The impacts of green credit guidelines on total factor productivity of heavy-polluting enterprises: A quasi-natural experiment from China

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Abstract: Whether tightening environmental regulations would enhance corporate productivity gains is still in question. This paper takes China's green credit guidelines (GCGs) as a quasi-natural experiment to test the effects of environmental regulations on total factor productivity (TFP) growth of heavy-polluting companies. A Malmquist index based on adjusted epsilon-based measure (EBM) is constructed to estimate corporate TFP. In addition, a propensity score matching-difference in difference in difference (PSM-DDD) approach is utilized to evaluate the impacts of such policy on enterprises' TFP followed by impact mechanism analysis. Empirical tests based on of Chinese listed heavy-polluting enterprises during 2007-2019 demonstrate that: 1) GCGs policy contributes remarkably to productivity gains of the heavy-polluting enterprises; 2) the positive effects of GCGs on TFP of the enterprises are mainly introduced by the improvement of technical innovation and allocation effect; 3) GCGs may restrain the increase of TFP of heavy-polluting enterprises through the financial constraints of bank credit and commercial credit; 4) it is unclear if GCGs contributes to productivity gains through improved management efficiency. Corresponding suggestions for the government, firms, and public are then proposed to facilitate the perfection of green finance policies as well as high-quality development of heavy-polluting firms based on the research findings.

Keywords: green credit guidelines (GCGs); PSM-DID; heavy-polluting enterprises; total factor productivity (TFP); influencing mechanism

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1. Introduction

Under the influence of business activities, environmental degradation as well as resource constraints have attracted extensive attention from the society for the past decades. As the biggest emerging economy worldwide, China plays a leading role in energy consumption and carbon emissions, and it also ranked 120 among the 180 countries of the world for environmental performance in 2020 (IEA, 2019; Wendling *et al.,* 2020). Furthermore, the expense of environmental pollution accounts for about 8% of GDP (Chen *et al.,* 2017). Under this background, the Chinese government has emphasized and promoted the concepts of green transformation and development on various levels to address the contradiction between economic improvement and environmental conservation, especially since the "greenization" was put forward as the national strategy in 2015. An array of policies and rules have been issued and implemented to constrain and rectify business behaviors to facilitate green and clean production (An *et al.,* 2021).

As the foundation of national economic and social development, the industrial sector is also responsible for the extensive energy use and pollution in China (Wang *et al.,* 2018). Specifically, the heavy-polluting industries within the industrial sector consume over 65% of national energy and the consumed more than 60% electricity (Lin and Liu, 2016). At the same time, such industries also account for about 1/4 of national CO_2 emissions (Ouyang *et al.*,2020). Therefore, the high quality development of heavy-polluting industries is critical for China to achieve its energy saving and pollution reduction targets. The former China Banking Regulatory Commission (CBRC) promulgated green credit guidelines (GCGs) in 2012 in order to adjust the credit structure and prevent environmental risks by implementing specific demands in terms of credit policies (China Banking Regulatory Commission, 2012). The issuance of the GCGs further strengthens government environmental supervision and encourages financial institutions to closely monitor the environmental and social risks of enterprises (Sun *et al.,* 2019). It requires financial organizations to strictly control credit loaning to enterprises with bad environmental practices to force them to transform from the traditional resource-dependent development mode to a green and recycling mode (Yin *et al.,* 2021). In accordance, firms especially the heavy-polluting ones are facing increasing pressures to undergo green transformation and

upgrading to achieve pollution reduction while maintaining economic prosperity (Cao & Yu, 2018).

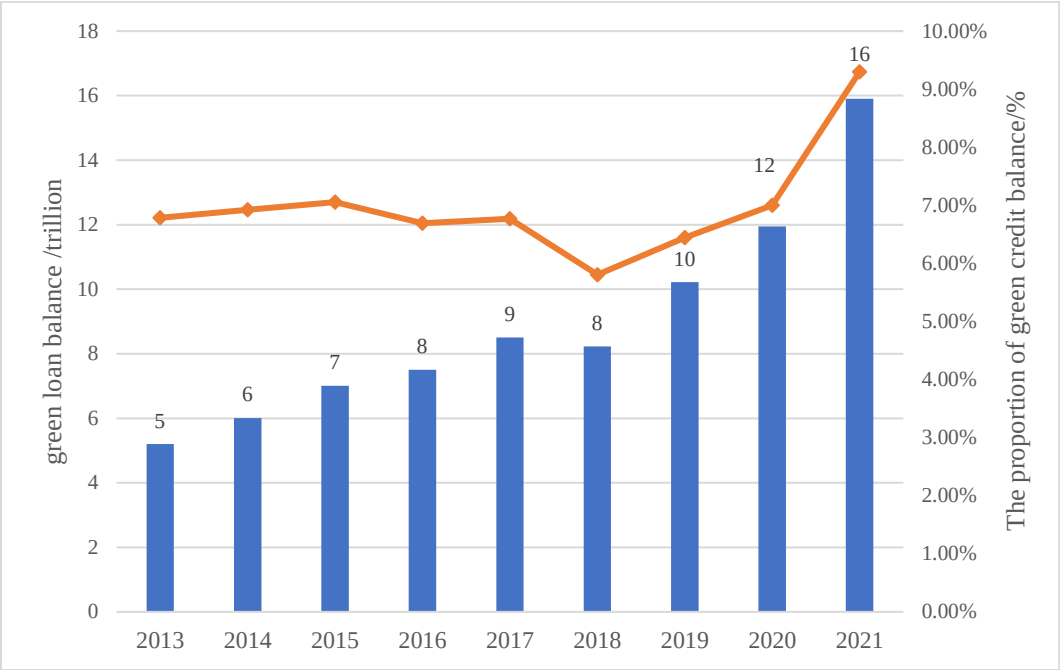

Fig1. China's green credit balance(source: Almanac of China's Finance and Banking)

With the help of the implementation of the GCGs, China's green loan balance reached about 22.03 trillion yuan by the end of 2022, making it the largest worldwide (China News, 2023). Generally speaking, fulfillment of green credit policies will lower the amount of financing of heavy-polluting enterprises and lead to higher costs of debt, which in turn, may affect corporate operation performance (Hsu *et al.*, 2014; Su & Lian, 2018). On the contrary, Porter Hypothesis (PH) indicates that well-designed supervision is able to promote innovations, which will further make a positive impact on the improvement of enterprise productivity (Porter & Van der Linde, 1995). Compared to single-factor efficiency indicator, total factor productivity (TFP) based on non-parameter approach (*i.e.*, data envelopment analysis, DEA) is an index of output divided by an index of total input usage and TFP index express the change in TFP between two consecutive periods (Fiordelisi & Molyneux, 2010). With the strength of dealing with multiple inputs and outputs, TFP has become an important index to measure the high quality of economic

development (Chen *et al.*, 2022; Li *et al.*, 2023c). Some empirical tests acknowledged the positive influence of environmental supervision on corporate productivity gains by the means of promoting management efficiency as well as innovation in technology (Wang *et al.*, 2021), whereas others found that green credit policy and new environmental protection laws actually lowered the R&D intensity as well as the TFP of energy-intensive enterprises (Cai *et al.*, 2020; Wen *et al.*, 2021).

Therefore, it is necessary to assess the impact of green credit policies on the TFP of heavy-polluting enterprises while specific research questions are still unsettled: How to evaluate the TFP on the firm level in a more comprehensive way? Is there a positive linkage between environmental regulation represented by the GCGs and corporate TFP? How to effectively estimate the policy impact of GCGs while avoiding sample selection bias or endogenous problem? What are the influencing mechanisms of GCGs on corporate TFP? In accordance, this paper attempts to construct a hybrid measure-based Malmquist index to estimate the firm-level TFP. On this basis, a quasi-natural experiment analytical framework is further applied to comprehensively estimate the impacts and influencing mechanisms of GCGs on the TFP of China's heavy-polluting enterprises.

The rest of this study is arranged as follows: Section 2 illustrates a conceptual framework based on literature review. Section 3 introduces the methodology as well as the data utilized in this research. Section 4 demonstrates empirical outcomes and the robustness tests. Section 5 further explores the influencing mechanisms of GGGs on TFP, and Section 6 discusses the research findings and puts forward corresponding implications.

2. Conceptual framework and literature review

2.1 Conceptual framework

Green credit means guiding the behavior of environmental conservation and facilitating the balanced growth of the economy and environment by the means of environmental leverage. Such policy aims to restrict the increase and growth of energy-intensive firms, providing the funds to firms which are environment-friendly for the intention of optimizing the substantial economy and finally achieving the goal of environment conservation (Hao *et al.*, 2020). In other words, it is designed for the purpose

of utilizing credit control measures to direct credit funds to facilitate the development of green industries, thus reducing corporate pollution (Liu & He, 2021).

The idea of GCGs goes back to 1995 when the People's Bank of China (PBC) released the *Notice on Implementation of Credit Policy and Strengthening of Environmental Protection Works.* This notice requires financial organizations to thoroughly consider the environmental elements when carrying out credit activities (PBC, 1995). The concept of green credit was first proposed in 2007 when the *Opinions on implementing environmental protection policies and regulations to prevent credit risks* was released. The GCGs was officially issued in February 2012, describing specific requests in terms of green credit policies and proposing to change the credit structure for the intention of preventing and reducing risks related to environment (CBRC, 2012). Three framework systems of green credit were proposed for the first time, namely, environmental and social risk management, green financial product innovation and banks' own environmental footprint. The policy also put forward more perfect, clear and operable requirements for banking financial institutions in terms of organizational structure, capacity building, credit policy, credit management, internal control evaluation, and external disclosure. (Zhang *et al.*, 2017).Unlike previous green credit related policies or regualtions, the GCGs make relatively specific arrangements for financial institutions in terms of green credit activities (Cui *et al*., 2022). This policy was viewed as a useful approach due to its strength in terms of handling the enforcement and incentive drawbacks which are hidden in command-and-control regulatory framework, indicating that Chinese green credit administration had developed to a new level. Therefore, the releasement of GCGs is also considered a milestone in the course of the country's credit policy (Liu *et al.*, 2019). According toXu *et al.* (2020), the polluting enterprise in this paper means the firm that belongs to a heavy-polluting industry and can be classified into 16 kinds based on the *Guidelines for Environmental Information Disclosure of Listed Companies*. Such enterprises are regarded as the primary cause for environmental degradation, thus are required to take greater environmental responsibilities (Du *et al*., 2019).

The theoretical framework of this paper is shown in Figure 2. Faced with increasing public stresses, heavy-polluting enterprises started to pay attention to green production. GCGs have also provided new chances for companies to help them increase efficiency and

innovations levels, which can enhance their competitiveness in business (Cai & Ye, 2020). In terms of the demand side, the regulations published by government can also encourage customers to use environment-friendly commodities, thus having positive influence on corporate TFP. As for the supply side, financial funding for firms which have produced extensive pollutions can also relieve pressures in terms of government regulation. Under the guidance of the PH, reducing loans to highly polluting or energy intensive enterprises will ultimately force or motivate enterprises to increase their productivity by promoting the adoption of advanced green production technologies and adjusting investment strategies (Wang *et al.*, 2021; Cai & Ye, 2020). In other words, a policy instrument is considered well-designed and effective for facilitating high-quality development when Porter effect appears. Therefore, it is necessary to examine the influences that the GCGs have on corporate TFP.

If the firms can adapt to the GCGs, the Porter effect will occur. The enforcement of the GCGs will increase the public's awareness about environmental issues and promote the progress of green markets, thus motivating more companies to take part in the green innovation and gradually increase the TFP (Li *et al.*, 2023c; Cui *et al.*, 2022; Cai & Ye, 2020). As for the specific influence mechanism, first of all, with the pressure of environmental regulations such as GCGs (Liu & He, 2021; Hao *et al.*, 2020; Yin *et al.*, 2021), the heavy-polluting enterprises may actively improve their TFP via technique effect (Wang *et al.*, 2021; Cai & Ye, 2020; Cai *et al.*, 2020). Secondly, green credit policies encourage enterprises to improve total factor productivity by optimizing resource allocation (Tang *et al.*, 2020; Cai & Ye, 2020). Under the same technical level, various production factors gradually flow from enterprises or departments with low productivity to enterprises or departments with high productivity, so as to improve the overall profit rate, which is also the embodiment of the improvement of total factor productivity. Thirdly, green credit can affect the total factor productivity of heavy polluting enterprises through the financial constraints of commercial credit (Ma *et al.*, 2023; Yao *et al.*, 2021), bank credit and government subsidies (Cai & Ye, 2020; Zhang *et al.*, 2019). Finally, regulatory performance plays a crucial role in the product quality and total factor productivity of enterprises. Green credit guidelines can improve the total factor productivity of heavily polluting enterprises by improving management efficiency (Wang *et al.*, 2021)

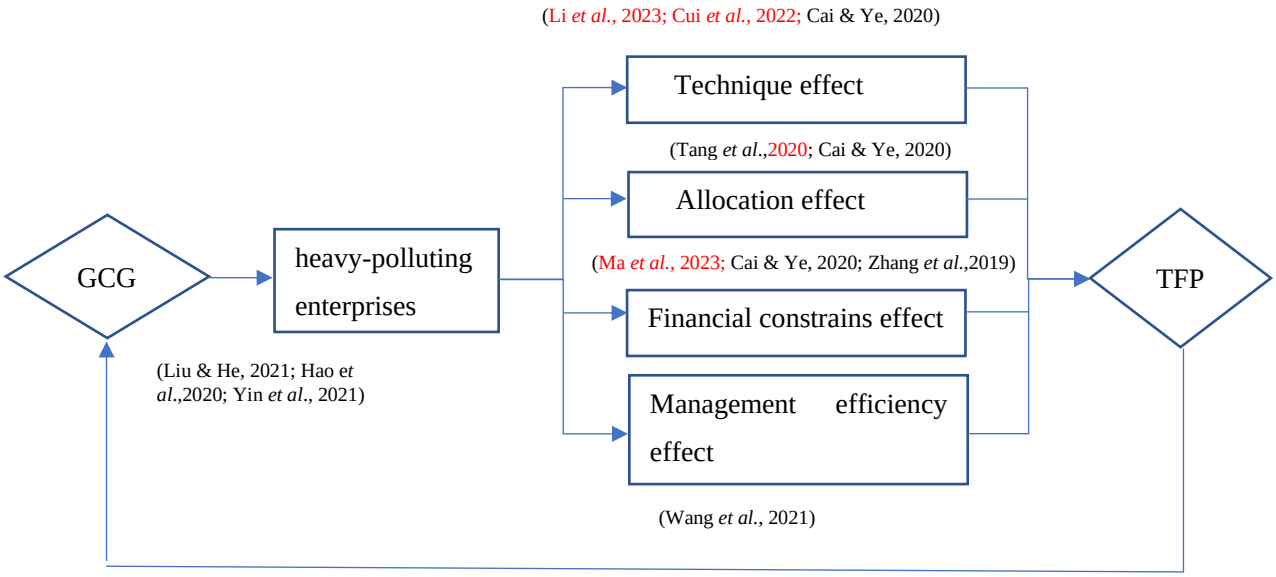

Fig. 2 Conceptual framework

2.2 Total factor productivity measures

Total factor productivity can be utilized to measure the output which is explained by the inputs that are employed during the course of production (Zheng *et al.*, 2021). In the existing literature, methods used to measure TFP include the index approach, Malmquist index based on Data Envelopment analysis (DEA) (*e.g.*, Hailu, 2003), the Olley-Pakes (OP)approach put forward by Olley and Pakes (1996), the Levinston-Petrin (LP) approach constructed by Levinsohn and Petrin (2003), and so on.

The LP approach has more advantage in terms of solving the problem of sample loss, while the OP approach is also employed for the purpose of testing the robustness of the outcomes (Zheng *et al.*, 2021). Compared with others, the DEA-based Malmquist approach is a non-parameter technique that takes multiple inputs into consideration in order to bring multiple outputs without setting particular functions (Lu *et al.*, 2020). Furthermore, it is also a frontier approach without parametric equation in terms of measuring the comparative efficiencies the peer decision-making units (DMUs) (Cook & Seiford, 2009). Accordingly,

the DEA method with its various developed models has become an important approach for measuring TFP and is widely used to reflect the productivity for diversified subjects (Shah *et al.*, 2019;Hu et al.,2019). For example, Chen *et al.* (2017) took the Yangtze River Economic Zone as the research object to analyze the static and dynamic environmental efficiency by employing the Malmquist index (MI) approach using data from 2003 to 2014. Lin and Chen (2018) measured TFP by employing DEA and Malmquist index for the intention of analyzing whether the market distortions would have negative impacts on China's green economic growth. Zhang *et al.* (2020b) combined the super slack-based measure (Super-SBM) (*i.e.*, a non-radial DEA model) with the Malmquist index to calculate the TFP of China's coal companies. Halkos and Aslanidis (2023) utilized Malmquist productivity index (MPI) and Malmquist-Luenberger productivity index (MLPI) productivity indices with a bootstrap-DEA approach to estimate the TFP of G20 economies.

2.3 Environmental regulation and TFP

The green credit policy imposed on enterprises is not only to curb the scale-driven development of heavy- polluting enterprises, but also aims to make full use of credit approaches to make heavy- polluting companies withdraw from projects that might result in severe environmental issues, encourage them to develop clean projects and focus on green technological innovation that reduces the negative externalities brought to the environment (Ding, 2019). However, not all companies responded positively to environmental regulations. Therefore, three types of research conclusions are usually found regarding whether the Porter effect exists on firm-level analysis. One argument is that environmental regulations hinder the improvement of enterprise productivity. For example, some studies found that regulations increased costs and uncertainties faced by enterprises, which in turn reduced enterprise productivity (Gray & Shadbegian, 2001; Cai & Ye, 2020; Feng &Liang, 2022). The second assertion is that governmental environmental rules can help to increase the total factor productivity of enterprises (Ren, S., *et al.*, 2019; Li *et al.*, 2023a; Cui *et al.*, 2022). The third perspective is that the association between regulations and the TFP of enterprises varies according to the intensity, methods, and implementation timing of rules and legislations (Lanoie *et al*., 2008; Wen *et al.*,2021).

Compared with quasi-natural experiments method, conventional regression investigation faced criticism because of endogeneity which is unable to accurately

identify the actual result of the policy (Greenstone *et al.*, 2012). Recently, studies have focused on the causal link between environmental regulations and corporate performance using quasi-natural experiments to observe the impacts of specific environmental policies. For example, Liu *et al.* (2019) took the GCGs strategy as a quasi-natural experiment and proves that the green credit policy has the directive function in terms of the resource configuration. Kong *et al.* (2020) studied the effects the anti-corruption activities have on TFP in China by utilizing a difference-in-differences assessment. Guo *et al.* (2021) observed the influence the anti-corruption activities have in terms of the resource reconfiguration in the area of energy in China by the means of the DID method. Zhang *et al.* (2020a) estimated the impacts of regulation related to environment on TFP of 216 prefectural-level cities on the foundation of a quasi-natural experiment approach.

2.4 Mechanisms of the environmental regulation on corporate TFP

The existing studies regarding the influencing mechanisms of environmental regulations and TFP are mainly investigated through three perspectives, which are innovation, allocation, and financial restrictions.

The PH could be supported under the circumstance that the companies managed to adapt to various environmental regulations. The execution of environmental regulations can help to increase the public's awareness about environmental issues and promote the progress of green markets, thus motivating more and more companies to take part in the green innovation and gradually increase their TFP (Ren, S., *et al.*, 2019). A large number of researchers have already proved that there is a positive association between environmental regulation and the corporate innovation level from various aspects (Wang *et al.*, 2021). For example, Cai *et al.* (2020) pointed out that regulations related to environment exerted a strong motivation on the green innovation of the indicated firms, especially the severely polluting enterprises. Li *et al.*(2023a) used the slack-based model with the Global-Malmquist-Luenberger technique to assess TFP and found that green credit can boost TFP through stimulating green innovation. Zhang & Xie (2023) revealed that renewable energy regulations increase energy businesses' TFP by the allocation of resources efficiency and technical innovation, and that the impact of policy implementation lasts for some time.

Environmental regulations will have impact on corporate TFP through resource configuration level as well as financial restrictions. For example, Ren *et al.* (2019) believed that the emission trading system increases a corporate TFP in the pilot areas via the capital allocation. Cai and Ye (2020) proved the new law which is aimed at environmental conservation can result in the decline in a firm's capital configuration by 9.78%, which will bring negative effect to the increase of TFP. Cui *et al.* (2022) demonstrated that the green credit policy mainly affects corporate total factor productivity through promoting technological innovation and enhancing resource allocation efficiency. Ge *et al.* (2023) concluded that environmental regulations indirectly affects TFP in the three industries by the comprehensive effect of production cost effects, compensation effects of innovation, and compensation effects of optimizing resource allocation. As for the financial restrictions, Zhang *et al.* (2019) pointed out that the environmental administration significantly restrained the financial environments，becauserestrains corporate financial activities by reducing investment for high-polluting companies, which in turn wipes them out of the industry or market. Consequently, the change of resource configuration will take place if the companies are supervised by the government regulation.Kong *et al,* (2022) proved that the People's Bank of China 's policy can tighten credit to firms in heavily polluting industries, forcing them to engage in green innovation and reduce their agency costs, thereby improving their TFP. Zhao *et al*. (2023) found that the green finance reform and innovation (GFRI) pilot policy affects the TFP of enterprises through financing constraints and environmental protection investment, and exerts greater levels of pressure on the financing constraints of private enterprises, large enterprises, and small environmental responsibility enterprises.

2.4 Research gap and contributions

As can be seen from the aforementioned literature, there are still many research gaps. First of all, the relationship between green credit policy and total factor productivity of enterprises especially the heavy-polluting ones, are not clear yet. Secondly, although some previous studies have investigated the association between management level and productivity, little research has taken the management efficiency as internal mechanisms of the GCGs' impact on corporate TFP to conduct the studies. However, enterprises with high supervision performance do better in the integration of human resources and financial

capital, demonstrating that the supervision performance plays a crucial role in the product quality and TFP for enterprises (Bloom *et al.*, 2019). Thirdly, the major DEA-based techniques are either radial or non-radial ones for most studies without considering the performance of efficient DMUs. Therefore, this paper takes the GCGs as a quasi-natural experiment, establishes the propensity score matching (PSM) and triple difference method (DDD) models based on the nature of property rights, and discusses the effectiveness and diversified mechanisms of market-based green credit policies on TFP gains of heavy-polluting enterprises using hybrid DEA techniques to further supplement the discussion on the effectiveness of market-based environmental regulation.

The possible contributions this research brings are threefolds. First, a Malmqusit index based on an adjusted hybrid measure of non-parameter model is constructed to evaluate the firm-level total factor productivity. Second, this study helps to enrich the current discussion regarding the efficiency of GCGs. Limited qualitative investigation, especially the experiential analysis, cannot ensure the full understanding of firms regrading green finiance policies (Wang *et al.*, 2019). According to the existing literature and referring to practical data, this paper helps to add evidence to prove the effectiveness of green credit policy. Third, this study further discusses the influencing mechanisms of GCGs on TFP of heavy-polluting enterprises from four aspects including innovation effect, allocation effect, financial constraint effect, and managerial effect to provide rich suggestions for dicision-making on for divergent stakeholders.

3. Methodology and data

3.1 Model construction

3.1.1 Total factor productivity estimation

In order to solve the problem existed in either radial (*i.e.*, Charnes, Cooper and Rhodes (CCR) and Banker, Charness, Cooper (BCC) models) or non-radial techniques (*i.e.*, SBM) as well as improve the dependability of the DEA approach, Tone and Tsutsui (2010) proposed a mixed model, *i.e.*, the epsilon-based measure (EBM), which deals with radial and non-radial characteristics of variables simultaneously. Cheng (2014) further proposed an adjusted model to improve the efficiency of EBM model (*i.e.*, adjusted EBM). In addition, the traditional DEA models fail to reflect the rankings and efficiency numbers for

efficient DMUs on the frontier, and such defect can be addressed using the super-efficiency approach proposed by Andersen & Petersen(1993).

Therefore, on the basis of the modified EBM (adjusted-EBM) measure, this study constructed and used a Malmquist index model based on the output-oriented super-efficiency. The proposed model aims to comprehensively evaluate the total factor productivity change of any given DMU, whose measurement formulas are shown in (1) and (2).

$$\gamma^* = \min \frac{1}{\phi + \varepsilon^+ \frac{1}{\sum_{r=1}^{q} w_r^+} \sum_{r=1}^{q} \frac{w_r^+ s_r^+}{y_k}}$$

$$s.t. \begin{cases} \sum_{\substack{j=1 \\ j \neq k}}^{n} \lambda_j x_{ij} \leq x_{ik} \\ \sum_{\substack{j=1 \\ j \neq k}}^{n} \lambda_j y_{ij} + s_r^+ \geq y_{ik} \\ \sum_{\substack{j=1 \\ j \neq k}}^{n} \lambda_j = 1 \\ \lambda \geq 0, s_r^+ \geq 0, \phi^{adjusted} \geq 1 \end{cases} \tag{1}$$

$$M_0(x_t, y_t, x_{t+1}, y_{t+1}) = \sqrt{\frac{D_0^t(x_{t+1}, y_{t+1})}{D_0^t(x_t, y_t)} \frac{D_0^{t+1}(x_{t+1}, y_{t+1})}{D_0^{t+1}(x_t, y_t)}} \tag{2}$$

where s_r^+ is the slack variable of the r output, $D_0^t(x_t, y_t)$ and $D_0^t(x_{t+1}, y_{t+1})$ are the efficiency scores of the t period and the $t+1$ period respectively.

3.1.2 Models for Quasi-natural experimental analysis

GCGs policy carried out in 2012 is regarded as a natural test. This study utilizes a DID approach for the intention of assessing the influence the GCGs have on the TFP for enterprises with heavy pollutions. This model is constructed on the foundation of quasi-natural test which is usually employed in the confirmation of the influence that the regulations with less external disturbance have (Hao *et al.*, 2020). Consequently, the regression model can be set up as follows:

$$TFP_{it} = \beta_0 + \beta_1 treat_i + \beta_2 treat_i * post_t + \gamma X_{it} + \lambda_t + \mu_i + \eta_i + \varepsilon_{it} \tag{3}$$

Where i is the enterprise, t is the year, and TFP_{it} refers to the TFP value, i at year t.

According to the "Guidelines for Environmental Information Disclosure of Listed Companies" released by the Ministry of Environmental Protection of the People's Republic of China in 2010 and the "Industry Classification Guidelines for Listed Companies" revised by the China Securities Regulatory Commission in 2012, listed companies belonging to 16 industries are defined as heavily polluting enterprises, while others are non heavily polluting enterprises(Xu *et al*.,2020a). $post_t$ =1 if the referred time is 2012 or later and $post_t$ = 0 otherwise. The β_2 refers to the GCGs net influence on TFP. If β_2 >0, it indicates that the GCGs have a more significant positive promoting effect on the TFP of heavily polluting enterprises compared to non heavily polluting enterprises. X_{it} refers to a series of variables and λ_t, μ_i and η_i refers to year, industry, and specific effect of the province, correspondingly. ε_{it} refers to the random interference item.

The GCGs issued in 2012 is the most critical and milestone guideline, which provides good external shock conditions for the green credit policy research in this paper. Before 2012, the green credit policy was mainly to guide banks to establish awareness of environmental protection and sustainable development; after 2012, the policy turned to revise and improve the evaluation system for the implementation of green credit policy. At the same time, according to Table 1, most of the existing research on green credit as a quasi-natural experiment takes 2012 as the impact year, so this paper chooses 2012 as the implementation year of the green credit policy.

Table 1 Literature summary of natural experiment based on green credit.

Research Topic	**Research period**	**Implementation Year**	**Literature source**
Green credit policy promotes research on green innovation	2007-2017	2012	Sun *et al.*, 2020
The Influence of Green Credit on Green Innovation of Enterprises	2007-2016	2012	Hu *et al.*, 2021
The relationship between green credit and corporate performance	2008-2015	2012	Yao *et al.*, 2021
The relationship between green credit and resource allocation	2009-2019	2012	Zhou *et al.*, 2021

The Impact of Green Credit on Corporate Debt Financing	2006-2018	2012	Peng *et al.*, 2022
How does green credit policy affect polluting firms' dividend policy? The China experience	2007-2017	2012	Li *et al.*, 2023b

3.2 Variable definition and description

3.2.1 Dependent variable

As the key variable of this research, TFP is an critical indicator in terms of measuring the production efficiency or change of technology level for a firm (Huang *et al.*, 2019). In this paper, the Malmquist indicator based on the foundation of adjusted EBM with super efficiency technique presented in Section 3.1.1 is employed to calculate the TFP. Following the study of Sun (2020), the corporate revenue is chosen as the output indicator, the net fixed assets and the number of employees can be regarded as the two inputs. Using 2010 as the base period, the output and input variables are deflated to remove the effects of price changes and other factors (Battisti, Belloc, and Gatto, 2020).

3.2.2 Control variables

Referring to the study of Cai and Ye (2020), Tang et al. (2020), and Liu et.al (2019), a group of control variables are also taken into account in this study. Generally speaking, older firms have richer supervision experience than new firms, and firms which are larger usually have stronger risk-resisting ability. Firms have lower leverage may be less affected by negative influence of the GCGs. Furthermore, firms have varied leadership will be affected variously by the policy while enterprises whose chairman and CEO are the same usually have substantial discursive power facing GCGs impacts, which is different from other enterprises. Therefore, firm size (*i.e.*, lnsize), lever age (*i.e.*lev), CEO duality (*i.e.*, dual), firm age (*i.e.*, lnage), revenue growth rate (*i.e.*, growth), cash flow (*i.e.*, cash =(Cash and cash equivalents)/total assets), return on asset (*i.e.*, roa) and Tobin Q (*i.e.*, tq) are selected as the control variables in this research.

3.2.3 Influencing mechanism variables

① Technological innovation: Discussed from the perspective of general technology innovation and green technology innovation respectively, the number of patents, as a direct reflection of the level of enterprise innovation, is an important indicator of the display of

enterprise researchers and R&D investment (Cai & Ye, 2020). Therefore, the logarithm of the total number of patents (i.e., patent) and the logarithm of the total number of green patents (i.e., green) are selected to reflect the technological innovation performance and the level of green technology innovation respectively.

② Allocation effect: capital allocation efficiency is used to test the impact of GCGs policy on resource allocation effect by referencing the study of Cai & Ye (2020). Specifically, the ratio of cash paid for the purchase and construction of fixed assets, intangible assets and other long-term assets - cash recovered from the disposal of fixed assets, intangible assets and other long-term assets - to the total assets (*i.e.*, Invest)measures the investment level of enterprise.

③ Financial constraints: Financial constraint effect refers to the influence of national policies and is the interpretation of fiscal constraint. Generally speaking, financial constraint includes commercial credit, bank credit and government subsidies. Therefore, this paper refers to the research of Cai and Ye (2020). The ratio of the sum of long-term loans and short-term loans to total assets (*i.e.*, BC) is chosen to reflect the bank credit level of the enterprise, the ratio of accounts receivable to operating income (*i.e.*, CC) is chosen to reflect the commercial credit level of the enterprise credit, and the ratio of government subsidies to revenue (*i.e.*,GS)is choosen to reflect the company's government subsidy level.

④ Management efficiency: The management efficiency of overregulation cost (*i.e.*, ME) refers to the ratio of administrative expenses and selling expenses to total operating revenue, and the ratio is inversely proportional to the company's management efficiency (Wang *et al.*, 2021). Under the pressure of environmental regulations, processes and projects with low management level will face the risk of elimination. As enterprises adapt to the new model by improving production processes and personnel management level, environmental regulations will urge enterprises to improve their management level to achieve their business results. Therefore, management efficiency is one of the possible ways that green credit guidelines can affect the total factor productivity of enterprises.

3.3 Data sources and processing

This research chooses heavy-polluting enterprises listed in the A-share markets of Shanghai Stock Exchange and Shenzhen Stock Exchange during 2007-2019[①]. 2007 is used as the starting year because it is the year in which the new accounting policy was

[①] A-shares, or RMB-denominated common shares, refer to ordinary shares issued by companies incorporated and listed in mainland China and subscribed and traded in RMB.

implemented (Hao *et al.,* 2020) . Financal indicators are collected from the China Stock Market & Accounting Research (CSMAR) database, and firms' patent-related information is obtained through Chinese Research Data Services (CNRDS). In addition, in order to ensure the integrity of enterprise disclosure data, this paper removes the following samples: (1) the samples of enterprises with poor financial data; (2) ST/PT/ST*/PT* enterprises; (3) In order to maintain the consistency of the company before and after the event, the samples of enterprises with missing financial data are excluded. (4) Companies listed after 2007. All in all, a dataset with 13510 observations is collected. This paper also winsorized of 1% the continuous variate for the intention of decreasing the negative influence of anomalous value.

The explanation and classification of the variables is described in Table 2.

Table 2 Definition and descriptive statistics.

Variable	Mean	S.D.	Min	Max	Definition
Independent variables					
TFP	1.0965	0.8095	0.0646	6.2370	TFP calculated using the Malmquist method
Policy variables					
$post_t$	0.2420	0.42834	0.0000	1.0000	Dummy variable, 1 or 0
treat	0.6667	0.4714	0.0000	1.0000	Dummy variable, 1 or 0
Control variables					
lnsize	22.3469	1.3418	19.1937	26.2531	Logarithm of total assets
lnage	2.6531	0.4496	0.6931	3.4012	Logarithm of current year-enterprise listing year
Lev	0.1944	0.2551	0.0000	3.4012	Total liabilities/total assets
dual	0.1636	0.3699	0	1	Dummy variable, 1 or 0
growth	0.4182	1.3009	-0.7751	15.6478	Revenue growth rate
cash	0.1394	0.1010	0.0058	0.5360	(Cash and cash equivalents)/total assets
Roa	0.0315	0.0535	-0.2601	0.2094	Return on Assets
Tq	7.7790	4.7787	2.5892	36.7535	(Equity market value and total liabilities)/Total Assets
Variables for mechanism analysis					
patent	1.9143	1.8330	0.0000	6.7081	Logarithm of total patents
green	0.5379	0.9976	0	4.3567	Logarithm of green patents
Invest	0.0400	0.1401	-11.524	0.5453	(Cash paid for the acquisition and construction of fixed assets, intangible assets and other long-term assets - cash recovered from the disposal of fixed assets, intangible assets and other long-term assets)/Total assets

BC	0.1796	0.1144	0.0000	0.6266	(Long-term loans+short-term loans)/ Total assets
CC	0.1781	0.1494	0.0040	0.6266	(Accounts receivable)/ Revenue
GS	0.0072	0.0133	0	0.1099	Government subsidies/ Revenues
ME	0.0889	0.0831	0.0070	0.8041	The ratio of the sum of management expenses and sale expenses / Revenues

4. PSM-DID estimation and robustness test

4.1 Parallel trend assumption

The DID model assumes that the parallel trends can be fulfilled, that is to say, the independent variables in treatment group and control group have the comparable tendency before the policy was carried out. Furthermore, Jacobson et al. (1993) put forward a more rigid approach that can be named event analysis method for the purpose of demonstrating the comparable tendency, which is built as follows (Cai & Ye, 2020):

Choosing 2012 as the base year ,the DID approach was utilized in order to assess the impacts of GCGs on corporate TFP from 2007 to 2019. Bertrand *et al.* (2004) commented that the similar tendency supposition acted as one of the preconditions for DID approach. Therefore, when using this method, other possible elements which will have influence on TFP of the enterprises need to be removed so as to ensure the TFP tendency in treatment group and control group is similar (Tang *et al.*, 2021). As is shown in Table 2, the preconditioning index from pre_4 to pre_1 shows no significance whereas the index in the post-years (post_2 & post_3) shows obvious significance, which proves that there is authenticity in the parallel tendency in the sample selected. The outcome of parallel trend experiment is also shown in Figure 3.

Table 3 Parallel trend test

Variables	**Parallel trend test**	
Pre_4	0.0570	(0.86)
Pre_3	-0.0073	(-0.11)
Pre_2	0.0262	(0.40)
Pre_1	0.0220	(0.34)
current	0.0765	(1.18)
Post_1	0.0110	(0.17)

Post_2	0.1367**	(2.10)
Post_3	0.1150***	(2.82)
Post_4	0.0529	(0.93)
_cons	0.5575***	(4.20)
Control	Yes	
Year Fixed effect	Yes	
Industry Fixed effect	Yes	
N	13510	
R^2	0.4839	

Note: The estimator of t-statistic of the parameters are in parentheses; *, **, *** which denote the significance level of 10%, 5%, and 1%, respectively. This notation is hereafter the same throughout following tables.

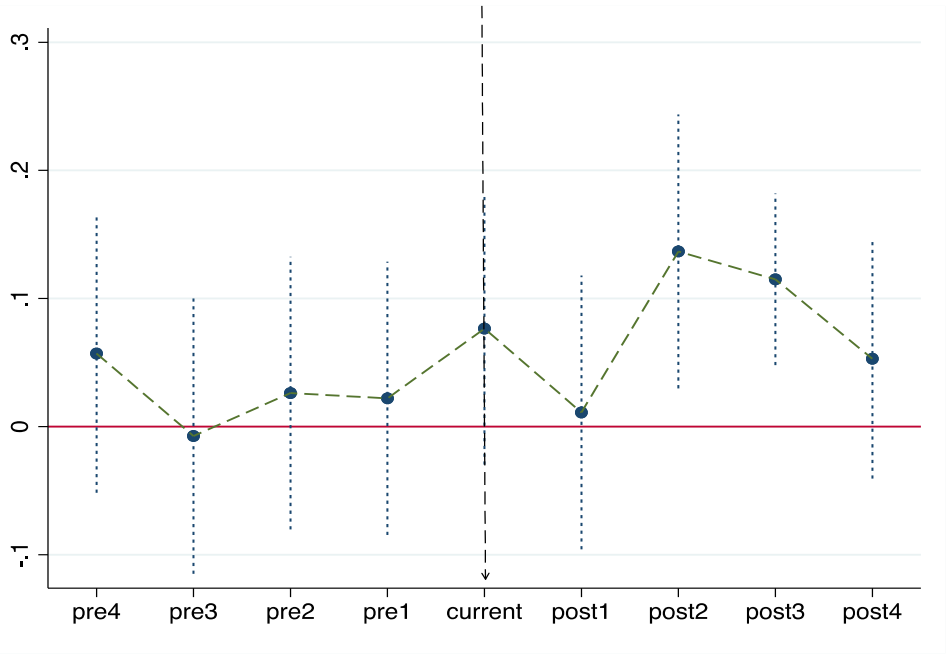

Figure3 Parallel trend test

4.2 Results and analysis of PSM-DID

Another significant hypothesis for DID model is that the samples selected have homogeneity. Firms in both groups are matched according to corporate features on the basis of PSM approach. According to the research of Tang *et al.* (2020) and Cui and Jiang (2019), size, leverage, firm age, growth, cash, roa and tq can help to improve the scientific use of samples. Therefore, such variables can be employed as match variables for the test. This study also utilizes nearest neighbor matching for the purpose of conducting the pairing

of firms as 1:1 between both treatment and control groups. The result presented in Table 4 justifies the effectiveness of the method used and the selection of matching variables (Cai & Ye, 2020).

This study utilized the approach of K-nearest neighbor matching in order to match the two groups. At first, the factors, such as age, growth, and roa were taken as covariates, after which the logit model was chosen for the intention of assessing the propensity score. The caliper width and K are 0.05 and 1, respectively. The enterprise whose difference in absolute number of propensity points is less than 0.05 will be chosen and the two firms with the smallest difference will be matched. Thus, there will be two groups of samples after unqualified firms are removed. The final outcome of the balance experiment of PSM is shown in Figure 4. Once the matching is done, the absolute numbers of the standard deviations decrease rapidly and greatly. The results of two groups show no obvious diversity, which proves that the effectiveness of PSM can meet the standard (Wang *et al.*,2021).

Table 4 Balance test of PSM-DID

Variable	**Unmatched**	**Mean**		**%Bias**	**%Reduct**	**t-test**	
	Matched	Treated	Control	%bias	|bias|	t	p>|t|
lnsize	U	22.48	22.371	8.3		4.66	0.000
	M	22.477	22.466	0.8	90.6	0.38	0.703
lev	U	0.19573	0.18913	2.6		1.45	0.148
	M	0.19584	0.19567	0.1	97.4	0.03	0.974
dual	U	0.16343	0.15516	2.3		1.27	0.205
	M	0.16373	0.17664	-3.5	-56.1	-1.70	0.090
lnage	U	2.6532	2.6849	-8.1		-4.48	0.000
	M	2.6545	2.6423	3.1	61.6	1.49	0.136
growth	U	0.22976	0.51976	-24.0		-12.86	0.000
	M	0.23072	0.29345	-5.2	78.4	-3.11	0.002
cash	U	0.12	0.1498	-30.4		-16.82	0.000
	M	0.12018	0.11816	2.1	93.1	1.12	0.265
roa	U	0.03326	0.03236	1.7		0.97	0.333
	M	0.03313	0.03597	-5.4	-216.8	-2.65	0.008
tq	U	7.5123	7.7201	-4.6		-2.58	0.010
	M	7.511	7.7465	-5.2	-13.3	-2.51	0.012

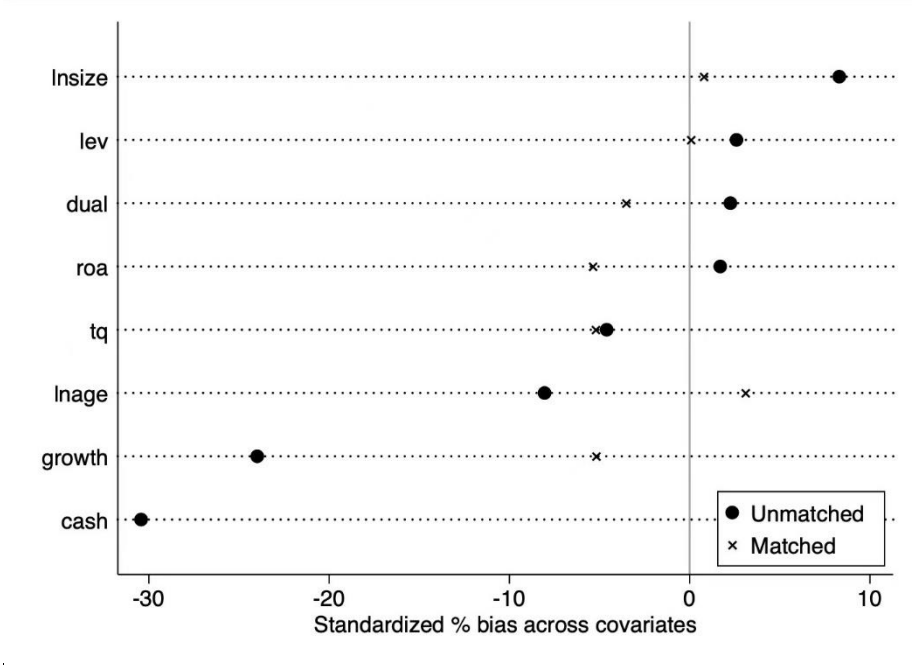

Figure 4 Balance test for propensity score matching

The results shown in Table 5 are the benchmark standard of GCGs' influence on TFP of industries which produce heavy pollution by the means of PSM-DID method. The time trend term is included in the regression due to the diversity of time trends in both groups (Beck *et al.*, 2010). The final results prove that the regression coefficients of $treat_i * post_t$ are positively remarkable at the level of 1%, demonstrating that the application of GCGs have a more pronounced impact on the TFP of heavy-polluting enterprises compared to non-heavy-polluting enterprises (Ouyang *et al.*, 2020). The assessment consists of four columns and the global Malmquist approach is employed for the intention of calculating the firms' TFP. The influence that the policy has on the firm TFP is described in Column 1 of Table 5. As for the statistical result, the interaction term's coefficient turns out to be positive at 0.3676, demonstrating that the implementation of GCGs have a more prominent effect on the growth of total factor productivity in heavy-polluting enterprises, increasing it by 0.3676 units. After excluding the influencing factors of fixed effect, the final results still increase by 0.0512 units. Column 3 and 4 also confirm the statistically positive effects of the guidelines on firms' TFP with an increase of 0.3676 and 0.0512 units, respectively. In addition, the results demonstrate that firm size, firm age, and Tobin Q show positive impact to firms' TFP.

Table 5 PSM-DID estimated effects

Variables	OLS		FE	
	(1)	(2)	(3)	(4)
$treat_i*post_t$	0.3676***	0.0512**	0.3676***	0.0512**
	(14.32)	(2.29)	(14.32)	(2.29)
lnsize	0.05429***	0.0006	0.0542***	0.0006
	(7.85)	(0.12)	(7.85)	(0.12)
lev	0.0185	-0.0098	0.0185	-0.0098
	(0.67)	(-0.48)	(0.67)	(-0.48)
dual	0.0308	-0.0037	0.0308	-0.0037
	(1.61)	(-0.26)	(1.61)	(-0.26)
lnage	0.1724***	0.0211	0.1724***	0.0211
	(8.63)	(1.23)	(8.63)	(1.23)
growth	0.0039	0.0063	0.0039	0.0063
	(0.69)	(1.50)	(0.69)	(1.50)
cash	-0.2288***	-0.1135**	-0.2288***	-0.1135**
	(-3.03)	(-2.04)	(-3.03)	(-2.04)
roa	-0.9401***	-0.3859***	-0.9401***	-0.3859***
	(-6.51)	(-3.61)	(-6.51)	(-3.16)
tq	0.0200***	0.0010	0.0200***	0.0010
	(10.61)	(0.68)	(10.61)	(0.68)
_cons	-0.7226***	0.5718***	-0.7226***	0.5718***
	(-4.26)	(4.32)	(-4.26)	(4.32)
Year fixed effects	No	Yes	No	Yes
Industry fixed effects	Yes	Yes	Yes	Yes
Observations	13510	13510	13510	13510
R-squared	0.0488	0.4833	0.0560	0.4923

4.3 Placebo test to check the policy influence

According to the regression results, the GCGs policy exerted a positive influence on the TFP of the firms which produce heavy pollutions. Nevertheless, other factors can also result in the growth in corporate TFP (Cai & Ye, 2020). This paper carries out a placebo test to find out whether the growth in TFP of the heavy-polluting firms can be ascribed to GCGs policy. It is assumed that the environmental regulation policies are enforced in the year before 2012 by means of the counter factual processing in terms of the policy enforcement year. If the processing index still turns out to be significant, we can draw the conclusion that the growth in TFP of the firms which produce heavy- pollution results from

other factors. Conversely, it is rational to draw the conclusion that GCGs in 2012 did exert a positive influence on TFP. The experiment outcome is listed in Table 6. In order to find out the policy influence of different years, this paper utilizes different years in 2009-2011 (except 2012) as the policy enforcement time and the results which are listed in Table 6 demonstrate that the influence the policy has on the TFP shows no significance for all the years before 2012, which proves that the results are significant only for the enforcement time of GCGs. Thus, there is no doubt that policies bring positive influence on the growth of the TFP, and that GCGs in 2012 had an impact on the TFP of heavy-polluting sectors is therefore confirmed (Ouyang *et al.*, 2020).

Table 6 Placebo test: counterfactual treatment of the policy execution year

Variables	**2009**		**2010**		**2011**	
	(1)	(2)	(3)	(4)	(5)	(6)
Tpo2009	-0.0223	-0.0399				
	(-1.55)	(-2.37)				
Tpo2010			-0.0045	0.0315		
			(-0.23)	(0.51)		
Tpo2011					0.0197	0.0229
					(0.73)	(0.74)
_Cons	0.1023	-0.0888	0.3286*	0.2769	-0.0258	0.1440
	(0.46)	(-1.29)	(1.85)	(1.61)	(-0.14)	(0.72)
Control	Yes	Yes	Yes	Yes	Yes	Yes
Industry fixed effects	No	Yes	No	Yes	No	Yes
Yearfixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Observations	3196	3196	3366	3366	3477	3477
R-square	0.0558	0.0793	0.0427	0.0631	0.0566	0.0731

Note: Tpoi means the processing indicator when the enforcement year of environmental polices is supposed to be assumed in year *i*.

5. Mechanism investigation

5.1 Technical innovation effects

As the direct reflection of corporate innovation levels, the quantity of patents is a vital indicator in terms of presenting firms' researchers, investment in terms of R&D and so on. Consequently, this paper employs the number of patents that the firms have as the explained variable for the intention of assessing the technique influence.

Columns (1) and (2) of Table 7 show the impact of green credit on corporate technology innovation .When only year is fixed, the interaction term coefficient is not significant. However, after controlling for industry characteristics, the coefficient of the interaction term is positive at the 1% significance level, which indicates that green credit policy increases the technological innovation of enterprises by 0.2040 units. Columns (3) and (4) are the results obtained using green patents as the dependent variable.It is also found that after fixing the year and industry at the same time, the coefficient of the interaction term is significantly positive, which indicates that green credit guidelines will affect the green technology innovation of enterprises.Improved by 0.0590 units. In conclusion, the findings of the test point out that the GCGs policy apparently enhances the growth of firms' technical innovations, which in turn, exerts positive impacts on firms' TFP.

Table 7 Technique influence

Variables	**Technique effect**		**Green Technique effect**	
	(1)	(2)	(3)	(4)
$treat_i*post_t$	-0.0809	0.2040***	-0.1374	0.0590**
	(-0.27)	(3.92)	(-1.05)	(2.35)
lnsize	0.4233***	0.5144***	0.2674***	0.2812***
	(6.86)	(40.72)	(7.29)	(9.79)
lev	0.1509	-0.0623	0.0828	0.0028
	(0.90)	(-1.31)	(0.98)	(0.11)
dual	0.1625*	0.0673**	0.0340	0.0107
	(1.75)	(2.03)	(0.46)	(0.42)
lnage	-0.9121***	-0.3529***	-0.2837***	-0.0553**
	(-4.74)	(-8.83)	(-3.76)	(-2.37)
growth	-0.1463***	-0.0875***	-0.0321**	-0.0195***
	(-4.10)	(-9.03)	(-2.07)	(-5.01)
cash	0.4264	-0.0874	0.1165	-0.0890
	(0.81)	(-0.67)	(0.62)	(-1.68)
roa	1.3465*	2.0064***	-0.4757	0.0435
	(1.93)	(8.07)	(2.62)	(0.31)
tq	0.0312**	0.01587***	0.0206**	0.01821***
	(2.27)	(4.65)	(2.62)	(6.50)
_cons	-6.2178***	-10.0345***	-5.1048***	-6.0861***
	(-4.72)	(-32.01)	(-6.48)	(-9.74)
Year fixed effects	Yes	Yes	Yes	Yes

Industry fixed effects	No	Yes	No	Yes
Observations	13658	13658	13658	13658
R-square	0.1651	0.4450	0.1578	0.2857

5.2 Allocation influence

Green credit policies encourage enterprises to improve total factor productivity by optimizing resource allocation. Under the same technical level, various production factors gradually flow from enterprises or departments with low productivity to enterprises or departments with high productivity, so as to improve the overall profit rate, which is also the embodiment of the improvement of total factor productivity. This paper takes two approaches to verify this path. (Ren *et al.*, 2019)：

(1) The logarithm of the number of patent applications is added to the model as a control variable to eliminate the effect of technological innovation on total factor productivity. As shown in columns (1) and (2) of Table 8, after adding the logarithm of the number of patent applications, the interaction coefficient is significantly positive regardless of whether the industry is fixed, indicating that green credit guidelines can indeed promote the improvement of total factor productivity by improving the efficiency of enterprise resource allocation.

(2) This paper uses capital allocation efficiency instead of resource allocation efficiency to test the impact of green credit guidelines on resource allocation efficiency. Therefore, the investment sensitivity model is built to investigate whether the green credit guidelines use resource allocation efficiency to affect the total factor productivity of enterprises. The other variables are defined in the same way as formula

(3). The matching degree between investment level and investment opportunity can directly reflect the level of capital allocation. Therefore, the level of capital allocation of an enterprise can be directly reflected by its sensitivity to investment opportunities. According to the research of Wurgler(2000), the investment opportunity sensitivity model can be used to evaluate the effect of policies on allocation level. Referring to Ren et al. (2019), the investment sensitivity model is constructed, as shown in Model (4):

$$\begin{aligned} invest_{it} = {} & \gamma_0 + \gamma_1 post_t * treat_i * roa_i + \gamma_2 treat_i * post_t + \gamma_3 treat_i * roa_i \\ & + \gamma_4 post_t * roa_i + \gamma_5 treat_i + \gamma_6 X_{it} + \lambda_i + \mu_i + \varepsilon_{it} \end{aligned} \tag{4}$$

In model (4), $invest_{it}$ represents the investment level of the enterprise, $post_t * treat_i * roa_i$ refers to the impact of green credit policies on the sensitivity of enterprises to investment opportunities, that is, the impact of policies on the level of capital allocation. The results are shown in Table 8, and it can be seen that $post_t * treat_i * roa_i$ is significantly positive whether it is fixed year only or fixed year and industry at the same time. At the same time, the regression results in column (4) further show that the impact of green credit guidelines on enterprise investment level is a positive promotion of 0.0493 units.

Combining the above two methods, it is proved that the efficiency of resource allocation is indeed an important way for green credit guidelines to affect the total factor productivity of enterprises. This conclusion proves that environmental regulation has brought some cost pressure to enterprises, and enterprises will reconsider the allocation of production factors based on long-term economic benefits. Increase total factor productivity across the company by reducing factor inputs to heavily polluting and inefficient production sectors and increasing investments in clean energy and efficient production sectors. Therefore, the regulatory authorities should take actions to guide enterprises to attach importance to green credit policies and establish effective incentive mechanisms to promote the improvement of total factor productivity of enterprises.

Table 8 Allocation influence

Variables	**Allocation influence**			
	TFP		**Allocation influence**	
	(1)	**(2)**	**(3)**	**(4)**
treat$_i$**post*$_t$	0.0386***	0.0493**		
	(2.99)	(2.19)		
treat$_i$**post*$_t$**roa*$_i$			0.0962***	0.0493*
			(4.66)	(1.95)
lnpatent	0.00784***	0.0075**		
	(2.60)	(2.03)		
lnsize	-0.0015	-0.0023	0.0061***	0.0065***
	(-0.28)	(-0.39)	(14.62)	(14.91)
lev	-0.1290	-0.0101	0.0074***	0.0083***
	(-0.64)	(-0.49)	(4.43)	(4.99)
dual	-0.0024	-0.0021	0.0006	0.0025**
	(-0.17)	(-0.15)	(0.48)	(2.11)
lnage	0.0262	0.0245	-0.0249***	0.0239***
	(1.63)	(1.42)	(-18.83)	(-17.13)
growth	0.0043	0.0067	-0.0032***	-0.0019***
	(1.08)	(1.60)	(-9.80)	(-5.86)
cash	-0.0944*	-0.1060*	-0.0611***	-0.0489***
	(-1.74)	(-1.89)	(-13.45)	(-10.71)

roa	-0.4165***	-0.4086***	0.1016***	0.1004***
	(-3.97)	(-3.79)	(10.26)	(10.09)
tq	0.0013	0.0009	0.0003***	0.0003***
	(0.92)	(0.59)	(2.78)	(2.56)
_cons	0.6323***	0.6237***	-0.0142	-0.0369***
	(5.28)	(4.45)	(-1.45)	(-3.40)
Year fixed effects	Yes	Yes	Yes	Yes
Industry fixed effects	No	Yes	No	Yes
Observations	13391	13391	13508	13508
R-square	0.4812	0.4827	0.1062	0.1662

5.3 Financial restriction effect

The financial constraint effect refers to the impact of national policies and is the explanation of financial constraints. Generally speaking, financial constraints include commercial credit, bank credit and government subsidies. Green credit policies guide the development of green industries, and at the same time significantly curb credit financing of heavily polluting enterprises, increase the costs and uncertainties faced by polluting enterprises, and also reduce the total factor productivity of enterprises by affecting the allocation of resources in the financial market. The results in columns (1) and (2) in Table 9 show that regardless of whether there is a fixed industry effect, the promulgation of the GCGs has a significant negative impact on the bank credit of enterprises, indicating that commercial banks provide funds and capital to the cleaner production industry by initiating green credit policies(Olley S & Pakes, 1992), which has indeed impacted the bank credit commitments of heavily polluting enterprises.。

It can also be concluded from columns (3) and (4) in Table 9 that the GCGs also have a negative impact on the commercial credit of heavily polluting enterprises, thereby inhibiting the implementation of their environmental protection plans, thereby reducing the total factor productivity of heavy polluting enterprise.

Table 9 Financial restriction effect

Variables	**BC**		**CC**		**GS**	
	(1)	(2)	(3)	(4)	(5)	(6)
$treat_i*post_t$	-0.0198***	-0.0156***	-0.0526***	-0.0080*	0.0002	-0.0003
	(-6.44)	(-3.56)	(-17.83)	(-1.68)	(0.80)	(-0.67)

lnsize	0.0327***	0.0246***	0.0124***	0.0109***	-0.0006***	-0.0003***
	(19.66)	(23.75)	(11.00)	(9.66)	(-5.68)	(-3.14)
lev	-0.0095	0.0073*	0.0201***	0.0158***	-0.0006	-0.0004
	(-1.26)	(1.83)	(4.39)	(3.62)	(-1.37)	(-0.93)
dual	-0.0022	0.0039	-0.0026	-0.0009	0.0005*	0.0003
	(-0.81)	(1.43)	(-0.83)	(-0.28)	(1.81)	(0.88)
lnage	0.0080	-0.0203***	-0.0112***	-0.0015	-0.0013***	-0.0015***
	(0.95)	(-6.07)	(-3.08)	(-0.42)	(-4.05)	(-4.33)
growth	0.0000	-0.0024***	0.0189***	0.0150***	-0.0000	0.0000
	(0.04)	(-3.00)	(20.48)	(16.69)	(-0.15)	(0.33)
cash	-0.2088***	-0.3740***	-0.0729***	-0.0856***	-0.0029**	-0.0011
	(-19.72)	(-34.43)	(-5.84)	(-7.16)	(-2.52)	(-0.93)
roa	-0.4591***	-0.6770***	-0.5743***	-0.5734***	-0.0048**	-0.0060***
	(-25.69)	(-32.25)	(-23.84)	(-25.06)	(-2.16)	(-2.75)
tq	-0.0003	-0.0019***	-0.0002	0.0007**	0.0001***	0.0001***
	(-1.06)	(-6.48)	(-0.50)	(2.17)	(4.01)	(3.00)
_cons	-0.4621***	-0.1323***	-0.0853***	-0.1650***	0.0232***	0.0166***
	(-11.56)	(-5.13)	(-3.20)	(-5.85)	(9.47)	(6.11)
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Industry fixed effects	No	Yes	No	Yes	No	Yes
Observations	13675	13675	13605	13605	13651	13651
R-square	0.2657	0.3632	0.1283	0.2596	0.0796	0.1397

5.4 Management efficiency effect

On the basis of Ang et al. (2000) and Davidson et al. (2006), the reflection of the excess supervision costs management efficiency (ME) refers to the ratio of total supervision costs and sale costs to the total business revenue. The ratio is inversely proportional to the management efficiency of the companies.

Columns (1) and (2) of Table 10 show the Green Credit's influence on firms' TFP through management efficiency. Column (1) indicates the Green Credit's total effects on

enterprises' management efficiency with the year fixed effects. After considering the industry fixed impacts, the coefficient of t*treat in column (2) is not significant, demonstrating that the impact mechanism of GCGs on enterprises' TFP through management efficiency does not exist.

Table 10 Management effect

Variables	**Management effect**	
	(1)	(2)
$treat_i*post_t$	-0.0114***	-0.0016
	(-7.71)	(-1.19)
lnsize	-0.0124***	-0.0119***
	(-21.87)	(-25.21)
lev	0.0034	0.0070***
	(1.46)	(3.55)
dual	0.0043***	0.0047***
	(2.67)	(3.19)
lnage	0.0111***	0.0093***
	(6.12)	(7.13)
growth	0.0020***	0.0018**
	(4.43)	(2.47)
cash	0.0140**	0.0089
	(2.24)	(1.06)
roa	-0.2136***	-0.2555***
	(-17.69)	(-8.89)
tq	0.0034***	0.0032***
	(20.86)	(10.75)
_cons	0.3066***	0.2998***
	(22.91)	(23.72)
Year fixed effects	Yes	Yes
Industry fixed effects	No	Yes
Observations	13583	13583
R-square	0.1656	0.2540

6. Conclusion and policy implications

6.1 Conclusion

The Chinese government has paid great attention to the ecological environment to ensure that the target of sustainable development could also be achieved during the course of economic growth. Against this background, whether and how environmental regulations

may lead to productivity gains of heavy-polluting enterprises have been increasingly concerning. Therefore, this paper utilizes the Malmquist index on the basis of adjusted EBM with super efficiency to evaluate the TFP of the enterprises. In addition, impacts and the influencing mechanisms of the GCGs policy on enterprise productivity gains are estimated using a quasi-natural experiment analysis.

On the basis of the data collected from the listed firms from China's A share market during 2007-2019, the following results are found: 1) GCGs facilitates the productivity gains of heavy-polluting firms, which validates that the Porter effect does exist. In other word, by reducing loans to highly polluting or energy-intensive enterprises, the GCGs will accelerate the process of upgrading industrial structure by encouraging enterprises to adopt advanced green production technologies and adjust investment strategies, and ultimately help to force or motivate enterprises to improve their total factor productivity.2) Enhancement of technical innovation and resource configuration contribute to productivity gains of heavy-polluting firms whereas financial constrains represented by bank credit and commercial credit inhibit the TFP growth. 3)

Under the circumstance that the various robustness tests are taken into consideration, the conclusion listed above still holds.

6.2 Robustness discussion

First, the parallel trend assumption outcome proves the authenticity of the parallel trend in our sample. Second, the outcome of the balance test for PSM shows that no obvious variance exists between the matching variables in both groups when utilizing the balance test (see Table 3), which further proves the reasonableness of the variables as well as the approach (Cai & Ye, 2020). Third, the placebo test experiential outcomes in Table 5 demonstrate that the influence of intervention on TFP shows no obvious significance at almost all years before 2012, which means that stable outcome only appreaed in the actual execution year of GCGs. Those aforementioned tests prove the robustness of the research design of this study. Furthermore, the research findings of this paper are in line with the following studies with similar topics presented in Table 10, which in turn, validates the reliability of this study as well.

Table 10 Comparison of our findings with those of previous literature

Variables	Our findings	Previous findings
Environment regulation to enterprise productivity	The GCGs policy exerted a positive impact on TFP of heavy-polluting enterprises.	Environmental regulations can increase the TFP of enterprises (Zhang *et al.*, 2020b) Cui *et al.* (2022) showed evidence of a significant and positive correlation between green credit and corporate total factor productivity.
Mechanisms of the environmental regulation on TFP	The GCGs policy significantly improves the development of enterprises' technical innovations, which in turn, exerts positive impacts on enterprises' TFP.	Cai *et al.* (2020) showed that regulations exerted a strong and significant incentive impact on green innovation of listed firms, especially the heavy polluting ones. Cui *et al*. (2022) believed that the green credit policy mainly affects corporate total factor productivity through promoting technological innovation.
	The GCGs improve the enterprises' capital allocation efficiency, which improves the development of the enterprise's TFP.	Ren *et al.* (2019) believed that the emission trading system has increased firm's TFP in the pilot areas via the capital allocation. Wang *et al.* (2023) proved that green credit can significantly improve TFP by industrial structure upgrading, such as human capital and R&D intensity, which improved the capital allocation efficiency.
	Green Credit hinders the TFP of the enterprises by increasing financial pressure.	Cai & Ye (2020) proved that the NEPL significantly hindered enterprises' bank credit, which in turn lead to the negative impact on enterprises. Ma *et al.* (2023) believed that GCGs increase compliance costs and decrease the long-term bank credit that supports environmental innovation ,which hinder the high-quality environmental innovation.

6.3 Policy implications

According to the outcomes, this paper puts forward several implications.

1) As a market-oriented environmental regulation, the experiential results of this study prove that the "win-win" goal between environmental regulation and productivity gains can be realized under the GCGs. Therefore, no discrepancy between the enhancement of regulations and economic prosperity is found.

2) Although there is no significant difference in the implementation of GCGs between SOEs and non-SOEs, it is still necessary for the government to attach importance to the leading and demonstrative roles of SOEs in the heavy-polluting industries in terms of environmental protection and carbon emission reduction to facilitate high-quality economic development.

3) It is essential for government, financial organizations, and firms to cooperate with each other for the intention of the promotion of GCGs. The key to improve corporate TFP is to be good at using flexible and appropriate environmental regulations to give enterprises continuous innovation incentives (Ren *et al.*, 2019). Financial institutions should also improve their green credit capacity by building a green financial management system to support the issuance of green loans and assess the financial status of green projects and enterprises.

4) The regulatory department is supposed to take action to guide firms to lay emphasis on the green credit policy and establish effective incentive systems for the intention of enhancing companies' capital allocation efficiency. Moreover, it is significant for governments to combine the green financial support along with environmental regulations so as to provide helpful conditions for companies that faces financial constraints for green transition.

In addition, this study only collected data from the listed firms due to data availability. GCGs policy is aimed to guide all industrial firms. The listed businesses are often larger in size, in other words, smaller companies have not been taken into consideration. More Chinese industrial companies are suggested to be included in future studies so as to draw conclusions which are more effective and universal. Moreover, the spatial spill-over effects of GCGs on corporate TFP is also an interesting topic that needs further investigation for the intention of examining the effectiveness of PH when utilized in developing economies.

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Appendix

The abbreviations used in this article are listed in Table A1.

Table A1 Abbreviations

No.	Full name	Abbreviation	No.	Full name	Abbreviation
1	green credit guidelines	GCGs	8	Olley-Pakes	OP
2	data envelopment analysis	DEA	9	Levinston-Petrin	LP
3	epsilon-based measure	EBM	10	slack-based measure	SBM
4	total factor productivity	TFP	11	ordinary least squares	OLS
5	propensity score matching	PSM	12	fixed effect	FE
6	difference-in-difference	DID	13	Charnes, Cooper and Rhodes	CCR
7	difference-in-difference-in-difference	DDD	14	Banker, Charness, Cooper	BCC

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