefore, we propose the following competing hypotheses:

**Hypothesis 1**. GCGs have a positive impact on high-quality environmental innovation of high-polluting firms.

**Hypothesis 2**. GCGs have a negative impact on high-quality environmental innovation of high-polluting firms.

The uniqueness of environmental innovation is reflected in its 'double externalities' (Marchi, 2012; Rennings, 2000). First, as discussed in the general innovation literature, innovation has a positive externality: firms that invest in innovation and R&D activities cannot fully own the value created due to knowledge spillover.[1] Second, environmental innovation has an environmental positive externality; part of the benefit of environmental innovation is owned by society in the form of

[1] Knowledge spillovers happen when knowledge is unintentionally shared among individuals, firms, and countries (Fallah and Ibrahim, 2004; Isakksson et al., 2016; Nichloas et al., 2013).

reduced environmental damage. Additionally, firms investing in cleaner technologies incur higher costs than polluting competitors. Owing to these externalities, firms may lack incentives for environmental innovation. The market failure caused by double externalities highlights the role of environmental regulations and government (Bi et al., 2016; Huang et al., 2019). Therefore, the interaction between GCGs and government subsidies is worth investigating. There are different possibilities regarding the performance of the policy mix of government subsidies and GCGs. The interaction between different policies may lead to positive, negative, or neutral effects (Costantini et al., 2017). The overall effect of a policy mix depends on how the constituent policies interact with each other (Flanagan et al., 2011). If policies are not appropriately coordinated, a policy mix can become a 'policy mess' (Kemp and Pontoglio, 2011). For example, Sorrell and Sijm (2003) found that adding policy instruments to the emission trading system may result in overlapping and conflicting instruments instead of coherence. Hu et al. (2020) found that government subsidies negatively moderate the positive impact of China's carbon emissions trading pilot on firms' innovation. If environmental regulations have played a positive role in stimulating high-quality environmental innovation, the emergence of government subsidies may negatively affect this positive relationship. This is because high-polluting firms can ease credit penalties through high-quality environmental innovation after GCGs. This can also alleviate the financial constraints of high-polluting firms by providing funding directly, and high-polluting firms may lose the incentive to conduct high-quality environmental innovation. Thus, the interaction between GCGs and government subsidies is not conducive to high-quality environmental innovations.

Whether a firm decides to invest in innovation depends on two factors: the incentive to conduct innovation and the capability to raise required funds (Peneder, 2008). A policy mix involving complementary interactions contributes to raising the level of innovation from both 'incentive' and 'capability' aspects (Rogge and Schleich, 2018; Duan et al., 2018). Using a non-parametric matching method, Bérubé and Mohnen (2009) found that Canadian plants that benefit from R&D grants and R&D tax innovate more than plants that benefit only from R&D tax. Magro and Wilson (2013) empirically verified the effectiveness of the policy mix of innovation advisory services and innovation vouchers in Italy. Further, applying data from German firms, Greco et al. (2020) found that the combined impact of general innovation and environmental policy instruments on eco-innovation is greater than that of individual policies. Using game theory, Chang et al. (2019a) found that a joint tax subsidy policy can encourage manufacturers to pursue eco-innovation. Under harsh environmental regulations, high-polluting firms are motivated to relieve regulatory pressure through high-quality environmental innovation. However, the huge compliance costs and increased credit discrimination effected by GCGs may cause high-polluting firms to lose their capability for environmental innovation. In this case, the role of government subsidies is highlighted. On the one hand, government subsidies can directly supplement funding for environmental innovation (Almus and Czarnitzki, 2003; Bianchi et al., 2019; González and Pazó, 2008; Huang et al., 2019; Xie et al., 2019; Li et al., 2021). On the other hand, government subsidies have a certification effect (Wu, 2017) and could send a positive signal to banks to moderate their credit discrimination. Thus, government subsidies and GCGs can be combined to contribute to the environmental innovation of high-polluting firms.

Based on the above arguments, the combination of GCGs and government subsidies may have a positive or negative impact on high-quality environmental innovation. Therefore, we propose the following competing hypotheses:

**Hypothesis 3**. Government subsidies negatively adjust the positive relationship between GCGs and the high-quality environmental innovation of high-polluting firms.

**Hypothesis 4**. Government subsidies positively adjust the negative relationship between GCGs and the high-quality environmental innovation of high-polluting firms.

## 3. Research design

### 3.1. Data

GCGs target high-polluting firms; therefore, they are classified as the treated group, and non-high-polluting firms are classified as the control group. Following Zhang et al. (2019a) and Zhang and Vigne (2021), we measure the pollution density of two-digit industry codes one year before the GCGs and identify high-polluting firms according to the industry to which they belong. Four major pollutants were considered: sulphur dioxide, industrial dust (smoke), solid waste, and industrial sewage. The specific calculation steps are as follows. First, we calculate the per-output pollution emission of each type of pollutant for each industry: $UE_{i,j} = \frac{E_{i,j}}{Output_i}$, where $E_{i,\,j}$ is the emission of pollutant j in industry i, and $Output_i$ is the gross production value of industry i. Second, the per-output emissions of these four kinds of pollution are linearised and normalised: $UE^s_{i,j} = \frac{UE_{i,j} - min(UE_j)}{max(UE_j) - min(UE_j)}$, where max($UE_j$)and min($UE_j$) are the maximum and minimum levels of per-output emission of pollutant j across all industries, respectively. Finally, we calculate the pollution intensity of each industry: $\delta_i = \sum_{j=1}^{n} UE^s_{i,\,j}$. The median of $\delta_i$is 0.184, and we identify high-polluting firms as those in industries with an industry-level $\delta_i$ above or equal to 0.184.[2]

Green patent data include green patent information on the listed firm, its subsidiaries, associates, and joint ventures. Patent data were collected from the State Intellectual Property Office website. We compared the classification number of patents with the International Patent Classification Green Inventory (IPC-GI)[3] launched by the World International Property Organization (WIPO) to identify green patents. Industry-level pollution emission data were collected from the China Statistical Yearbook on the Environment. The industrial production value data for each industry come from the China Industrial Statistical Yearbook, and the rest of the data are from the CSMAR database. We winsorised the continuous variables at the 1st and 99th percentiles to eliminate the influence of extreme values.

Our initial sample includes all industrial firms[4] listed on the Shenzhen or Shanghai Stock Exchange (A-share). Subsequently, we exclude firm-year observations with (1) ST and *ST status, (2) industry change, and (3) missing data. After filtering, we obtain 8768 observations from 1602 firms — 730 from the treatment group and 872 from the control

[2] Highly polluting industries include the following: B06. Mining and washing of coal industry; B08. Ferrous metals mining and dressing industry; B09. Non-ferrous metals mining and dressing industry; B10. Non-metallic metals mining and dressing industry; B12. Other mining industries; C13. Agricultural and sideline food processing industry; C14. Food manufacturing industry; C15. Liquor, beverage, and refined tea manufacturing industry; C17. Textile industry; C20. Wood Processing, Timber, Bamboo, Cane, Palm Fibre, and Straw Products industry; C22. Paper making and paper product industry; C25. Processing of petroleum; coking; processing of nuclear fuel; C26. Raw Chemical Materials and Chemical Products industry; C27. Pharmaceutical industry; C28. Chemical fibre manufacturing industry; C30. Non-metallic Mineral Products; C31. Smelting and Pressing of Ferrous Metals industry; C32. Smelting and Pressing of Non-ferrous Metals industry; D44. Production and Distribution of Electric and Heat industry.

[3] According to the 'United Nations Framework Convention on Climate Change', IPC-GI summarises green patents into seven areas: transportation, waste management, energy conservation, alternative energy production, administrative regulatory or design aspects, agriculture or forestry, and nuclear power generation.

[4] Firms engaged in mining, manufacturing, and production and supply of electricity, heat, gas, and water are collectively referred to as industrial firms. They are the main sources of energy consumption and pollution emissions.

group.

### 3.2. Model specification and variable definition

The DID model has advantages in identifying causality; therefore, it is suitable for policy evaluations. This study uses DID to evaluate the effect of GCGs on high-quality environmental innovation and a difference-in-difference-in-difference (DDD) model to evaluate the moderating effect of government subsidies. The models were set as follows:

$$ln(1+GIP)_{it} = \alpha_0 + \alpha_1 Post_{it-1} + \alpha_2\ Controls_{it-1} + \eta_c + \tau_t + \varepsilon_{it} \quad (1)$$

$$ln(1+GIP)_{it} = \alpha_0 + \alpha_1 Post_{it-1} + \alpha_2 Post_{it-1}{*}Sub_{it-1} + \alpha_3 Sub_{it-1} + \alpha_4\ Controls_{it-1} + \eta_c + \tau_t + \varepsilon_{it} \quad (2)$$

The independent variables are lagged by one year, relative to the dependent variables; here, *i* represents the firm, and *t* represents the year. $Ln(1+GIP)_i$ is the natural logarithm of the number of green invention patents applied by firm i in year t plus 1. $Post_{it-1}$ is a dummy variable that equals 1 for firm i if it belongs to the high-polluting industry and after the promulgation of GCGs in 2012 and 0 otherwise. $Controls_{it-1}$ represents control variables, $\eta_c$ and $\tau_t$ denote the firm and year fixed effects, respectively, and $\varepsilon_{it}$ is the error term. Further, coefficient $\alpha_1$ captures the effect of GCGs on high-quality green innovation, and $Sub_{t-1}$ is measured as the natural logarithm of 1 plus the government subsidy received in year *t-1*. The coefficient of the interaction term ($Post_{it-1}$ * $Sub_{it-1}$) captures the moderating effect of the government subsidies.

In terms of measuring environmental innovation, following previous literature (Liu et al., 2021; Ren et al., 2021), we use the number of green invention patent applications (including independent and joint applications) by enterprise groups as a proxy.[5] The Chinese green patent system grants two types of green patents: invention and utility. Green invention patents must undergo rigorous examination. To obtain authorisation, innovation must meet the requirements of 'novelty, creativity, and practicality'. Conversely, green utility patents only need to be different from previously granted patents, and no substantial examination is required. Patents differ significantly in quality (Hirshleifer et al., 2012), especially in China. Firms in China tend to apply for low-quality patents for strategic purposes such as obtaining government subsidies (Dang and Motohashi, 2015). This study focuses on green invention patents that represent high-quality environmental innovation (Hu et al., 2020). In the robustness test, following Hall et al. (2005) and Chen et al. (2021), we used the number of green invention patents granted and forward citations of green patents to measure the level of firms' environmental innovation.

Following prior studies (Liu et al., 2021; Chen et al., 2021; Wen et al., 2021), we added 10 control variables in this study to control the firm-level characteristics that potentially affect firm's high-quality environmental innovation: firm size (Size), listing years (Age), asset-liability ratio (Leverage), return on assets (ROA), growth ability (TQ), cash holdings (Cash), fixed assets ratio (Fixed), ownership concentration (Top1), nature of equity (Nature), and board size (Board). The variable definitions are listed in Table 1.

**Table 1**
Variable definitions.

| Variables | Symbols | Definitions | Sources |
|---|---|---|---|
| High-quality green innovation | Ln(1 + GIP) | Natural logarithm of 1 plus the number of green invention patents applied by a firm in a year (Log) | State Intellectual Property Office |
| Government subsidy | Sub | Natural logarithm of 1 plus the government subsidy received by the firm of the period (Log) | CSMAR |
| Green credit policy | Post | A dummy variable equals 1 for high-polluting firms in or after 2012 and 0 otherwise (Dummy) | CSMAR |
| Firm size | Size | Natural logarithm of total assets (Log) | CSMAR |
| Asset-liability ratio | Leverage | Ratio of total liabilities to total assets (%) | CSMAR |
| Growth ability | TQ | Ratio of the sum of market value of tradable shares, book value of non-tradable shares, and liabilities to book value of total assets (%) | CSMAR |
| Listing years | Age | Natural logarithm of the number of years since listing (Log) | CSMAR |
| Return on assets | ROA | Return on total assets (%) | CSMAR |
| Fixed assets ratio | Fixed | Ratio of fixed assets to total assets (%) | CSMAR |
| Cash holdings | Cash | Ratio of the balance of cash and cash equivalents to total assets (%) | CSMAR |
| Nature of equity | SOE | A dummy variable representing the nature of equity, which equals 1 for SOEs and 0 otherwise (Dummy) | CSMAR |
| Ownership concentration | Top1 | Shareholding ratio of the largest shareholder (%) | CSMAR |
| Board size | Board | Natural logarithm of the number of directors (Log) | CSMAR |
| Environmental investment | LNENV | Natural logarithm of 1 plus firm's environmental capital expenditure (Log) | CSMAR |
| Long-term bank credit | Lcredit | Ratio of long-term loan to total assets (%) | CSMAR |
| Short-term bank credit | Scredit | Ratio of short-term loan to total assets (%) | CSMAR |

## 4. Empirical results

### 4.1. Descriptive statistics

Table 2 presents descriptive summary statistics of the main variables used in this study. Among the 8768 firm-year observations from 2009 to 2016, the mean of *Ln(1 + GIP)* is 0.54, and the median is 0, indicating that the environmental innovation of Chinese firms is still in its infancy. The third quantile of *Ln(1 + GIP)* is 0.693, indicating that more than 25% of the firm-year observations have environmental invention patent application records. The mean for *Post* is 0.295, indicating that 29.5% of the firm-year observations belong to our treatment group, which is a highly polluting firm after the implementation of GCGs. The mean, first quantile, median, and third quantile of the *Sub* were 15.86, 15.12, 16.13, and 17.15, respectively. This indicates that at least 75% of firm-year observations have positive government subsidies. However, there is a large variation in government subsidies. For example, the nominal difference between the first and third quantiles is approximately 24 million RMB. The average *Size*, *leverage*, *TQ*, *Age*, *ROA*, *Fixed*, *Cash*, *Top1*, and *Board* are 21.95, 0.42, 2.45, 1.84, 0.04, 0.27, 0.16, 36.43, and 2.17, respectively, and 44% of firms are SOEs. These statistics are consistent with those in the previous literature.

### 4.2. Main results

Table 3 lists the results of Eqs. (1) and (2), which reflect the impact of GCGs on a firm's environmental innovation level and the moderating effect of government subsidies. As *Post* is a dummy variable equal to 1

[5] Green patent applications are close to the time of innovation and are a good summary of current environmental technology (Boeing, 2016).

**Table 2**
Summary statistics.

| Variables | Mean | SD | Min | P25 | P50 | P75 | Max |
|---|---|---|---|---|---|---|---|
| Ln(1 + GIP) | 0.543 | 0.953 | 0 | 0 | 0 | 0.693 | 7.058 |
| Sub | 15.856 | 2.784 | 0.000 | 15.120 | 16.128 | 17.145 | 20.358 |
| Post | 0.295 | 0.456 | 0 | 0 | 0 | 1 | 1 |
| Size | 21.944 | 1.209 | 19.765 | 21.066 | 21.753 | 22.602 | 25.706 |
| TQ | 2.453 | 1.540 | 0.914 | 1.416 | 1.978 | 2.942 | 9.126 |
| Leverage | 0.423 | 0.201 | 0.041 | 0.263 | 0.423 | 0.584 | 0.852 |
| Cash | 0.165 | 0.130 | 0.010 | 0.073 | 0.127 | 0.218 | 0.706 |
| Age | 1.837 | 0.884 | 0.000 | 1.099 | 2.079 | 2.565 | 3.045 |
| ROA | 0.041 | 0.049 | −0.114 | 0.013 | 0.036 | 0.066 | 0.198 |
| Fixed | 0.271 | 0.155 | 0.024 | 0.152 | 0.238 | 0.364 | 0.711 |
| SOE | 0.440 | 0.496 | 0 | 0 | 0 | 1 | 1 |
| Top1 | 36.433 | 14.776 | 8.980 | 24.700 | 35.100 | 46.960 | 75.790 |
| Board | 2.172 | 0.196 | 1.609 | 2.079 | 2.197 | 2.197 | 2.708 |

Note: This table shows descriptive statistics, from left to right, mean, standard deviation (SD), minimum (Min), first quartile (P25), median (P50), third quantile (P75), and maximum (Max).

**Table 3**
Impact of GCGs on high-quality environmental innovation and the moderating effect of government subsidy.

| Variables | ln(1 + GIP) | | | |
|---|---|---|---|---|
| | 1 | 2 | 3 | 4 |
| Post | −0.179*** | −0.178*** | −0.400*** | −0.353*** |
| | (−5.13) | (−5.29) | (−4.27) | (−3.88) |
| Post*Sub | | | 0.0135** | 0.011* |
| | | | (2.28) | (1.85) |
| Sub | | | −0.00379 | −0.008*** |
| | | | (−1.47) | (−3.16) |
| Size | | 0.278*** | | 0.282*** |
| | | (7.44) | | (7.51) |
| TQ | | 0.010 | | 0.010 |
| | | (1.25) | | (1.24) |
| Lev | | 0.084 | | 0.086 |
| | | (0.76) | | (0.78) |
| Cash | | 0.096 | | 0.091 |
| | | (0.89) | | (0.84) |
| Age | | −0.057* | | −0.058* |
| | | (−1.82) | | (−1.84) |
| ROA | | 0.862*** | | 0.866*** |
| | | (3.98) | | (4.03) |
| Fixed | | 0.203** | | 0.206** |
| | | (1.98) | | (2.02) |
| SOE | | 0.083 | | 0.082 |
| | | (0.69) | | (0.69) |
| TOP1 | | 0.003 | | 0.003 |
| | | (1.39) | | (1.4) |
| Board | | −0.0292 | | −0.028 |
| | | (−0.4) | | (−0.39) |
| Constant | 0.204*** | −5.921*** | 0.260*** | −5.894*** |
| | (8.25) | (−7.24) | (6.37) | (−7.2) |
| Firm F.E. | Yes | Yes | Yes | Yes |
| Year F.E. | Yes | Yes | Yes | Yes |
| Observations | 8768 | 8768 | 8768 | 8768 |
| Adjusted $R^2$ | 0.106 | 0.128 | 0.106 | 0.129 |

Note: Table 3 presents the effect of GCGs on the level of environmental innovation and the moderating effect of government subsidies. Firm and year fixed effects were controlled for; t-statistics are shown in parentheses. ***, **, and * indicate that the coefficient is significant at the 1%, 5%, and 10% levels, respectively.

for high-polluting firms after GCGs, its coefficient reflects the impact of GCGs on high-polluting firms compared with non-high-polluting firms. As shown in Column (1) of Table 3, the coefficient of *Post* is significantly negative (−0.179, *t-value* = −5.13). In Column (2), after adding control variables, the coefficient of *Post* remains significantly negative at the 1% significance level (−0.178 with *t-value* = −5.3). This implies that, compared with non-high-polluting firms, the high-quality environmental innovation of high-polluting firms decreases by 17.8% after GCGs. Our results support Hypothesis 2, which is different from previous studies where a positive relationship between GCGs and environmental innovation is identified (Hu et al., 2021). Once we employ high-quality substantial environmental innovation, we find a negative relationship, indicating that GCGs is not conducive to improving the environmental innovation level of high-polluting firms. Du et al. (2022) discussed the difference between substantial innovation and strategic innovation. Substantial innovation, measured by the number of environmental invention patents, aims to raise the technical level, which is of high quality and requires more and longer investments. Strategic innovation focuses on quantity and speed to meet government scrutiny and set up an image of environmental protection, which can be measured by the number of environmental utility patents. In Columns (3) and (4), the coefficients of the interaction term (*Post*Sub*) are significantly positive (0.014 with t-value = 2.28, and 0.011 with t-value = 1.85). This indicates that government subsidies can mitigate the negative relationship between GCGs and high-quality environmental innovation. Our results support Hypothesis 4. The result demonstrates that the policy mix of GCGs and subsidies helps incentivise high-quality environmental innovation.

The coefficients of the control variables are consistent with the existing literature (He and Tian, 2013; Choi et al., 2011). For example, the bigger, the younger, and more profitable the firm is, and the higher the capital intensity of the firm, the more the firm's high-quality green patents. An increase in government subsidies has a negative impact on high-quality environmental innovation. One possible reason is that subsidies are misused to pursue innovation quantity and multiple objectives contrary to promoting high-quality innovation (Dang and Motohashi, 2015; Jia et al., 2019; Antonelli and Crespi, 2013; Xia et al., 2022; Guan and Yan, 2016). Firms receiving more government subsidies tend to invest in low-quality innovations with fast output or rent-seeking. This is because such behaviour helps firms obtain more policy preferences and hence receive more government subsidies.

### *4.3. Mechanism analysis: compliance cost*

In this section, we examine whether GCGs hinder environmental innovation by increasing compliance costs. Following Chen et al. (2018), we used a two-step regression approach to conduct the mechanism test. First, we tested the relationship between GCGs and compliance costs. In the second step, we tested the link between compliance costs and high-quality environmental innovation. If GCGs decrease the environmental innovation level by increasing compliance cost, we expect GCGs to positively affect compliance cost in the first-step regression and compliance cost to negatively affect high-quality environmental innovation in the second-step regression. GCGs set a high environmental compliance threshold to obtain bank credit. To obtain bank credit for new projects and continue to obtain credit support for existing projects, firms inevitably need to increase investment in environmental governance, which may crowd out investments in environmental innovation.

Additionally, to test whether government subsidies can moderate the negative impact of GCGs by alleviating the negative impact of high compliance costs on green innovation, we add an interaction term between government subsidies and compliance costs in the second-step regression. If the coefficient of this interaction term is significantly positive, we can conclude that subsidies can effectively mitigate the crowding-out effect of high compliance costs on investment in environmental innovation.

Compliance costs can be proxied by a firm's investment in environmental governance. According to Patten (2005), a firm's environmental capital expenditure is a relatively accurate and objective indicator of its environmental governance. Thus, we use the natural logarithm of a firm's environmental capital expenditure plus one as a proxy for compliance costs, denoted by *LNENV*. Following Zhang et al. (2019b), we manually collected relevant data from construction projects in the firm's annual report. Environmental capital expenditure is the firm's current environmental investment, including sewage treatment, desulphurisation equipment upgrades, hazardous waste disposal, and equipment energy-saving renovations.

Table 4 presents the results. Panel A presents the first-step regression results. The coefficient of *Post* is significantly positive (0.473 with *t-value* = 1.66), indicating that GCGs increase firms' investment in environmental governance. Panel B reports the results of the second-step regression. The coefficient of *LNENV* is significantly negative (−0.00286 with *t-value* = −1.72), indicating a negative relationship between compliance costs and high-quality environmental innovation. The results in Panels A and B demonstrate that GCGs reduce a firm's high-quality environmental innovation by increasing compliance costs. In Panel C, we have no evidence that government subsidy helps alleviate the crowding-out effect of compliance cost as the coefficient of *LNEVN*Sub* is not significant.

### 4.4. Mechanism analysis: bank credit

In this section, we examine whether GCGs hinder environmental innovation through bank credit channels. First, we tested whether GCGs reduce the bank credit of high-polluting firms. Bank credit was divided into long-term bank credit (*Lcredit*) and short-term bank credit (*Scredit*). We regressed the bank credit variables on *Post*, and the coefficient of *Post* for the long-term bank credit regression was significantly negative (−0.0154 with *t-value* = −5.06). This indicates that GCGs decrease high-polluting firms' long-term bank credit, while its effect on short-term bank credit is not significant. Even if the bank credit of high-polluting firms is reduced, environmental innovation is not necessarily negatively affected. Studies have shown that internal funding provides support for innovation rather than external funding (Galende et al., 2003). The original intention of GCGs is to penalise high-polluting firms in bank lending to limit their careless expansion and encourage high-polluting firms to conduct environmental innovation, which is effective if banks favour firms with a high level of high-quality environmental innovation (Naqvi et al., 2021).

Inspired by Wen et al. (2021), we investigated the impact of GCGs on credit allocation efficiency. An interaction term between the lag term of the level of high-quality environmental innovation and *Post* was added to the regression. The coefficient of the interaction term (*Post**ln*(1 + GIP)*) is significantly negative (−0.0053 with *t-value* = −2.39) for the long-term bank credit regression. This suggests that high-polluting firms with a high level of high-quality environmental innovation obtain fewer long-term loans after GCGs. Thus, bank credit does not flow to high-polluting firms with high-quality environmental innovation, which creates inefficiency in credit allocation after GCGs. However, we found no evidence of inefficiency in credit allocation for short-term bank credits.

To further test the moderating effect of government subsidies, we added the interaction item (*Post*ln(1 + GIP)*Sub*) in the regression. The coefficient of the interaction term is significantly positive (−0.005 with *t-value* = −2.39) for the long-term bank credit regression, which suggests that government subsidies can alleviate bank credit inefficiency. Again, this effect is not significant for short-term bank credits.

The results, as given in Table 5, show the inefficiency of long-term credit allocation of banks. Firms with a high level of high-quality environmental innovation may lack long-term support for innovation activities. Therefore, GCGs restrain high-quality environmental innovation activities via both fewer credit quotas and the mechanism of credit allocation inefficiency. However, government subsidies can act as a certification for firms with a high level of high-quality environmental innovation and help alleviate such credit allocation inefficiency.

### 4.5. Subgroup analysis

To explore the heterogeneity effect of the policy mix of GCGs and government subsidies, we conducted a subgroup analysis from four perspectives: ownership, political connection, degree of regional marketisation, and firm size.

The government will intervene to bail out firms with government guarantee under a situation of financial distress (Boubakri et al., 2012; Dong et al., 2021). Based on government guarantee, the subsidy would send a more positive signal to banks, thereby eliminating credit discrimination. Moreover, firms with government guarantee have comprehensive goals covering economic, environmental, and social benefits. They tend to make good use of government subsidies and make more efforts to conduct high-quality environmental innovation. In this sense, in the context of GCGs, government subsidies help firms with more political connections. As the ultimate controlling shareholder of SOEs is the government, SOEs are more likely to receive government guarantees. In line with our expectation, as Panel A of Table 6 shows, the coefficient of *Post*Sub* is significantly positive only for the SOE subsample. Additionally, politically connected managers allow firms to seek government-related benefits and obtain a guarantee. If a firm's Chairman or CEO currently holds a position in the government, we define it as a politically connected firm (Li and Zhang, 2010; Li et al., 2015). The biographical information of CEOs and Chairman is collected from CSMAR. As Panel B of Table 6 shows, the coefficient of *Post*Sub* is significantly positive only for the politically connected subsample.

There are significant differences in the economic development levels and system mechanisms in various regions of China. A developed region typically has more effective local governments and less government intervention than a less-developed region (Firth et al., 2008). A higher degree of local government intervention implies that local officials have

**Table 4**
Mechanism analysis: compliance cost.

| Panel A: regression of LNENV on Post | | Panel B: regression of ln(1 + GIP) on LNENV | | Panel C: moderating effect of government subsidy | |
|---|---|---|---|---|---|
| Variables | LNENV | | ln(1 + GIP) | | ln(1 + GIP) |
| Post | 0.473* | LNENV | −0.003* | LNENV | −0.0003 |
| | (1.66) | | (−1.71) | | (−0.06) |
| | | | | LNENV*Sub | −0.0002 |
| | | | | | (−0.42) |
| Controls | Yes | Controls | Yes | Controls | Yes |
| Firm F.E. | Yes | Firm F.E. | Yes | Firm F.E. | Yes |
| Year F.E. | Yes | Year F.E. | Yes | Year F.E. | Yes |
| Observations | 8768 | Observations | 8768 | Observations | 8768 |
| Adjusted $R^2$ | 0.005 | Adjusted $R^2$ | 0.123 | Adjusted $R^2$ | 0.123 |

Note: Table 4 presents the impact of GCGs on a firm's high-quality environmental innovation and the moderating effect of government subsidies on compliance cost. Panel A shows the result of the regression of LNENV on Post, Panel B shows the result of the regression of ln(1 + GIP) on LNENV, and Panel C explores the moderating effect of government subsidies. t-statistics are shown in parentheses. ***, **, and * indicate that the coefficient is significant at the 1%, 5%, and 10% levels, respectively.

**Table 5**
Mechanism analysis: bank credit.

| | Panel A: Long-term bank credit | | | Panel B: Short-term bank credit | | |
|---|---|---|---|---|---|---|
| Variables | Lcredit | | | Scredit | | |
| Post | −0.015*** | −0.013*** | 0.017** | −0.005 | −0.006 | −0.01 |
| | (−5.06) | (−4.14) | (2.01) | (−1.31) | (−1.41) | (−1.58) |
| Post * ln(1 + GIP) | | −0.005** | −0.027** | | 0.002 | 0.012 |
| | | (−2.39) | (−2.03) | | (0.86) | (1.4) |
| Post * ln(1 + GIP) * Sub | | | 0.001* | | | −0.001 |
| | | | (1.75) | | | (−1.16) |
| Controls | Yes | Yes | Yes | Yes | Yes | Yes |
| Firm F.E. | Yes | Yes | Yes | Yes | Yes | Yes |
| Year F.E. | Yes | Yes | Yes | Yes | Yes | Yes |
| Observations | 8768 | 8768 | 8768 | 8768 | 8768 | 8768 |
| Adjusted R2 | 0.076 | 0.078 | 0.08 | 0.102 | 0.103 | 0.103 |

Note: Table 5 presents the impact of GCGs on firms' high-quality environmental innovation and the moderating effect of government subsidies through bank credit. t-statistics are shown in parentheses. ***, **, and * indicate that the coefficient is significant at the 1%, 5%, and 10% levels, respectively.

a higher level of political power over the local economy, which, in turn, means that government subsidies can provide more guarantees and help release more positive signals. The eastern provinces tend to be more developed than the central or western provinces (Fan et al., 2011). Therefore, following Li and Cheng (2020), we classify firms registered in the eastern coastal provinces as having a high degree of marketisation, while the low marketisation level group is composed of firms located in a central or western province. The results reported in Panel C of Table 6 meet expectations; the coefficient of *Post*Sub* is significantly positive only for the subsample with lower marketisation. The results indicate that while GCGs have a negative impact on both the good and low marketisation groups, the policy mix of GCGs and government subsidies is effective for firms in the low marketisation area.

According to the resource-based view (Wernerfelt, 1984), successful innovation depends on a firm's resources and capabilities. Research suggests that large firms outperform small firms in terms of resources and capabilities related to innovation (Shefer and Frenkel, 2005). Small firms may not benefit from the policy mix because they lack a sound foundation for innovation. Firms are divided into large and small groups according to the median firm size in the year of implementation of the GCGs. The results in Panel D of Table 6 show that the coefficient of the interaction term *Post*Sub* is significantly positive only for the big firm subsample, which is in line with our expectations.

## 5. Robustness test

### 5.1. Parallel trend and dynamic effect

A parallel trend is an important premise for using the DID model. We have added *Pre2*, *Pre1*, *Pre2*Sub*, and *Pre1*Sub* to Eq. (1) to verify the parallel trend assumption. *Pre1* equals 1 for high-polluting firms in 2011 and 0 otherwise. *Pre2* equals 1 for high-polluting firms in 2010 and 0 otherwise. According to Table 7, the coefficients of *Pre2*, *Pre1*, *Pre2*Sub*, and *Pre1*Sub* are insignificant, and the parallel trend assumption holds. We also add *Post1*, *Post1*Sub*, *Post2*, *Post2*Sub*, *Post3*, *Post3*Sub*, *Post4*, and *Post4*Sub*, in which the definition of the time dummy variable is the same as before, to test the dynamic effect of GCGs and government subsidies. The coefficients of these interaction terms are significant, indicating that the impacts of GCGs and government subsidies on high-quality environmental innovation are instant and persistent.

### 5.2. PSM-DID

To test the causal relationship between GCGs, government subsidies, and environmental innovation, the DID model shown in Eq. (1) assumes that non-high-polluting firms provide a good counterfactual to high-polluting firms. However, there are differences in firm characteristics between the treatment and control groups before GCGs. Table 8 shows the averages of the variables during the pre-GCGs period. High-polluting firms have larger firm size and board size, higher leverage rate, ownership concentration, and fixed asset rate, longer listing years, fewer cash holdings and government subsidies, and higher proportions of SOEs. Although we add them as control variables in our DID model, this may fail to solve the endogeneity problem completely. Following Lu and Wang (2018), we solve this problem using the propensity score matching (PSM) method, creating a new sample in which the control group firms match the treated group firms in various dimensions. When applying PSM, we first estimate a logit model based on samples before the event, in which the dependent variable is a dummy variable that equals 1 if the firm is a high-polluting firm and 0 otherwise. The independent variables are the average values of all the control variables before GCGs. The predicted probabilities from the logit model were then used to perform nearest-neighbour PSM (with no replacement). As shown in Panel A of Table 8, after PSM, none of the differences in the control variables between the treated and control groups is statistically significant, which confirms that the matching procedure is successful. In Panel B, we re-estimate Eqs. (1) and (2) using the sample after matching. The coefficient of *Post* remains significantly negative, and that of *Post*Sub* remains significantly positive, which confirms our conclusion. These results help further establish the causal relationship between GCGs, government subsidies, and high-quality environmental innovation.

### 5.3. Alternative measures of environmental innovation

In this section, we use two alternative measures of a firm's environmental innovation level. First, patent counts sometimes imperfectly capture the success of innovation. Therefore, we follow Hall et al. (2005) in using the forward citations of a patent to measure its quality or scientific value because other patents tend to cite high-quality patents. Owing to the time effect, there is bias in the use of the original citation data. More specifically, the 2009 patent is cited more than the 2016 patent; the reason may not be higher quality but that it has existed for a longer period. To address this issue, we follow Chang et al. (2019b) and use the fixed effects method, which scales original citation counts by the average citation counts of all green patents applied for in the same year. As shown in Table 9, using the natural logarithm of 1 plus the adjusted green patent citation number to measure the high-quality environmental innovation of a firm, we obtain the same result. In other words, GCGs have a negative impact on the level of environmental innovation of high-polluting firms, and government subsidies help mitigate this negative relationship. Second, patent applications may not represent actual technological progress because they may not always be authorised. Patent authorisation can reflect the level of innovation to some extent despite the time lag. Thus, we use the natural logarithm of the sum of 1

**Table 6**
Subgroup analysis.

| Panel A: SOEs vs. non-SOEs | | | | |
|---|---|---|---|---|
| Variables | ln(1 + GIP) | | | |
| | SOEs | | non-SOEs | |
| Post | −0.199*** | −0.588*** | −0.184*** | −0.041 |
| | (−3.68) | (−3.63) | (−4.72) | (−0.49) |
| Post * Sub | | 0.023** | | −0.009 |
| | | (2.39) | | (−1.59) |
| Controls | Yes | Yes | Yes | Yes |
| Firm F.E. | Yes | Yes | Yes | Yes |
| Year F.E. | Yes | Yes | Yes | Yes |
| Observations | 3828 | 3828 | 4906 | 4906 |
| Adjusted $R^2$ | 0.163 | 0.167 | 0.099 | 0.099 |
| Panel B: With political connection vs. Without political connection | | | | |
| Variables | ln(1 + GIP) | | | |
| | With political connection | | Without political connection | |
| Post | -0.170*** | −0.410 *** | −0.177*** | −0.295** |
| | (−3.12) | (−3.21) | (−4.06) | (−2.42) |
| Post * Sub | | 0.015* | | 0.007 |
| | | (1.74) | | (0.94) |
| Controls | Yes | Yes | Yes | Yes |
| Firm F.E. | Yes | Yes | Yes | Yes |
| Year F.E. | Yes | Yes | Yes | Yes |
| Observations | 3624 | 3624 | 5144 | 5144 |
| Adjusted $R^2$ | 0.134 | 0.137 | 0.128 | 0.129 |
| Panel C: High degree of marketisation vs. low degree of marketisation | | | | |
| Variables | ln(1 + GIP) | | | |
| | Low marketisation | | High marketisation | |
| Post | −0.148*** | −0.402*** | −0.193*** | −0.278* |
| | (−2.64) | (−4.62) | (−4.49) | (−1.74) |
| Post * Sub | | 0.016*** | | 0.005 |
| | | (2.99) | | (0.5) |
| Controls | Yes | Yes | Yes | Yes |
| Firm F.E. | Yes | Yes | Yes | Yes |
| Year F.E. | Yes | Yes | Yes | Yes |
| Observations | 3220 | 3220 | 5548 | 5548 |
| Adjusted $R^2$ | 0.122 | 0.124 | 0.139 | 0.14 |
| Panel D: Big firms vs. small firms | | | | |
| Variables | ln(1 + GIP) | | | |
| | Big firms | | Small firms | |
| Post | −0.196*** | −0.517*** | −0.167*** | −0.068 |
| | (−4.14) | (−2.88) | (−3.91) | (−1.06) |
| Post * Sub | | 0.019* | | −0.007 |
| | | (1.76) | | (−1.63) |
| Controls | Yes | Yes | Yes | Yes |
| Firm F.E. | Yes | Yes | Yes | Yes |
| Year F.E. | Yes | Yes | Yes | Yes |
| Observations | 4911 | 4911 | 3857 | 3857 |
| Adjusted $R^2$ | 0.158 | 0.16 | 0.09 | 0.09 |

Note: Table 6 presents the impact of GCGs and government subsidies on firms' high-quality environmental innovation considering firms' ownership, political connection, degree of regional marketisation, and size. t-statistics are shown in parentheses. ***, **, and * indicate that the coefficient is significant at the 1%, 5%, and 10% levels, respectively.

plus the number of green invention patents granted (GGIP) as the dependent variable to conduct a robustness test. This result remains the same.

### *5.4. Alternative definition of high-polluting firms*

'Guidelines for Environmental Information Disclosure of Listed Firms' promulgated by China Environmental Protection Administration categorise 16 industries (such as electrolytic aluminium, petrochemical, and tanning) as heavy polluting industries. Thus, in this section, we adjust the definition of high-polluting firms. If the firm belongs to these 16 heavily polluting industries, we classify them as the treated group, and *Post* equals 1 for these firms after 2012 and 0 otherwise. As shown in Table 10, the result remains the same.

**Table 7**
Parallel trend and dynamic effect.

| Variables | ln(1 + GIP) |
|---|---|
| Pre2 | −0.159 |
| | (−1.55) |
| Pre2 * Sub | 0.004 |
| | (0.63) |
| Pre1 | −0.16 |
| | (−1.55) |
| Pre1 * Sub | −0.002 |
| | (−0.37) |
| Current | −0.230** |
| | (−2.35) |
| Current * Sub | 0.003 |
| | (0.47) |
| Post1 | −0.416*** |
| | (−4.32) |
| Post1 * Sub | 0.011** |
| | (1.98) |
| Post2 | −0.378*** |
| | (−2.77) |
| Post2 * Sub | 0.004 |
| | (0.44) |
| Post3 | −0.622*** |
| | (−4.35) |
| Post3 * Sub | 0.018** |
| | (2.1) |
| Post4 | −1.035*** |
| | (−5.31) |
| Post4 * Sub | 0.037*** |
| | (3.18) |
| Controls | Yes |
| Firm F.E. | Yes |
| Year F.E. | Yes |
| Observations | 8768 |
| Adjusted $R^2$ | 0.135 |

Note: Table 7 shows the parallel trend and dynamic effect of GCGs and the moderating effect of government subsidies. t-statistics are shown in parentheses. ***, **, and * indicate that the coefficient is significant at the 1%, 5%, and 10% levels, respectively.

## 6. Conclusions and policy implications

To promote substantiality and environmental innovation, China implemented GCGs and provided a considerable government subsidy. In this study, we examine to what extent the policy mix of green credit policy and government subsidy affects the high-quality environmental innovation of high-polluting firms. Using the DID method, we find that GCGs negatively impact the high-quality environmental innovation of high-polluting firms in China. Next, we examine the interaction effect of GCGs and government subsidies on high-quality environmental innovation. We find that the policy mix of GCGs and government subsidies is positively related to high-quality environmental innovation. The effect of the policy mix is more pronounced for SOEs, firms with political connections, firms in areas with low marketisation, and large firms. Additionally, we explore why GCGs hinder high-quality environmental innovation. We show that there was an increase in compliance costs for high-polluting firms after the implementation of GCGs and that high compliance costs crowd out high-quality environmental innovation. We also find that bank credit does not flow to high-polluting firms with high-quality environmental innovation, which creates credit allocation inefficiency after GCGs. However, government subsidies can act as a certification for firms with a high level of high-quality environmental innovation and help alleviate credit allocation inefficiency.

In recent years, as the pressure of environmental deterioration mounted, the 'win-win' of environmental protection and economic development has received enormous attention. Environmental innovation is a cost-effective way to achieve the dual goals of economic

**Table 8**
PSM-DID.

Panel A: Balancing test

| Variables | Unmatched/ Matched | Mean of treated group | Mean of control group | Bias (%) |
|---|---|---|---|---|
| Sub | Unmatched | 15.129 | 15.451 | −11.5* |
| | Matched | 15.335 | 15.247 | 3.2 |
| Size | Unmatched | 21.886 | 21.492 | 34.8*** |
| | Matched | 21.547 | 21.538 | 0.8 |
| Lev | Unmatched | 0.44 | 0.38 | 29.8*** |
| | Matched | 0.4 | 0.388 | 6.1 |
| TQ | Unmatched | 2.423 | 2.376 | 3.8 |
| | Matched | 2.403 | 2.512 | −8.9 |
| Age | Unmatched | 1.681 | 1.259 | 41*** |
| | Matched | 1.413 | 1.386 | 2.7 |
| ROA | Unmatched | 0.049 | 0.05 | −2.5 |
| | Matched | 0.05 | 0.053 | −7.9 |
| Fixed | Unmatched | 0.326 | 0.2 | 90.9*** |
| | Matched | 0.251 | 0.248 | 2.8 |
| Cash | Unmatched | 0.174 | 0.24 | −43.7*** |
| | Matched | 0.206 | 0.212 | −4 |
| SOE | Unmatched | 0.561 | 0.367 | 40*** |
| | Matched | 0.439 | 0.424 | 3 |
| TOP1 | Unmatched | 38.623 | 36.619 | 13.5** |
| | Matched | 36.184 | 37.392 | −8.1 |
| Board | Unmatched | 2.22 | 2.165 | 30.2*** |
| | Matched | 2.183 | 2.183 | 0 |

Panel B: DID and DDD estimates using matched sample

| Variables | ln(1 + GIP) | ln(1 + GIP) |
|---|---|---|
| Post | −0.174*** | −0.463*** |
| | (−4.18) | (−3.31) |
| Post * Sub | | 0.018* |
| | | (1.96) |
| Controls | Yes | Yes |
| Firm F.E. | Yes | Yes |
| Year F.E. | Yes | Yes |
| Observations | 3984 | 3984 |
| Adjusted $R^2$ | 0.155 | 0.157 |

Note: Table 8 shows the effect of GCGs on firms' high-quality environmental innovation and the moderating effect of government subsidies using PSM-DID. Panel A shows the balancing test before and after matching. Panel B presents the results for the matched sample. t-statistics are shown in parentheses. ***, **, and * indicate that the coefficient is significant at the 1%, 5%, and 10% levels, respectively.

**Table 9**
Alternative measures of environmental innovation.

| Variables | ln(1 + CITA) | | ln(1 + GGIP) | |
|---|---|---|---|---|
| Post | −0.276*** | −0.861*** | −0.079*** | −0.237*** |
| | (−6.29) | (−8.53) | (−2.89) | (−3.54) |
| Post * Sub | | 0.036*** | | 0.010** |
| | | (5.79) | | (2.2) |
| Controls | Yes | Yes | Yes | Yes |
| Firm F.E. | Yes | Yes | Yes | Yes |
| Year F.E. | Yes | Yes | Yes | Yes |
| Observations | 8768 | 8768 | 8768 | 8768 |
| Adjusted $R^2$ | 0.398 | 0.405 | 0.078 | 0.079 |

Note: Table 9 shows the effect of GCGs on firms' environmental innovation levels and the moderating effect of government subsidies using alternative measures. t-statistics are shown in parentheses. ***, **, and * indicate that the coefficient is significant at the 1%, 5%, and 10% levels, respectively.

development and environmental protection (Rennings, 2000; Lv et al., 2021). Various policy instruments are used to incentivise firms to engage in green innovation. These policies reflect the fact that governments have become highly aware of the crucial environmental situation and importance of environmental innovation. However, the empirical results show some shortcomings in the existing policy design. This study has several implications for policy design. First, the green credit policy should avoid a one-size-fits-all approach. Highly polluting firms actively engaging in environmental innovation should be rewarded with credit. Second, the government needs to provide subsidies to assist green credit policies to improve the level of environmental innovation. Third, more policy instruments could be introduced to interact with other policies and motivate firms to undertake high-quality environmental innovation. Examples include environmental innovation certification and green bonds (Karim et al., 2022).

**Table 10**
Alternative definition of high-polluting firms.

| Variables | ln(1 + GIP) | |
|---|---|---|
| Post1 | −0.155*** | −0.331*** |
| | (−4.68) | (−3.4) |
| Post1 * Sub | | 0.011* |
| | | (1.73) |
| Controls | Yes | Yes |
| Firm F.E. | Yes | Yes |
| Year F.E. | Yes | Yes |
| Observations | 8768 | 8768 |
| Adjusted $R^2$ | 0.126 | 0.127 |

Note: Table 10 shows the effect of GCGs on firms' level of environmental innovation and the moderating effect of government subsidies using alternative definitions for high-polluting firms. t-statistics are shown in parentheses. ***, **, and * indicate that the coefficient is significant at the 1%, 5%, and 10% levels, respectively.

## CRediT authorship contribution statement

**Yechi Ma:** Conceptualization, Formal analysis, Writing – review & editing. **Yezhou Sha:** Methodology, Visualization, Writing – review & editing. **Zilong Wang:** Formal analysis, Validation, Writing – original draft, Supervision. **Wenjing Zhang:** Conceptualization, Software, Data curation, Investigation, Writing – original draft.

## Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.eneco.2023.106512.

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