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Green credit and $PM_{2.5}$: a time-varying perspective of China

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ABSTRACT
The causal link between green credit (GC) and particulate matter 2.5 ($PM_{2.5}$) is discussed this paper for the case of China using the bootstrap rolling-window Granger causality test. The fresh empirical results show that GC had both positive and negative influences on $PM_{2.5}$ in two separate sub-sample periods. In turn, $PM_{2.5}$ positively and consistently affected GC in two sub-sample periods. In addition, time periods without causalities were also found in the sample. These inconsistent conclusions do not provide strong support for the hypothesis that GC and $PM_{2.5}$ would affect each other throughout the whole sampling period. Government intervention, public environmental awareness, the domestic economic situation, and other factors were fully considered in interpreting the deviations in certain periods. Thus, the major contribution of this study is that the linear assumption of causality was relaxed, which is more in line with China's realities. Some policies are suggested to further strengthen the construction of the GC framework and establish a multiparticipant GC system. Moreover, $PM_{2.5}$ is an important reference and can be incorporated into enterprises' green financing strategy.

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1. Introduction

This paper aims to discuss the time-varying and dynamic causal relationship between green credit (GC) and particulate matter 2.5 ($PM_{2.5}$) from the perspective of China. The issue of $PM_{2.5}$ has become an important problem (Song et al., 2022; Tao et al., 2022), as it negatively affects human physical and mental health, e.g., through respiratory diseases, cardiovascular disease, and impaired brain function (Chen et al., 2020; Song et al., 2022; Yang et al., 2022). Meanwhile, its influences have spread to the economy, including economic development (Hao et al., 2018), labor supply (Li & Li, 2022), financial markets (Song et al., 2022), and firm performance (Tan et al., 2021). Thus, $PM_{2.5}$ reduction is an urgent issue. Nevertheless, environmental activities need

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financial support and capital investment (Zhang et al., 2022a). In environmental governance, the effect of economic means has become increasingly important in recent years, among which green finance plays a pivotal role.

Green credit is an innovative financial instrument that adopts a noncoercive approach to balance ecological protection and economic development (Wang et al., 2021). Commonly, GC policy preferentially guides financial resources to green firms while reducing or even stopping the granting of loans to high-pollution firms. The environmental influences and changes triggered by GC can be summarized in the following aspects. From a micro perspective, the preference for green credit intensifies the financing dilemma for high-pollution firms, decreasing their capacity to extend production and reducing production (Liu et al., 2019), passively decreasing pollutant emissions. Moreover, GC accelerates the innovation of green technology and thus reduces pollutant emissions (Cai et al., 2020). From a macroscopic perspective, GC is able to promote and optimize the industrial structure and develop environmentally friendly industries, which are conducive to environmental protection. The causalities are not limited to the effect of GC on $PM_{2.5}$ emission; the opposite direction is also worth discussing. Increasing $PM_{2.5}$ emission has aroused widespread concern from the public and government. Under the strong pressure of reduction, enterprises, especially those with high pollution levels, pursue GC to invest in environmentally friendly projects, processes, and technologies. Therefore, we hypothesize that GC can reduce $PM_{2.5}$ emission, and in turn, $PM_{2.5}$ emission increases the demand for green credit.

China has experienced rapid economic development in recent decades (Wang et al., 2022a), and some features make it an interesting case. First, China faces serious pollution of $PM_{2.5}$. China's average $PM_{2.5}$ concentration was approximately 39 μg/m^3 in 2019, whereas the standard of the WHO is only 10 μg/m^3. This value is higher than that of developed countries, such as the U.S. and the U.K., as well as developing countries, such as Brazil and Malaysia. Second, China is striving to improve the policy framework of green credit. In 2012, Green Credit Guidelines were proposed, which is a fundamental document that marks the arrival of the GC era (Li et al., 2022a). In 2016, China published the 13th Five-Year Plan and emphasized the role of GC in pursuing sustainable development, attracting more attentions from firms and authorities (Chai et al., 2022). The market for GC has great potential to expand, even though GC in China began later than that in developed countries. In 2021, China's GC stock scale rose to the top ranking worldwide (Tan et al., 2022a). Last, China still faces some difficulties. Even though it has experienced rapid development, GC still occupies a small percentage of society's whole credit, which is basically less than 10% (Lian et al., 2022). Furthermore, the urgency and proportion of pollution control are low in the GC market, and it is important to discuss how to establish an established and long-term GC system in environmental management.

This study assesses the dynamic causalities between green credit and $PM_{2.5}$ during the period from 2013:M01 to 2022:M05. The method combination, including full sample causality test, parameter stability test and rolling window causality test, is utilized in the paper. Those tests investigate the hypothesis that GC and $PM_{2.5}$ can affect each other in the full sample. The results find that causal links and influencing directions between these two variables change with time, which does not always support the mentioned hypothesis. The deviations may result from China's economic new normal, government intervention, public environmental protection awareness, imperfect incentive system and other factors.

Thus, some contributions are added to the previous literatures. First, under the guidance of a national sustainable development strategy, GC has become a relatively important business for banks and is incorporated into banking assessment systems (Hu et al., 2020). Meanwhile, the concentration of $PM_{2.5}$ in 2020 has decreased noticeably compared with 2013 (Su et al., 2021). Thus, the topic is interesting and is worth discussing based on time-varying aspects, which are significant for constructing a green economic system. Second, the feedback effect from $PM_{2.5}$ emission to GC is considered, which is based on the negative externality of environmental pollution. In contrast to previous studies that focus on the unidirectional influence of GC on $PM_{2.5}$ and other environmental issues (Zhang et al., 2021a), this article reports an impact of $PM_{2.5}$ on GC. $PM_{2.5}$ is regarded as an important factor that drives GC, which provides useful information for banks to establish a virtuous relationship between the environment and GC. Third, dynamic and time-varying causalities are captured for $PM_{2.5}$ and GC. Although some studies have shown the effects of GC on reducing $PM_{2.5}$ emission (Wang et al., 2021; Zhang et al., 2021a), no consensus has been reached. The divergence comes from the simple and linear assumption of the effect of GC policy. In addition, when suffering external shocks, the causalities would also change. Thus, we fill this research gap by using the bootstrap subsample rolling-window causality approach, taking the time-varying factor into account.

The remaining parts are as follows. Part 2 presents the literature review, and Part 3 shows the theoretical basis and hypothesis for GC and $PM_{2.5}$. The methods are introduced in Part 4, and details of the data are provided in Part 5. Part 6 displays the main empirical results, and Part 7 shows the conclusions and policy suggestions.

2. Literature review

2.1. Green credit definition and practices

Green credit is an interdisciplinary concept, which incorporates environmental protection into financial instruments, especially commercial loans (Xi et al., 2022; Zhao & Chen, 2022). Its features can be summarized from the following angles. The first is environmental financing. Financial institutions need to comprehensively conduct environmental assessments and then decide whether to grant commercial loans to firms (Luo et al., 2021). The second is social responsibility. Green credit strengthens not only firms, especially those with heavy pollution, but also commercial banks' social responsibility for protecting the environment (Wang et al., 2019a). The third is sustainable financing. Firms' environmentally friendly projects are conducive to achieving sustainable and green development and granting preferential access to credit loans (Zhang et al., 2021a). Apart from firms, financial institutions, especially banks, also need to consider sustainable development strategies in their daily operations (Zhang et al., 2021b).

Green credit is commonly discussed with green bonds, green securities, and other instruments in Western countries (Bhatnagar & Sharma, 2022). In 2003, the "Equator

Principles" were signed by the world's top 10 banks for dealing with green financial issues (Mngumi et al., 2022). In 2010, more than 190 countries agreed to set up green climate funds, and since then, green finance has frequently appeared on international platforms (Zhang et al., 2019). In 2017, the 'One Planet Summit' was held in France, and global major banks and important financial market participants achieved consensus in developing and adopting eco-financed products (Wang et al., 2022b). In 2019, the United Nations formally launched the 'Financing Roadmap for Achieving Sustainable Development Goals', which is regarded as an important guide in pursuing sustainable development through financial resource allocation (Su et al., 2022a).

By contrast, China owns a bank-dominated financial system, making green credit the most fundamental and important financial instrument. GC is commonly regarded as an important financial tool in pursuing green development (Xi et al., 2022), energy conservation (Wang et al., 2022b), and emission reduction (Su et al., 2022a), and it has been vigorously promoted by China's government (Tan et al., 2022b). In 2007, the People's Bank of China (PBC) launched the "Opinions on Implementing Environmental Protection Policies and Regulations to Prevent Credit Risks", marking the start of the green credit era (Ma et al., 2021). In 2012, the PBC launched the "Green Credit Guidelines", which has become the basic document and criterion for banks to develop GC (Zhang et al., 2022b). In 2013, China issued the "Green Credit Statistics System", which further accelerated the process of developing green credit, and the green credit system has become increasingly mature (Luo et al., 2021). In 2016, China strove to cultivate and develop green industries in the 13th Five-Year Plan by strengthening green credit and other financial resource support (Hu et al., 2020). In 2021, China issued the 14th Five-Year Plan, which set long-term development objectives, focused on accelerating the green transformation of the economy and actively developing green credit. Based on the rapid development, Zhang et al. (2021b) argued that the increasingly sophisticated GC policy in China can meet international criteria and can achieve good effects.

2.2. Green credit and the environment

With the extensive practices of various countries, the environmental influences brought about by GC have attracted increasing attention (Hu et al., 2021; Liu et al., 2017). Kang et al. (2020) indicated that South Korea's GC policy is an environmentally friendly measure that enables firms to decrease pollutant emissions. Liu and He (2021) showed that green credit has an obvious environmental welfare effect and is able to reach a balance between economic growth and environmental protection. Zhang et al. (2021a) discovered that GC is beneficial for China's total environment, but the emission-reduction effect is more obvious in areas with high financial levels. Zhang et al. (2021b) also proved that GC policy promotes environmental quality by reducing credit issuance for firms with high energy consumption and high pollution levels. Zhang (2021) showed that GC obviously decreases pollutant emissions and promotes cleaner production, which ultimately increase green total factor productivity. Song et al. (2021) indicated that GC policy can increase China's energy utilization efficiency under the constraints of environmental protection. Lei et al. (2021) proved that GC is able to promote local green development while producing a positive spatial spillover effect in surrounding areas. Zhang et al. (2022b) found that GC obviously decreases carbon emissions, and the reduction effect gradually strengthens over time. Liu et al. (2022a) demonstrated that GC promotes environmentally induced innovation activities and thus accelerates China's low-carbon transition. Guo et al. (2022) proposed that GC development promotes green transformation and emphasized its role in modern environmentally friendly development systems. Hu and Zheng (2022) argued that GC is considered an effective measure in China to reduce carbon emissions and achieve economic low-carbon transformation. Li et al. (2022b) found that green finance, especially green credit, is an important financial instrument in pursuing the sustainable goals of high-quality economic development and environmental protection. However, as shown by Taghizadeh and Yoshino (2019), GC is accompanied by high risk and low return characteristics. Meanwhile, state-owned firms with heavy pollution still prefer to obtain credit from banks (Dong et al., 2020). Therefore, GC is difficult to produce significant influence on reducing pollution and improving environment in the short time (Su et al., 2022a).

3. Theoretical basis and hypothesis

In this paper, mainly subsample rolling-window causality test, supplemented by full sample causality and parameter stability test, are employed to deeply investigate the following hypothesis between GC and $PM_{2.5}$. As shown in the hypothesis, GC and $PM_{2.5}$ are related tightly, and they keep single and unchanged influencing directions.

3.1. The influence of green credit on $PM_{2.5}$

Green credit is a commercial, nonmandatory, voluntary, and green oriented instrument that inspires firms to take on their social responsibilities by allocating limited financial resources (Bai et al., 2022). It has significant influences on $PM_{2.5}$ emission through the following channels. First, green credit promotes investment in green technological innovation. In China, debt financing from banks is still an important exogenous financing channel (Zhang & Kong, 2022); thus, green credit will be an influential factor in green technology innovation. Benefitting from the positive externalities brought about by technological progress, enterprises emit fewer $PM_{2.5}$. Second, green credit preferentially supports low-emission and green projects. Banks can optimize their credit structure by, on the one hand, granting more credit to green projects and, on the other hand, decreasing loans to high-pollution projects (Cui et al., 2022). A higher percentage of green projects would decrease $PM_{2.5}$ emission. Third, green credit can adjust credit resource allocation and offer different levels of interest rates to promote industrial structure upgrades and optimization (Cheng et al., 2022). GC not only limits the activities of high-pollution firms but also offers support for development of the green industry, which is beneficial for $PM_{2.5}$ reduction. Last, green credit has a signal role for the society. China is pursuing green and sustainable development and implements many policies to balance economic growth and ecological protection. Therefore, green credit policy was formally enacted in 2012, which reflects the state's determination in reducing $PM_{2.5}$ emission by directly allocating financial resources (Xing et al., 2021). Thus, we present the following hypotheses:

H1: Green credit significantly reduces $PM_{2.5}$.

3.2. The influence of $PM_{2.5}$ on green credit

The issue of $PM_{2.5}$ has become a hot topic in China and is attracting increasing attention. Its impacts are not limited to people's health, but also spreads to economic activities. First, the increasing concern for $PM_{2.5}$ emission has forced China to launch strict environmental regulations, which impose additional financial constraints on corporate production, sales, and management (Zhang et al., 2022c). With the purpose of eliminating difficulties, firms must seek green credit from banks to maintain normal operations and adopt green technology to achieve environmental requirements. Second, with the awakening of environmental awareness of $PM_{2.5}$ reduction, the public increases the demand for green products and services (Wu et al., 2022). Enterprises are market oriented and always try to cater to consumer preferences. Thus, they inevitably need external financing to update equipment and optimize processes to meet new consumption trends, which leads to increasing demand for green credit. Therefore, we present the second hypothesis.

H2: $PM_{2.5}$ increases the demand for green credit.

4. Methodology

This paper utilizes the collocation of methods, including full-sample causality test, Parameter Stability Test, and subsample rolling-window causality test, to investigate the relationship between GC and $PM_{2.5}$. The internal logic is described as follows. The first step, according to the hypothesis, this paper builds the VAR model for GC and $PM_{2.5}$, as shown in Equation (2), to check whether exists causalities in the full sample. Through full-sample causality test, we obtain the corresponding results. However, the results may be incredibility, because the test assumes the causalities between GC and $PM_{2.5}$ are unidirectional and linear. In other word, the test assumes the parameters in the VAR model is constant. That ignores the influence from structural breaks triggered by government intervention, policy adjustment, and other factors, on the causalities. The second step, in order to verify the conjecture, the parameter stability tests of Exponential-*F*, Supremum-*F* and Mean-*F*, as presented in Equations (3)–(5), are subsequently applied in our paper. When their statistics are significant, we obtain that the parameters in the VAR model are not constant, and change with time. The third step, if pass the parameter stability tests, the subsample rolling-window causality test is further employed to investigate the dynamic and time-varying causalities. Depending on a fixed window size and rolling technique, this test can capture causalities in each sub-samples, and recognize the influencing direction, such as positive or negative, which can provide more valuable results for the link between GC and $PM_{2.5}$. To sum up, full-sample causality test preliminarily explores the relationship, parameter stability tests verify that whether the conclusion is credible, and subsample rolling-window causality test further recognizes causalities in each subsample.

4.1. Bootstrap Full-sample causality test

The discussion of the causality between GC and $PM_{2.5}$ is based on the framework of the vector autoregression (VAR) model. Balcilar et al. (2010) clearly defined Granger causality as one variable having the ability to affect another variable's forecasted values. The Wald and likelihood ratio (LR) tests are commonly applied to examine Granger causalities. Both tests have a precondition that variables or time series need to be stationary. If the premise does not hold, variables may present nonstandard asymptotic distributions and can cause difficulties in estimation (Toda & Phillips, 1994). In addition, Shukur and Mantalos (1997) proved that the Wald test performs well for small- and medium-sized samples.

Some studies have been done to make up for these deficiencies. Shukur and Mantalos (2000) presented the modified LR test, which performed well regardless of the sample size. Shukur and Mantalos (1997) utilized the residual-based bootstrap (RB) method to improve the estimation of critical values. In addition, Mantalos (2000) showed that the bootstrap technique can maintain good performance without considering cointegrated or non-cointegrated processes.

Combining the advantages of the above methods, this paper applies a bootstrap RB-based modified LR test to recheck the Granger causalities between green credit and $PM_{2.5}$. Relying on the bivariate VAR model, we construct the following equation:

$$y_t = \varphi_0 + \varphi_1 y_{t-1} + \varphi_2 y_{t-2} + \ldots + \varphi_p y_{t-p} + \varepsilon_t,\ t = 1, 2 \ldots T \tag{1}$$

where y_t denotes the variable. ε_t is a white noise process. p is the optimal lag length. Because two variables are considered, we obtain the following form:

$$\begin{bmatrix} GC_{1t} \\ PM_{2.5t} \end{bmatrix} = \begin{bmatrix} \varphi_{10} \\ \varphi_{20} \end{bmatrix} + \begin{bmatrix} \varphi_{11}(L) & \varphi_{12}(L) & \varphi_{13}(L) \\ \varphi_{21}(L) & \varphi_{22}(L) & \varphi_{23}(L) \end{bmatrix} \begin{bmatrix} GC_{1t} \\ PM_{2.5t} \\ FDI_{3t} \end{bmatrix} + \begin{bmatrix} \varepsilon_{1t} \\ \varepsilon_{1t} \end{bmatrix} \tag{2}$$

where GC, $PM_{2.5}$ and FDI indicate green credit, particulate matter 2.5, and foreign direct investment, respectively. In addition, $\varphi_{ij}(L) = \sum_{k=1}^{p+1} \varphi_{ij,k} L^k$, $i = 1$, 2 and $j = 1$, 2, 3. L is the lag operator. To test the Granger causality between GC and $PM_{2.5}$, the null hypothesis of $\varphi_{21}(L) = 0$ and $\varphi_{12}(L) = 0$ is imposed in Equation (2). Thus, once the null hypothesis is rejected, causalities are proven to exist.

4.2. Parameter Stability test

The precondition of unchanged parameters exists in the conventional VAR model during the full sample period. However, this presumption is vulnerable when suffering shocks, and original causal links may deviate (Balcilar & Ozdemir, 2013; Cristea et al., 2022; Pirtea et al., 2019; Su et al., 2022b). To check whether the parameters are stable, Exponential-F (*Exp-F*), Supremum-F (*Sup-F*) and *Mean-F* tests were conducted in this study. Consider a time series ψ_t, and $t = 1, 2, \ldots, i, \ldots, n$. β is a parameter and is assigned to β_1 and β_2 when $t < i$ and $t > i$, respectively. F_i is employed to examine the hypothesis of $\beta_1 = \beta_2$ for a given i. If the hypothesis is rejected, structural breaks exist, and the parameter is not stable. In turn, if no structural breaks exist, the parameter is stable. When i is located in the interval $[i_1, i_2]$, the tests of *Exp-F*, *Sup-F*, and *Mean-F* are as follows:

$$Sup - F = \sup_{i_1 \le i \le i_2} F_i \tag{3}$$

$$Mean - F = \frac{1}{i_2 - i_1 + 1} \sum_{i=i_1}^{i_2} F_i \tag{4}$$

$$\mathrm{Exp} - F = \ln\left(\frac{1}{i_2 - i_1 + 1} \sum_{i=i_1}^{i_2} \exp\left(\frac{1}{2} F_i\right)\right) \tag{5}$$

Although these tests were employed to examine the stabilities of the parameters, different hypotheses exist. The *Sup-F* test assumes that there is no one-time sharp change in the parameters. *Mean-F* and *Exp-F* assume that the parameters do not follow a random walk process and are not time-varying features.

4.3. Subsample Rolling-window causality test

Because the results from the full-sample Granger causality were not convincing, this paper adopted a rolling-window bootstrap test to investigate time-varying causalities in different subsamples. We first set a fixed window width, which contained m observations. The window moved sequentially from the start to the end of the sample, which can be described as $\tau - m + 1, \ \tau - m \ldots, T$ for $\tau = m, \ m + 1 \ldots, T$. Next, the p *value*s in each subsample were calculated to assess whether causalities existed between variables. Considering the advantages of the RB-based modified-LR causality test, we applied it in our study. $N_b^{-1} \sum_{k=1}^{p} \widehat{\varphi}^{*}_{12,k}$ describes the influence of GC on $PM_{2.5}$, and N_b is the number of bootstraps. In turn, $N_b^{-1} \sum_{k=1}^{p} \widehat{\varphi}^{*}_{21,k}$ represents the impact of $PM_{2.5}$ on GC. In addition, a 90% confidence interval was estimated, where the upper limit was the 0.95 quantile and the lower limit was the 0.05 quantile.

A key issue during the estimation process is how to choose the window size. A window width that is too large or too small would influence the estimation results. Thus, we need to choose a moderate trade-off. In general, a large window width increases estimation accuracy while decreasing the representativeness of subsamples that are split by the rolling-window technique. In contrast, a small window width improves representativeness while reducing estimation accuracy. According to experience and suggestions from Pesaran and Timmermann (2005) and Wang et al. (2022c), a window size exceeding 20 is better when a time series frequently suffers structural breaks.

The rolling window technique means that through a fixed window size, multiple subsamples can be obtained by moving sequentially by adding one observation from the forward direction and removing one from the end. After division into multiple subsamples, the causalities can be tested in each subsample. Meanwhile, the positive and negative influences are also captured. The influential direction is not unidirectional, which means that positive causality, negative causality, and noncausality are possible using the full sample. Due to the advantages of the method, it has been applied to many fields, such as green finance (Wang et al., 2022b), environmental protection (Su et al., 2021), the labor market (Su et al., 2022c), and the energy market (Khan et al., 2022).

5. Data sources and descriptive analysis

Monthly data from 2013:M01 to 2021:M12 were used in this study. The CBIRC[1] published *the Green Credit Statistics System* in 2013, which is the first official document and is commonly regarded as a cornerstone in the development of GC. In the same year, the Ministry of Ecology and Environment of China started to monitor $PM_{2.5}$ in 74 cities. Therefore, our sample began in 2013:M01. Three variables were considered in this study. The first variable is green credit (GC). Referring to the work of Chen and Chen (2021), this paper utilizes the same index to measure GC. The index consists of two parts, six high-pollution industries' interest expenditure (HIE) and total interest expenditure for all industries (TIE), and is described as GC = 100-(HIE/TIE)*100. The second variable is $PM_{2.5}$. According to Shi et al. (2017) and Su et al. (2021), $PM_{2.5}$ is a key target affecting air quality and a prominent symbol of air pollution hazards. The last variable is foreign direct investment (FDI), which is also regarded as a control variable. In 2011, China surpassed the U.S. and became the largest global destination for FDI (Feng et al., 2022). Since then, the amount of FDI flowing into China has consistently ranked at the forefront worldwide and reached 163 billion U.S. dollars in 2020. The massive capital flows unavoidably have significant impacts on China's economy and environment. Multiple impacts of FDI are summarized as follows: pollution increases because FDI brings financial support and stimulates economic activities (Hille et al., 2019). Meanwhile, FDI aggravates the environmental problems of the host country through pollution transfer (Liu et al., 2022b). In addition, FDI fosters technological innovations and promotes industrial structure adjustment, which can reduce pollution to some extent (Liu et al., 2021a).

Figure 1 depicts the fluctuating trends of GC and $PM_{2.5}$. It is seasonal, lower values commonly appear in summer, and higher values usually emerge in winter. In 2015, China made strong efforts to reduce emissions, and decreases the monthly average values of $PM_{2.5}$ to less than 100. In 2016, the PBC[2] launched *The Guiding Opinions on Building a Green Financial System*, which is only a framework document (Zhang, 2022). In 2018, the PBC published *The Guidance on Evaluating Green Bank*, which focuses on utilizing differentiated interest rates to develop green credit. By June 2019, twenty-one major commercial banks in China had 10.6 trillion RMB of green credit, nearly twice as much as that in 2013 (Lian et al., 2022). By the end of 2020, the amount of GC further increased to 11.6 trillion RMB (Chai et al., 2022). In

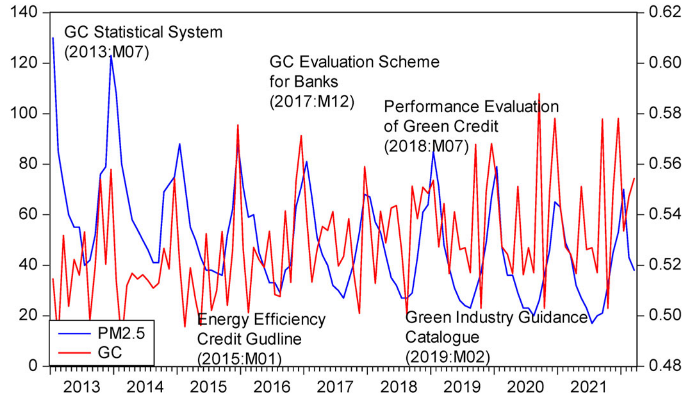

Figure 1. The trends of GC and $PM_{2.5}$.
Source: Author's calculation

Table 1. Descriptive statistics.

	Max	Min	Mean	Skewness	Kurtosis	Jarque-Bera
GC	0.576	0.489	0.533	−0.133	2.038	4.611*
$PM_{2.5}$	130.000	17.000	50.018	1.063	4.576	32.411***
FDI	220.200	65.000	114.461	0.976	3.812	20.687***

Notes: * and *** indicates significance at the 10% and 1% levels.
Source: Author's calculation.

summary, the scale of GC presented an upward trend, while $PM_{2.5}$ showed seasonal and fluctuating downward trends.

Table 1 shows descriptive statistics for GC, $PM_{2.5}$ and FDI. The mean values of GC, $PM_{2.5}$ and FDI were 0.533, 50.018 and 114.461, respectively. Moreover, the skewness values of $PM_{2.5}$ and FDI exceeded 0; thus, these two variables were right-skewed. In contrast, the GC value was −0.133, i.e., left-skewed. The kurtosis values for $PM_{2.5}$ and FDI were 4.576 and 3.812, respectively; thus, they followed a leptokurtic distribution. The kurtosis value of GC was 2.038, i.e., lower than 3, and followed a platykurtic distribution. In addition, the statistics of the Jarque-Bera test for all three variables were significant at the 1% and 10% levels; thus, they followed a nonnormal distribution. Referring to Qin et al. (2021), this paper also used logarithmic processing and the first difference for GC, $PM_{2.5}$ and FDI to avoid potential heteroscedasticity and to ensure time series stability.

6. Empirical findings

In terms of Equation (3), the VAR model was employed to examine full-sample causality between GC and $PM_{2.5}$. FDI was chosen as a control variable and was examined to overcome the effect of endogeneity. The optimal lag length was 4, which was determined by the Schwarz information criterion (SIC). The results of the bootstrap full-sample Granger causality test are shown in Table 2. Based on the statistics and *p values*, GC did not affect $PM_{2.5}$, and $PM_{2.5}$ could influence GC. The results are not completely consistent with our hypothesis. Based on the bivariate model, the causality results will be reliable if the parameters in the model are invariable. However, because

Table 2. Full-sample Granger causality test.

	H0: GC does not Granger cause $PM_{2.5}$		H0: $PM_{2.5}$ does not Granger cause GC	
	Statistics	*p*-values	Statistics	*p*-values
Bootstrap LR test	2.219	0.114	3.975**	0.022

Notes: ** indicate significance at the 5% level.
Source: Author's calculation.

Table 3. Parameter stability tests.

	GC equation		$PM_{2.5}$ equation	
	Statistics	*p*-value	Statistics	*p*-value
Sup-F	94.371***	0.000	42.208***	0.000
Ave-F	30.044***	0.000	27.837***	0.000
Exp-F	44.307***	0.000	17.671***	0.000

Notes: *** denotes significance at 1%.
Source: Author's calculation.

of the existence of structural variations, the parameters had difficulty remaining stable (Su et al., 2022a), which resulted in unreliable causality between GC and $PM_{2.5}$ in the full sample. Therefore, parameter stability is needed to determine whether structural breaks exist.

The *Sup-F*, *Ave-F* and *Exp-F* tests (Andrews, 1993; Andrews & Ploberger, 1994) were employed in this paper. The results are shown in Table 3, demonstrating sudden structural changes between GC and $PM_{2.5}$ at the 1% significance level. In other words, the causal linkage was unstable between GC and $PM_{2.5}$. Because of the time-varying features of the parameters, the possibility of an unreliable Granger causality experiment was proven in the full sample. Thus, utilization of the bootstrap sub-sample rolling-window causality experiment to explore the two-way connection between GC and $PM_{2.5}$ became more significant. However, it is meaningful that the selection of the window width requires taking the optimal width into full consideration. Although a larger width yields more precise empirical conclusions, it is not conducive to improving the rolling frequency. Based on the conclusion of Pesaran and Timmerman (2005), we should set the width to 20 or higher in the testing process. Therefore, we chose a width of 24 months to ensure reliable conclusions in this paper.

Figure 2 indicates the *p* values of the influence of GC on $PM_{2.5}$. Figure 3 shows the direction of the effect. Based on these two figures, GC positively affected $PM_{2.5}$ in the period 2015:M05-2017:M07. The positive coefficient of influence indicated that GC had an adverse effect on reducing $PM_{2.5}$ emission. This phenomenon can be summarized in the following aspects. First, banks lack motivation. Although the government strives to utilize the potential of banks to decrease emissions and promote sustainable development, it made no significant contributions to ecological promotion in the short term, particularly in 2015 and 2016. One of the reasons for inadequate policy implementation is the separation of policymakers and implementers (Zhang et al., 2016). Second, asymmetric information exists between banks and firms, especially green information. High-pollution firms always disclose as little information as possible, thus pushing banks to spend more time investigating the truth, which

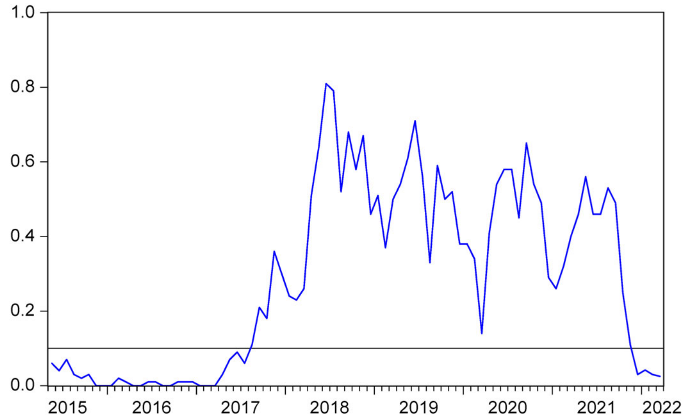

Figure 2. Bootstrap *p*-values of rolling-window test statistic testing the null hypothesis that GC does not Granger cause $PM_{2.5}$.
Source: Author's calculation

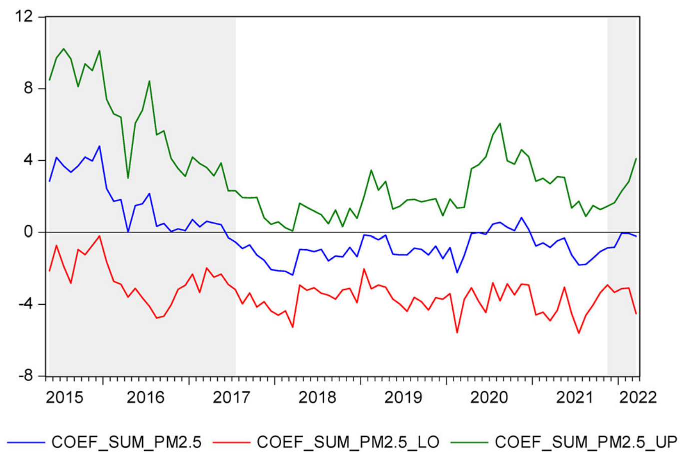

Figure 3. Bootstrap estimates of the sum of the rolling-window coefficients for the impact of GC on $PM_{2.5}$.
Source: Author's calculation

reduces credit allocation efficiency (Wen et al., 2021). More seriously, some firms illegally obtain loans through false advertising, which prevents green firms with real financing demand from obtaining GC (Lazzarini, 2015). Third, the effect of GC depends largely on banks' actions. The main target of these banks is self-profitability, and their profits are negatively influenced by the execution of GC policy in the short term (Su et al., 2022a). Once green credit policy is adopted by banks as a criterion, these financial institutions face higher costs in a short time and may reduce credit supply (Scholtens & Dam, 2007). Banks need to ensure that interest and principal are recovered from high-pollution firms and to reduce new credit amounts for them. Fourth, the credit financing channel of high-pollution firms may be cut due to the GC policy, but other channels, such as trade credit, may solve the financing dilemma and provide financial support for production. These firms' production activities are important factors that result in ecological deterioration (Yuan et al., 2020).

However, in the period of 2021:M10-2022:M03, the causal relationship became negative, demonstrating that GC was able to reduce $PM_{2.5}$ emissions. GC emphasizes social responsibility for protecting the environment through financial tools, which tightly integrate the government, banks, and enterprises (Rupp, 2011). From the perspective of the government, in 2019, the *Green Industry Guidance Directory* was jointly published by the PBC, the CBIRC, and the NDRC,[3] which was the first official document and laid the foundation for green industry development (Huang et al., 2021). Subsequently, the 14th Five Year Plan was published in 2021, which strengthens legal and policy guarantees for green development and develops green finance. Under the policy framework, financial institutions, especially banks, ought to reduce and even stop issuing loans for those enterprises with high pollution and environmental damage. Meanwhile, the Ministry of Ecology and Environment is required to join in the work of GC policy and is empowered to punish projects and enterprises that lack environmental protection permits (Zhang et al., 2021b). From the aspects of banks, in China, banks are the most representative financial institutions, are in a dominant position, and have huge capital deposits. This determines that banks have the ability to improve the ecology and environment by allocating credit resources (Dong et al., 2020). China is pursuing green and sustainable development (Hu et al., 2022), and the pressures from the government and the public have forced banks to grant more credit to green enterprises. Meanwhile, banks can obtain better returns from green credit and can further optimize the structure of assets; thus, they have a voluntary preference for green credit (Cui et al., 2018). From the aspect of credit demanders, enterprises that belong to high-pollution industries have to pay higher costs for obtaining loans and even suffer financing dilemmas. Thus, these enterprises have difficulty expanding production and possibly even reduce production, which indirectly decreases pollutant emissions (Hochberg et al., 2007). In addition, GC provides financial support for research and development (R&D) activities, especially for green firms, and increases the green innovation level, which directly reduces pollutant emissions (Hong et al., 2021; Liu et al., 2021b). Thus, GC is able to improve environmental quality and has gradually achieved the set target.

Figure 4 depicts the p value of the effect of $PM_{2.5}$ on GC. Figure 5 indicates the direction of the influence. Based on these two figures, we found that $PM_{2.5}$ positively influenced the promotion of GC during the period of 2018:M04-2018:M10. Hazy weather hinders businesses' ability to thrive, which has an impact on banking institutions' credit policies. Due to serious pollution of $PM_{2.5}$, high-pollution firms are more vulnerable to significant environmental risks, such as the risk of incurring environmental forfeiture costs, legal trouble, and bad debt. The danger of joint and partial culpability increases dramatically when banking institutions lend money to these high-pollution businesses. To mitigate the aforementioned risks, banks are willing to grant credit for green businesses, which encourages GC to grow in scope. When facing high $PM_{2.5}$, the government must improve its regulations and policy to address this issue. In July 2018, to spur banks' interest in conducting GC business, the government published a series of documents, such as *Opinions on Building up Statistical System for Green Credits*. These regulations incentivize banks to offer GC to environmentally friendly businesses and look for additional profit margins. The media also

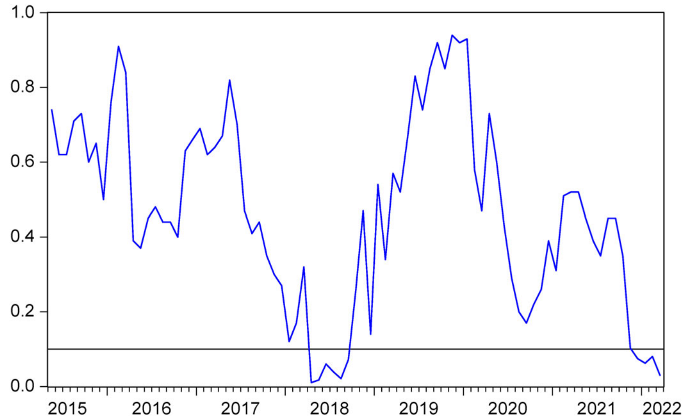

Figure 4. Bootstrap *p*-values of rolling-window test statistic testing the null hypothesis that $PM_{2.5}$ does not Granger cause GC.
Source: Author's calculation

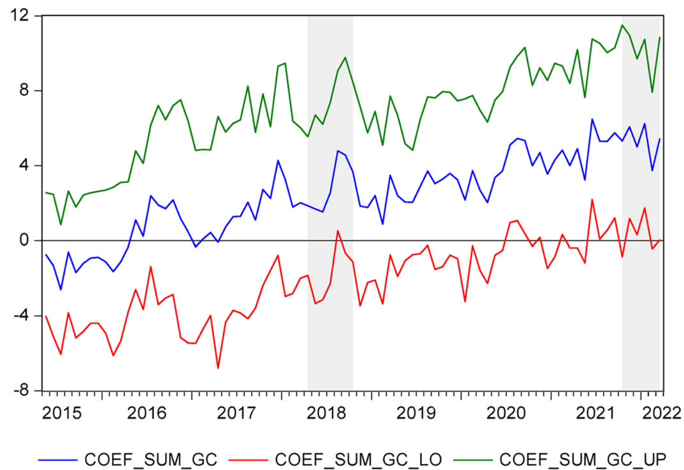

Figure 5. Bootstrap estimates of the sum of the rolling-window coefficients for the impact of $PM_{2.5}$ on GC.
Source: Author's calculation

actively report pollution incidents, which creates great pressure for the government and banks and forces them to solve the pollution of firms. From the aspect of social responsibility (He et al., 2019), firms should take into account the effects of their routine operations on the social and natural environment and their own financial and operational conditions. Banks are eager to offer more GC to prove their strong sense of social responsibility and build a positive image of environmental protection. In conclusion, the extension of the GC scale will be impacted by the rising $PM_{2.5}$ emission.

Similarly, we found another positive causality in the period of 2021:M10-2022:M03. In February 2022, Beijing, the capital of China, held the 24th Winter Olympic Games. To successfully host these games, China's government adopted many measures. In general, serious $PM_{2.5}$ pollution commonly appears in winter and spring, which is attributed to weather, heating periods and other factors. However, the values of $PM_{2.5}$ in 2022 were much lower than they were at the same period of previous years. The potential reasons are summarized as follows. First, China's government closed small coal mines, steel factories, and thermal power plants located near Beijing. The major purpose was to reduce $PM_{2.5}$ emission and create good conditions for athletes who participated in the Olympic Games. Second, relying on the opportunity of the Olympic Games, China pursued green and sustainable development while also working to foster green innovation. At the same time, some supporting policies, such as *Opinions on guiding green finance for banking and insuring industries*, were offered to ensure the achievement of emission reduction targets. The awakening public consciousness of environmental conservation and the determination of government not only require banks to increase the percentage of green loans but also stimulate enterprises to borrow green credit. Thus, the level of $PM_{2.5}$ was consistent with GC and is an important indicator of the latter.

In summary, it cannot be said that GC always contributes to a decrease in $PM_{2.5}$. Especially during the initial stages of GC policy adoption, due to environmental information asymmetry, a lack of incentives for banking institutions, and the other financing channels chosen by enterprises (Wang et al., 2019b; Zhang et al., 2021a), GC does not achieve the expected environmental effect. However, the role of GC in reducing $PM_{2.5}$ emission gradually gains prominence when policy and regulations are improved, which conforms to the interaction mechanism and hypothesis. It is important to identify the issues that arise throughout the GC policy implementation process to improve the GC system. Additionally, it was found that $PM_{2.5}$ had a beneficial impact on GC in the subsample, which is conducive to making $PM_{2.5}$ an important reference for understanding bank credit preferences in advance and promoting the creation of a system that balances economic benefits and environmental protection.

7. Conclusions

The causality relationship between $PM_{2.5}$ and GC is regarded as an entry point to verify how much GC has contributed to the increase in environmental quality since the adoption of the policy. First, we conducted empirical studies on the full-sample and subsample Granger causal connection between $PM_{2.5}$ and GC. The result showed that during the initial stages of adoption, GC had no beneficial impact on $PM_{2.5}$. Then, we analyzed the reasons for the inadequate execution of the GC policy from the perspectives of policymakers, banking institutions and target enterprises. The fact that GC had a detrimental effect on $PM_{2.5}$ concentration was found as a result of the system's ongoing improvement. This suggests that GC can be used effectively for environmental control, which conforms to the GC and $PM_{2.5}$ interplay mechanism. Therefore, GC requires a more comprehensive policy as well as the collaboration of banking institutions and businesses to ensure it contributes positively to improving environmental quality. Finally, we also obtained evidence that $PM_{2.5}$ had a feedback impact on GC, which indicates that when $PM_{2.5}$ increases, environmental conservation policies become more stringent, and banking institutions issue more GC. With the improvement of residents' requirements for reducing $PM_{2.5}$ emission and the enhancement of environmental awareness, the supervision from society is bound to promote the role of banking institutions in the implementation of GC.

Through understanding the environmental effect of GC and how GC interacts with $PM_{2.5}$, we believe that GC has the ability to affect the environment from the following angles. First, there should be stronger regulation of the environmental information that businesses disclose. This improves the effectiveness of how GC funds are allocated and ensures that credit resources are used to support green businesses and environmental conservation. In addition, the government can increase the pay structure for banks to issue GC, which avoids the declining profitability brought on by the policy's initial introduction and affects the practice effect of GC policy. Banks and other financial institutions may receive favorable tax treatment and other financial incentives to pique their interest in contributing to the construction of a green financial system. Third, GC-related laws and policies need to be continually improved by legislators. One of the reasons the effect of the policy is not what was anticipated is the lack of legal compulsion and the deterrent force of GC policy. Currently, the majority of policies have more of a guiding influence than a formal legal enforcement effect. There is no legal basis for enforcement measures against high-pollution businesses if they employ GC in violation of the policy. Finally, $PM_{2.5}$ emission might act as a signal for decision-makers to implement regulations. Although serious pollution reduces the investment activities of enterprises, the government should not relax regulations. Meanwhile, banks can monitor $PM_{2.5}$ to assess the effectiveness of GC policy and determine whether to continue to grant credits. With the help of this assessment, a positive feedback loop between the conservation of GC resources and the reduction of emissions can be created, which promotes the growth of a sustainable economy.

Notes

1. CBIRC represents the China Banking and Insurance Regulatory Commission.
2. PBC represents the People's Bank of China
3. NDRC represents the National Development and Reform Commission

Disclosure statement

No potential conflict of interest was reported by the author(s).

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