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The Economic Impact of Green Credit: From the Perspective of Industrial Structure and Green Total Factor Productivity

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Abstract: Promoting economic growth while achieving sustainable development is the original purpose of green credit. Based on panel data of 30 Chinese provinces from 2008 to 2020, we systematically evaluate the economic impact of green credit by exploring the influencing factors, regional differences, and underlying mechanisms. The results show that: (1) Green credit is more prevalent in provinces with higher foreign direct investment (FDI), research and development expenditures (R&D), financial development, urbanization rates, and lower government fiscal spending. At the regional level, green credit issuance gradually decreases as the region moves towards the west. (2) From a national perspective, green credit issuance has a significant impact on local economies. Local GDP increases by 0.482% for every 1% increase in green credit. (3) The underlying mechanisms are the rationalization of intra-industry structure and the improvement of green total factor productivity. These findings are robust against alternative measures of economic growth, quantile regression estimation, and the construction of instrumental variables. Finally, we propose policy recommendations for China's continued implementation of green credit policies.

Keywords: green credit; economic growth; rationalization of industrial structure; green total factor productivity

Citation: Chen, C.; Zhong, S.; Zhang, Y.; Bai, Y. The Economic Impact of Green Credit: From the Perspective of Industrial Structure and Green Total Factor Productivity. *Sustainability* **2023**, *15*, 1224. https://doi.org/10.3390/su15021224

Academic Editors: Lóránt Dénes Dávid, Luigi Aldieri, Antonio Boggia and Xueting Zeng

Received: 28 September 2022
Revised: 8 December 2022
Accepted: 4 January 2023
Published: 9 January 2023

1. Introduction

In 2007, the introduction of the Opinions on Implementing Environmental Protection Policies and Regulations to Prevent Credit Risks marked the official opening of green credit, an environmentally oriented financing policy, in China. According to the latest edition of 2020 China Banking Social Responsibility Report, the green credit balance of 21 major banks exceeds 11.6 trillion yuan, making China the world's largest country in terms of green credit development. On 10 March 2022, the five major state-owned banks (ICBC, ABC, BC, CCB, BCC) issued an announcement, jointly demonstrating their firm determination and strong ability to support and serve the real economy, and continued to increase their investment in financing for key areas of sustainable industries, with total green credit investment reaching a record high. China's economic development has achieved remarkable achievements since the country's reform and opening-up, but it has also bred environmental problems. In the case of smog caused by worsening air quality, China's smog pollution has covered more than 1.3 million square kilometers, or 13.54 percent of the country's land area [1]. The environmental problems caused by haze or total suspended particulate matter (TSP) pollution are more harmful to the human body, as evidenced by an increase in cardiopulmonary mortality and a significant decrease in life expectancy [2,3]. In order to improve the current situation of high pollution, as well as to achieve "carbon peak" by 2030 and "carbon neutral" by 2060, environmental issues for China are imminent. And environmental pollution issues, inefficient resource allocation and industrial structure show a certain correlation. That is, the deterioration of industrial structure will largely bring about the aggravation of environmental problems [4]. After the 12th Five-Year Plan, China's economic growth has slowed and is facing greater downward pressure. As the largest developing country, China's economic growth cannot be stalled because of environmental concerns [5]. It is particularly important to adopt sustainable policies to promote the transformation and upgrading of two high and one surplus (high pollution, high energy consumption and overcapacity) enterprises, while achieving economic growth [6]. Therefore, it is essential to assess the performance of green credit policies in terms of whether the above objectives can be achieved.

As a policy with both financial and environmental attributes, green credit has attracted a lot of attention. The essence of green credit is a credit activity that promotes environmental improvement, addresses climate change and uses resources efficiently. Credit will be granted only to companies with qualified environmental and social performance to promote energy-efficient transformation of traditional industries and support the development of green industries. Green credits not only protect the environment, but also guide businesses to transform and upgrade from high-polluting and energy-hungry industries. Slowing the deterioration of environmental problems while exploring channels for green credit's impact on economic development is a key link between green credit and high-quality economic development. However, there is a lack of research on the theoretical mechanisms and empirical evidence for the economic impact of green credit.

Based on this, we use panel data of 30 Chinese provinces from 2008 to 2020 to conduct empirical analysis and enrich the research related to this field. We also investigate which province features promote the issuance of green credit, as well as the distribution of green credit in the east, middle and west. Moreover, by constructing instrumental variable, we also find the relationship between the number of local financial institutions and enterprises on green credit issuance.

We observe a positive relationship between green credit issuance and economic growth, implying that more green credit issuance is associated with a corresponding increase in the local economy. The mechanism is the rationalization of the industrial structure and the increase of green total factor productivity, where green total factor productivity shows a "U"-shaped relationship, i.e., short-term inhibition and long-term promotion. By dividing the sub-sample, we find that the economic impact of green cred-it is more pronounced in the West. The main reason may be related to diminishing marginal effects and the migration of firms away from environmental regulations. By constructing instrumental variables, we find that the issuance of green credit is also related to the number of local financial institutions and the number of firms, which may be mainly due to the frictional cost of incurring loans and the competition faced by firms. Combining the above studies, we propose corresponding policy recommendations for the continued implementation of green credit.

2. Literature Review

As a national policy in China, few studies have systematically examined the economic effects of green credit and the mechanisms behind them. Regional evolutionary economic geography focusing on path-dependence, and options for moving beyond path-dependence, which may result the differences across regions [7,8]. And since China varies widely across regions, the impact of each region cannot be generalized and need to be explored in the context of the specific situation of different regions. For the domestic empirical study in China, Xu Sheng [9] found that the role of green credit on industrial restructuring is relatively obvious, manifested by three mechanisms: capital formation, signaling and credit catalysis, and there are differences in the restructuring role in the eastern, central and western regions. However, the starting point for the data is 2004, not 2007, when green credit was fully implemented, which would lead to an assessment of its performance in relation to other influences from 2004–2006. Taking Huzhou City, Zhejiang Province as an example, Pei Yu [10] found that green credit can effectively promote the development of green industries and local economy. For the northwest region, Liu Sha [11] found that green credit has improved local environmental quality, but there is room to improve the impact on the economy. As for the six central provinces (Henan, Hubei, Jiangxi, Anhui, Shanxi, and Hunan), Liu Xia [5] concluded that for every 1% increase in total per capita investment in environmental pollution control, per capita GDP increases by about 1.115%, while the impact of green credit on the economy is not significant, which may be related to the lack of scale of green credit development. For theoretical studies, Patrick [12] proposed that developing countries should adjust their financial supply earlier in order to facilitate the transformation of industrial structure and thus effectively promote economic development. From the perspective of corporate financing, Michael [13] found that green credit reduces the difficulty of obtaining loans for environmentally friendly companies through financing allocation, thereby promoting industrial transformation. At the same time, green credit as an environmental regulation will, on the one hand, stimulate local enterprises to innovate green technology and improve total factor productivity (TFP) [14], and on the other hand, cause heavy polluters to flee and change the local industrial structure [15,16]. Lha [17] found that green credit or investment have different stages of promoting and inhibiting the development of green economy respectively. And specifically, green investment in environmental regulation is more effective in promoting the development of a green economy [17].

For the discussion of green credit performance, existing studies mainly remain the following deficiencies: First, although China is the world's largest issuer of green credit, there is still regional heterogeneity in green credit, and most studies only focus on parts of China rather than the whole country, for example, the northwestern [11], Beijing, Tianjin and Hebei [18,19], the six central provinces [5], Zhejiang province [10]. Few studies have assessed its performance for the overall or subregions East, Central and West. By contrast, China is a vast country, covering 9.6 million square kilometers, leading to a possible bias in understanding the impact of green credit within China. Moreover, there is some inaccuracy in the time period selected for the green credit, which does not start from 2007 [9]. Second, as green credit issuance gradually expands, whether its original intention—sustainable development—can be achieved requires further verification. And what are the mechanisms behind them? What provincial features influenced it? In 2007, green credit was introduced nationwide. And in 2008, the China Central Bank issued the Green Guidelines, a series of documents aimed at limiting the disorderly expansion of the "two high and one surplus" enterprises and restructuring industries while reducing environmental pollution [18]. With the domestic economy under dual pressure from the environment and economy, the purpose of green credit does not mean sacrificing economic development for environmental protection, or even sacrificing the environment for economic development. Neither path is a long-term solution.

In summary, this paper focuses on making innovations in the following areas: 1. A reverse indicator is constructed to measure the issuance of green credit in each province, using the interest share of six high-energy consuming industries. In contrast to previous measures of commercial bank performance, this paper aims to explore the issuance of green credit in each region and its influencing factors from a macro perspective. 2. Empirically testing the positive effects of green credit on regional economic growth, examining the mechanisms behind them, and providing theoretical foundations and empirical evidence for sustainable development. 3. Using sub-regional regressions, the heterogeneous impact of green credit on regional economic growth is explored, and regions are found to differ in their impact on local economies. The above study completes the related research on impact of green credit on economic growth and also provides policy recommendations for the subsequent sustainable implementation of green credit.

3. Theoretical Analysis and Hypothesis Proposed

3.1. Green Credit and Industrial Structure Adjustment

Prior to 2007, when the Green Credit was introduced, all firms would not have faced major differences in lending policies. The ease and size of access to loans for polluting and environmentally friendly companies are almost identical. However, it is difficult for environmental companies to show a good performance in the financial statements due to the environmental considerations, including sewage treatment costs, environmental management expenses and support for public welfare. On the contrary, highly polluting companies continue to expand their scale due to "rough" expansion and outperform environmental companies in terms of financial statement. To promote a high-growth economy at the expense of the environment, focusing on the development of heavy chemical industries is logical as the guiding ideology of some enterprises [20]. The Matthew effect makes high pollution enterprises in a favorable position for a long time, such enterprises also caused the early "two high and one surplus". The cumulative behavior of enterprises is manifested in changes in industrial structure. In other words, the over-expansion of "two high and one surplus" enterprises has caused distortion of the industry and serious mismatch of resources. As a credit guideline policy, the most direct effect of green credit is to lead the flow of loans to environmentally friendly enterprises, reduce the financing cost and increase availability for such companies, so that the loans can be used for their development and scale expansion, correcting the allocation of social resources. When such a correction reaches a certain scale, it will in turn have a positive impact on the local industrial structure. Bert [21] believes that green finance can provide financing channels for economic development and contribute to the transformation of industrial structure and sustainable development. Wang Yao [22] analyzed that green credit will lead to the formation of green investment and ultimately industrial restructuring. Xu Sheng [9] found that green credit can change the industrial structure by influencing the capital channel of enterprises, which has a positive impact on it. Slovakia [23] and Fangmin [24] argued that green finance can direct the capital flow to green industries and thus promote its development. Soundarrajan [25] concluded that green finance can facilitate the development of environmentally friendly businesses and influence the structure of local industries.

Green credit first directs the flow of bank as well as institutional capital so that spare funds can be utilized by companies that meet this guideline. Such companies mostly conform to the concept of sustainability and expand on this basis. In contrast, companies that did not meet the credit guidelines struggled and their performance weakened. In addition, companies that have difficulty in obtaining credit are faced with two types of choices at this time: either to push themselves to make technological innovations and bring their firms into compliance with relevant policies, or to exit the market. Either option would have a fundamental impact on the type of local businesses and industrial structure. The changes of industrial structure will tend to be more rationalized and the utilization rate of resources will be higher under the guidance of green credit.

Hypothesis 1. *The issuance of green credit exert a positive effect on the adjustment of industrial structure.*

3.2. Green Credit and Green Total Factor Productivity

Neoclassical economics argues that environmental protectionist policies have a negative impact on economic growth by raising the cost of private production and reducing the competitiveness of firms, thus offsetting the positive impact of environmental protection on society. However, Porter et al. [14] argue that the relationship between environmental protection and economic development cannot be simply divided into two. They argue that appropriate environmental regulation can induce firms to engage in more innovative activities, and that these innovations will increase the productivity of firms, thus offsetting the cost of environmental regulation and increasing their influence in a competitive environment, i.e., the Porter hypothesis. The company's actions avoid the short-term disadvantages of environmental regulation policies on the one hand, and achieve long-term productivity gains for the company on the other hand. When the local governments impose related regulatory policies, such shocks are sudden and polluting firms do not react in a short time to produce optimally according to the principle that marginal cost equals marginal benefit.

Due to increased pollution costs and restricted operations, the raw costs often outweigh the marginal benefits, which is detrimental to the advancement of innovations and reduces their productivity. However, in the long run, external transfers such as government R&D subsidies [26] as well as internal incentives from firms can enable themselves to innovate and thus improve their competitiveness and productivity.

When green credit was first implemented in China, fewer enterprises were able to borrow money, and the most affected were the "two high and one surplus" enterprises, whose production and operation were restricted in the short term. In the long term, however, it will spur such industries to upgrade and force in-house technological innovations to replace traditional ones, which will benefit green economic growth [14]. Green credit is close to an environmental regulatory policy, but it is more of a financing guideline. It targets the capital flow to reduce costs for compliant enterprises while increasing the opportunity cost for other firms. Therefore, green credit policy is more of a "cost-based environmental regulation", and the cost-based environmental regulation has a "U" shape relationship with green total factor productivity (GTFP) [27]. Before the inflection point, polluting companies face sudden increases in environmental management costs are not respond in time, resulting in a decline in productivity and operating performance. As costs continue to rise, high financing costs spur companies to increase R&D investment, recruit relevant staff, improve production equipment, minimize undesired output, and meet relevant policy standards, thus improving productivity and crossing the inflection point.

Hypothesis 2. *Green credit issuance has a "U" shaped relationship with GTFP, showing a short-term disincentive and a long-term boost.*

3.3. Green Credit and Economic Growth

In the initial stage of economic development, Clark et al. [28] found that the primary industry grew faster in the early years. Then, with further economic development, primary industries slowed down and were replaced by secondary and tertiary industries. And since the primary and secondary industries are dominated by agriculture, forestry, fishing and manufacturing, tertiary industries have a larger share in a relatively mature economy. This is a process of dynamic adjustment of the industrial structure, leading to a more rational level. The main expression is the pursuit of a high quality of life after the basic material needs have been satisfied. Primary industries create the basic output of an economy and meet the fundamental requirements of the population. Derived from this is the secondary industry such as manufacturing, and services in the tertiary industry, which meet a higher standard of living. This switch in industries is also accompanied by higher output creation. Sachs et al. [29] found that the backward industrial structure is one of the core reasons for China's rapid economic growth since the reform and opening up. One of the influential studies for China is the finding by Chunhui Gan [30] that industrial structural change has a significant boosting effect on the economy. At the same time, as the proportion of tertiary services continues to rise, it can itself absorb a wide range of labor and promote local employment to bring economic growth [31], and the output created by the service industry is higher than that of the primary and secondary industries.

The next is the "structural dividend" of productivity change [32]. For the early stages of a country's economy, the industrial structure is irrational, that is, the production efficiency is not balanced and there are large differences in the marginal efficiency. When capital flows from less productive industries to more productive ones, the latter expand and the average production efficiency increases. Such a "structural dividend" brings remarkable economic growth. And the efficiency improvement will lead to the "learning by doing" of the former, which will further improve the productivity level of the whole industry [33]. Thus, the hypothesis of "structural dividend" is based on the difference in efficiency between industries, which allows industries to achieve endogenous economic growth [34].

Combined with the above theoretical analysis, industrial rationalization and improved TFP have positive effects on economic growth, while green credits in turn have theoretical effects on industrial structure and GTFP. Based on this, the main hypothesis is proposed:

Hypothesis 3. *Green credit issuance has been shown to exert a positive effect on local economic growth.*

4. Model Specification

4.1. Data

The data is obtained from the China Statistical Yearbook for Industry, Urban City, and the Environment. The missing values are filled by linear interpolation. Since the "Opinions on Implementing Environmental Protection Policies and Regulations to Prevent Credit Risks" was promulgated in July 2007, excluding the impact of the lag in the implementation of related policies, the starting time is 2008. The data is taken through the end of 2020 for the most recent year of each statistical yearbook. As the linear interpolation is less reliable due to the high missing information for Tibet, Tibet is removed for the 31 Chinese provinces. The final selected data is derived from 30 Chinese provinces from 2008 to 2020.

4.2. Variable Selection

4.2.1. Green Credit

The idea of green credit indicator selection with reference to Chen's [35] research. Although China is among the countries with the largest volume of green credit, its development is still immature. A notable feature is that there is no direct indicator to measure its issuance. Therefore, the following types of approaches to structuring green credit exist in China: Lily Lian [36] measured green credit as a dummy variable, 0 before the year of 2007 and 1 afterwards. Xu Sheng [9] divided the balance of loans for environmental protection related projects by the total loan balance of the financial institutions as its issue volume. Tina Hsieh [37] measured green credit as an inverse indicator of the interest expense ratio of the six energy-consuming industries. Guo and Liu [38] used the ratio of green credit balance and the ratio of "two high and one leftover" loans to total loans as green credit to measure its issuance of major banks. Wang Kangshi [39] measured green credit using the flow of credit resources from polluting industries to environmental industries.

The subject of this paper is the provincial cities where the use of data from banks or financial institutions is not sufficient. Considering the completeness of the data, the interest expense ratio for six high-energy-consuming industries is chosen to measure the green credit. The six energy-intensive industries include "petroleum and nuclear processing", "chemical materials and products manufacturing", "ferrous and nonferrous metal smelting and rolling processing", "nonmetallic mineral products", and "electricity and heat production and supply".

The calculation is as follows,

$$Green\ credit = [1 - (Interest\ disbursements\ for\ six\ high - energy\ industries / Industrial\ interest\ expenditure)] \times 100\% \quad (1)$$

4.2.2. Economic Growth

The GDP of each province was selected to measure the economic growth of each province. Despite its various biases or deficiencies, it is still an important indicator for measuring economic growth [40]. The GDP per capita is used for the robustness test in the follow-up.

4.2.3. Control Variables

The control variables were selected were selected according to the province features:

(1) Inputs: Control the impact of foreign direct investment-FDI, R&D investment and government fiscal spending on the economy-Fp [41].

(2) Edu: Human capital is measured using the average length of education received by people in each province [42]. Average length of education = the proportion

of population with no education × 0 + the proportion of population with elementary school education × 6 + the proportion of population with junior high school education × 9 + the proportion of population with senior high school education × 12 + the proportion of population with college education or above × 16.

(3) Urban: Urbanization rate by province, controlling the impact of urbanization process on economic growth.

(4) Findex: The degree of financial development, controlling the impact of the level of financial development in each province [43]. Calculation: the balance of deposits and loans of financial institutions in each province divided by GDP.

(5) EC: Environmental regulation intensity. We define green credit as a "cost-based environmental regulation", but environmental regulations are far from the only. A composite index is introduced here to control the impact of government environmental policies [44]. The index is calculated based on the discharge of industrial wastewater, SO_2 and smoke. And the calculation is detailed in Appendix A.

All the variables used in this paper has been tabulated in the Appendix A (Table A1).

4.3. Descriptive Statistics and Analysis of Factors for Green Credit Issuance

4.3.1. Descriptive Statistics

For Table 1, there are significant differences between the East and the West in terms of GDP, foreign direct investment, R&D and environmental regulation index. Differences approach or exceed the overall mean. In part, this reflects the structural differences in economic levels, industrial structures and environmental policies between the East and West, and indirectly, the possible differences in the impact of green credits on the East and West. For the more volatile indicators, GDP, years of education, FDI, R&D, financial development index and government fiscal expenditure are treated logarithmically to mitigate the possible heterogeneous issues. Combined with the China's regional division, the 30 provinces are divided into East, Central and West in Table 2. In order to exclude the effect of unobservable factors, which vary between regions in terms of economy, customs and culture, the models are constructed controlling for fixed effects in each region.

Table 1. Descriptive statistics.

Type	Variables	Symbols	N	Mean	Std.Dev	Min	Max	*t*-Test for Differences in Means between East and West
Explained variable	Gross domestic product	*GDP* (#)	390	21,892	19,376	896.9	110,761	20,004.42 *** (8.425)
Explanatory variable	Green credit	*Gc* (%)	390	0.464	0.150	0.0940	0.808	0.207 *** (13.144)
Control variable	Years of education	*Edu* (#)	390	9.058	0.953	6.764	12.800	1.162 *** (10.265)
	Foreign direct investment	*FDI* (#)	390	762,003	769,823	446	3.576×10^6	1,019,767 *** (12.225)
	Research and development expenditure	*R&D* (#)	390	443.5	552.3	3.300	3480	621.142 *** (9.246)
	Urbanization rate	*Urban* (%)	390	0.560	0.131	0.291	0.896	0.171 *** (11.430)
	Financial development index	*Findex*	390	3.100	1.166	1.392	8.131	0.357 *** (2.426)
	Environmental regulation intensity	*Ec*	390	0.540	0.546	−0.151	2.754	0.480 *** (7.228)
	Fiscal expenditure	*Fp* (#)	390	4366	2826	324.6	17,485	1937.711 *** (5.367)

Note: # and % represent absolute and relative values respectively, *t*-statistics in parentheses, *** indicates statistical significance at the 1% level.

Table 2. National provinces divisions of east, central and west regional.

Regions	Cities
Eastern	Beijing, Tianjin, Hebei, Liaoning, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong, Hainan
Central	Shanxi, Inner Mongolia, Jilin, Heilongjiang, Anhui, Jiangxi, Henan, Hubei, Hunan, Guangxi
Western	Sichuan, Chongqing, Guizhou, Yunnan, Tibet (excluding), Shaanxi, Gansu, Qinghai, Ningxia, Xinjiang

4.3.2. Analysis of Green Credit Impact Factors

$$Gc_{i,t} = \beta_0 + \beta_1 X_{i,t-1} + \nu_i + \mu_t + \varepsilon_{i,t} \tag{2}$$

The green credit influencing factors model is set up as above, where $Gc_{i,t}$ denotes the green credit issuance in province i in year t. X represents a set of lagged one-period inter-provincial features, including all the control variables mentioned above. And v_i denotes the time-invariant regional fixed effect, μ_t denotes the province-invariant time fixed effect, and $\varepsilon_{i,t}$ represents the random disturbance term. Considering that there are some unobservable factors in some years or regions. For example, the subsidy policy for Northwest China may affect the issuance of green credit or the policies implemented in some specific years. Therefore, in order to estimate the impact factors of green credit as correctly as possible, we set time and region dummy variables as fixed effects here to mitigate the problem of missing variables. The following regressions adopt a fixed effects model based on the same idea. The above model settings capture the inter-provincial and regional effects on green credit, respectively. The following table reports the results, where columns (1) and (2) control for region and region-time fixed effects, respectively. Combining the common significant factors of both models, it reveals that provinces with higher FDI, R&D and financial development, urbanization rates and lower government fiscal spending have a higher share of green credit issuance. Table 3 also shows the eastern, central, and western differences in green credit distribution. The negative coefficients of the dummy (region) variables of Model (1) & (2) indicate that the issuance of green credit decreases as it gradually moves closer to the west, which is consistent with the above mean differences *t*-test results.

Table 3. Influencing factors of green credit issuance.

	(1)	(2)
Variables	**Gc**	**Gc**
L.lnEdu	0.227 **	0.194
	(0.103)	(0.129)
L.lnFdi	0.032 ***	0.037 ***
	(0.006)	(0.007)
L.lnR&D	0.049 ***	0.065 ***
	(0.014)	(0.015)
L.Urban	−0.196 **	−0.260 ***
	(0.093)	(0.091)
L.lnFindex	0.070 **	0.074 **
	(0.032)	(0.033)
L.Ec	−0.011	−0.003
	(0.012)	(0.012)
L.lnFinexp	−0.037 *	−0.090 ***
	(0.021)	(0.029)

Table 3. *Cont.*

	(1)	(2)
Variables	**Gc**	**Gc**
Dummy-region		
Central	0.022	0.024 *
	(0.015)	(0.015)
Western	−0.073 ***	−0.071 ***
	(0.017)	(0.017)
Constant	−0.356	0.034
	(0.231)	(0.351)
N	360	360
R^2	0.629	0.643
Region	Yes	Yes
Year	-	Yes

Note: This table reports the relationship between green credit and the provincial features. Robust standard errors in parentheses, *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels.

4.4. Model Specification

We develop a fixed-effects model to test the impact of green credit on economic growth:

$$lnGdp_{i,t} = \alpha_0 + \alpha_1 lnGc_{i,t} + \sum \eta X_{i,t} + \nu_i + \mu_t + \varepsilon_{i,t} \tag{3}$$

where $lnGdp_{i,t}$ is the explained variable, denoting the GDP of province i in year t. $lnGc_{i,t}$ is the share of green credit issuance in province i in year t. $X_{i,t}$ denotes the above mentioned series of control variables. ν_i, μ_t denotes regional and time fixed effects, and $\varepsilon_{i,t}$ is the residual term. This paper focuses on the sign of the α_1 and its significance, i.e., the effect of green credit on economic growth.

5. Empirical Results

5.1. Baseline Regression Analysis

Considering that the coefficients and significance may be largely influenced by fixed effects, where (1) and (2) control for region and region-time fixed effects, respectively. Column (3) introduces control variables on this basis to ensure the initial robustness of the findings. The coefficients of columns (1)–(3) are all significantly positive at the 1% level. In column (3), for example, at the national level, every 1% increase in green credit issuance increases GDP by about 0.482% per year, on average. This suggests that the impact of green credit issuance on the economy is significant, and hypothesis 3 is proven. For the stability of the regressions, both of the following regressions control for the region-time fixed effects to minimize the effect of unobservable factors.

5.2. Robustness Tests

5.2.1. Variable Substitution-GDP per Capita

Given the differences in the number of people in each province, regional GDP may not be a reasonable measure of the level of local economy. Here, GDP per capita is introduced to test whether the effect of green credit on economic growth is robust. The regression results are shown in column (1) of Tables 4 and 5, where each 1% increase in the share of green credit issuance is able to raise GDP per capita by about 0.613%, which holds at 1% significance level. Therefore, the effect of green credit on economic growth remains significant after accounting for regional population differences.

Table 4. Results of baseline regression.

	(1)	(2)	(3)
	lnGDP	**lnGDP**	**lnGDP**
Gc	3.624 ***	3.097 ***	0.482 ***
	(0.288)	(0.286)	(0.082)
Control variables	-	-	Yes
Constant	7.936 ***	8.181 ***	3.166 ***
N	390	390	390
R^2	0.441	0.523	0.979
Region	Yes	Yes	Yes
Year	-	Yes	Yes

Note: This table reports the relationship between green credit and economic growth. *** indicates statistical significance at the 1% level.

Table 5. Robustness test results.

	(1)	(2)	(3)	(4)	(5)
	lnPergdp	**Q25-lnGDP**	**Q50-lnGDP**	**Q75-lnGDP**	**Q90-lnGDP**
Gc	0.613 ***	0.493 ***	0.378 ***	0.381 ***	0.344 ***
	(0.185)	(0.167)	(0.110)	(0.107)	(0.111)
Constant	9.256 ***	3.460 ***	3.125 ***	3.416 ***	4.416 ***
	(0.301)	(0.871)	(0.870)	(0.861)	(0.646)
Control variables	Yes	Yes	Yes	Yes	Yes
N	390	-	-	-	-
R^2	0.690	-	-	-	-
Region	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes

Note: This table reports the results of robustness tests. Column (1) is the result of alternative measure of economic growth. Columns (2)–(5) are the results of quantile regression at different quantile points. *** indicates statistical significance at the 1% level.

5.2.2. Quantile Regression

It is observed that GDP is not uniformly distributed (Figure 1), and there are certain jumps at different quartiles, especially near the two ends. The ordinary least square (OLS) method used in the regression above yields the conditional mean $E(Y \mid X)$ of the explanatory variables on the explained variables, i.e., the conditional mean function of the explanatory variables. Thus, when the dependent variables are not uniformly distributed, there are differences in the estimated coefficients at different quantile points. This can lead to inconsistencies between the global and local estimates of the OLS, resulting in incorrect estimates and ultimately affecting the robustness of the conclusions. The OLS takes the minimization of residuals $\left(\sum_i e_i^2\right)$ as the objective, while for quantile regression, the objective is to minimize the symmetric absolute value residuals $\left(\sum_i |e_i|\right)$. Denoting the quantile level by q, the quantile regression estimator β_q is the objective function that minimizes:

$$Q(\beta_q) = \sum_{i:y_i > x_i'\beta_q}^{N} q|y_i - x_i'\beta_q| + \sum_{i:y_i < x_i'\beta_q}^{N} q|y_i - x_i'\beta_q| \tag{4}$$

From the above equation, the main advantage of quantile regression is to comprehensively estimate the relationship between variables at different quantile points. Combined with this model, the regressions are conducted by taking the dependent variable at the 25%, 50%, 75% and 90% quantile points, respectively, and the regression results are presented in Table 5, columns (2)–(5). The results show that the impact of green credit issuance on regional economic growth are significantly positive at the corresponding points, without large differences. In summary, the results of the quantile regression support the positive effect of green credit on economic growth and the results are robust.

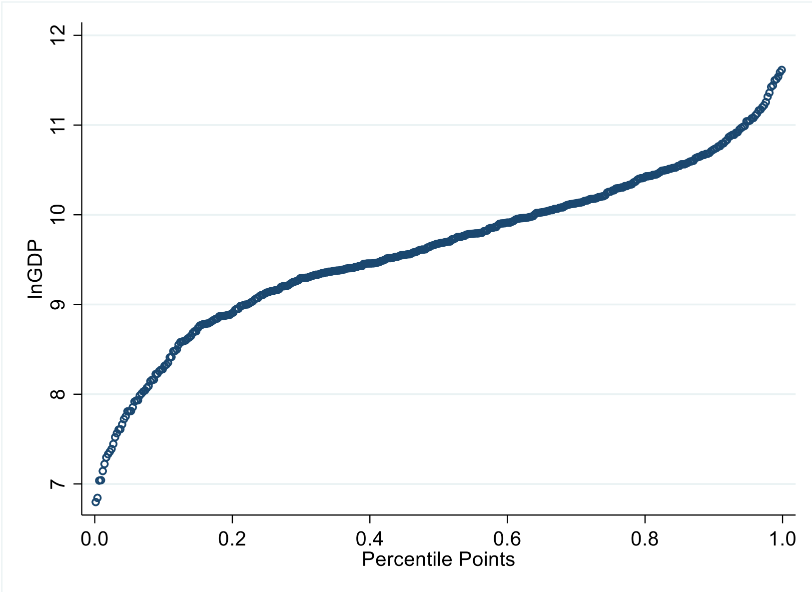

Figure 1. Distribution of different quartiles of regional GDP.

5.3. Endogeneity

This section addresses possible endogenous problems. 1. Two-way causality. Green credit issuance partly promotes regional economic growth, but regional economic growth drives more borrowing behavior of local industrial enterprises while increasing green credit issuance, which will underestimate the impact of green credit on economic growth. 2. Missing variables. There may be unobservable factors beyond region and year that affect both green credit and economic growth, thus overestimating the impact of green credit. 3. Problems with indicator construction. Although China has the largest volume of green credit in the world, there is no data directly used to measure its volume in each province, and the measure chosen in this paper is the inverse indicator, as in Equation (1). According to the "Green Credit Guidelines" issued by the China Banking Regulatory Commission, using the total interest expenses of the six energy-consuming industries would ignore another part of loans that are harmful to the environment and society. Thus, this would overestimate or underestimate the impact of green credit issuance on economic growth. Combined with the above analysis, it may not be possible to determine the true impact of green credits on the economy by looking at the OLS regression coefficients. To overcome this endogeneity problem as much as possible, we need to find a variable that is not correlated with the explained variable but is correlated with the explanatory variable, namely the instrumental variable. And the instrumental variable is re-estimated in the same model. If the re-estimated coefficients do not change significantly in terms of direction and significance, our above conclusions hold. This is the idea of instrumental variable estimation.

$$IV_{i,t} = \frac{In(Institution_{i,t})}{Firm_{i,t}} \tag{5}$$

The explanatory variable in this paper is green credit issuance, where the corresponding instrumental variable is constructed as in Equation (6). where $Institution_{i,t}$ denotes the number of local financial institutions in province i in year t and $Firm_{i,t}$ denotes the number of local industrial enterprises in province i in year t. Considering that green credit issuance is constrained by the level of local financial development and the number of industrial enterprises, i.e., the higher the level of local financial development, the lower the frictional cost of borrowing occurs, and the more likely enterprises are to generate borrowing behavior. On the contrary, the higher the cost, the less likely to borrow. Second, the greater the number of local industrial enterprises, the greater competition faced by a single enterprise. And the more time it takes financial institutions to confront many firms, the harder it will be for them to get credit disbursements, and vice versa, the easier it will be. Moreover, the constructed instrumental variable is less likely to affect economic growth in other ways. In summary, the constructed instrumental variable satisfies both exclusivity and relevance requirements. Combined with Figure 2, there is a high spatial correlation between the constructed instrumental variables and the share of green credit issuance.

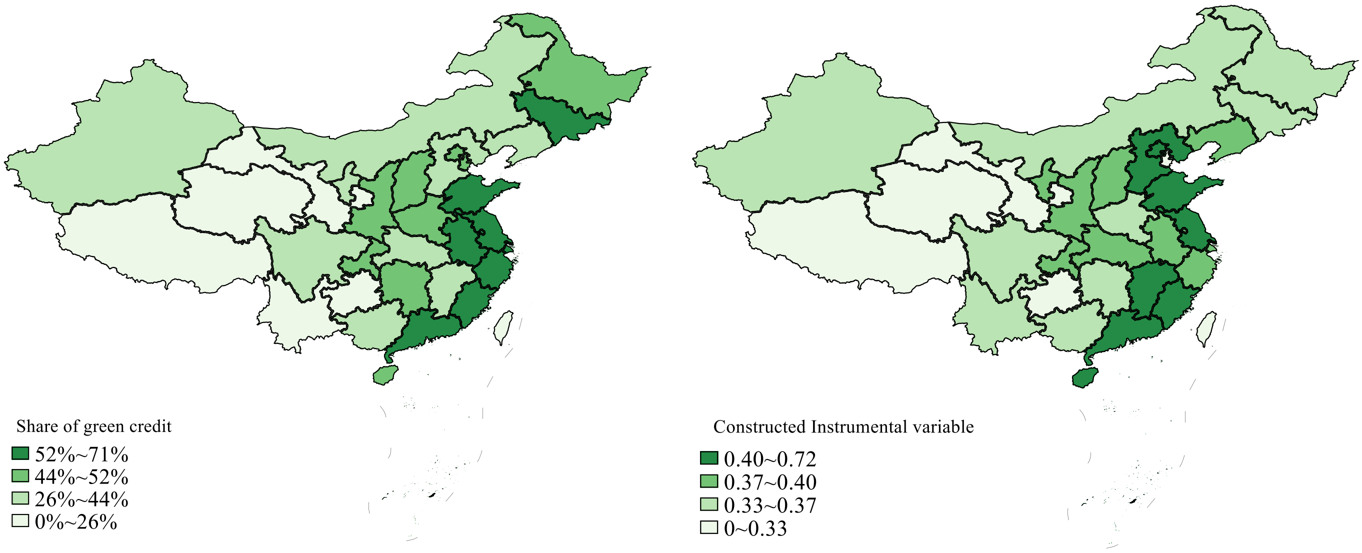

Figure 2. Green credit (**left**) and constructed instrument variables (**right**).

The above regressions all include control variables as well as regional and year fixed effects. According to the results of the first stage regression shown in column (1) of Table 6, the instrumental variables are highly correlated with green credit, which is consistent with the above inferences. In the correlation test, the Cragg-Donald F-statistic is 40.567, which is above the 10% threshold of the Stock-Yogo weak instrumental variable test of 16.38 and passes the under-identification test in the first stage. The LM statistic has a p-value of 0.000. The effect of green credit on regional economic growth remains significantly positive in the second stage regression shown in column (2) of Table 6, that is, after dealing with the endogeneity issues, supporting the above findings.

Table 6. Two-stage instrumental variable regression.

	(1)	**(2)**
	First-Stage	**Second-Stage**
	Gc	lnGDP
IV	10.443 **	
	(1.640)	
Gc		13.521 ***
		(1.897)
Constant	0.353 ***	4.591 ***
	(0.050)	(0.707)
Control variables	Yes	Yes
Region	Yes	Yes
Year	Yes	Yes
Observations	390	390
R^2	0.544	0.983
F-statistic-Weak instrumental variable test	40.567	
(Cragg-Donald)	(10% Threshold value = 16.38)	
LM-statistic-Under-identification test	38.63	
(Anderson canon. corr)	(p-Value = 0.000)	

Note: This table reports the result of instrumental variable regression. **, and *** indicate statistical significance at the 5%, and 1% levels, respectively.

6. Additional Analysis

6.1. Mechanisms

6.1.1. Industrial Rationalization

To verify the impact of green credit on the adjustment of industry structure (Hypothesis 1), we construct an indicator to measure this effect—industrial rationalization (*IR*). Drawing on the method of Chunhui Gan [30], i.e., the degree of *IR* is first measured by using industrial deviation, which reflects the efficient use of resources and labor. The industrial deviation is calculated as follows.

$$E = \sum_{i=1}^{n}\left|\frac{Y_i/L_i}{Y/L} - 1\right| = \sum_{i=1}^{n}\left|\frac{Y_i/Y}{L_i/L} - 1\right| \tag{6}$$

where E denotes the degree of industrial structure deviation, L_i denotes the number of employees or labor in each industry category i, and n denotes the number of industries, which is taken to be 3 here. It is assumed that an economy will tend to equilibrium with equal productivity of each factor, i.e., Y_i/L_i is equal. This leads to $Y_i/L_i = Y/L$, i.e., $E = 0$. Further, the right side of the equation can be derived, i.e., the structure of the economy (Y_i/Y) is equal to the structure of the industry (L_i/L). The larger the sectoral deviation, the more unbalanced the economy. Such a phenomenon is more common, so E is often not equal to 0. Moreover, this approach does not take into account the absolute value of each industry. Namely, there will be an effect of the magnitude, and in the final summation, it is easy to see that the larger number covers the smaller ones. To avoid these problems, the Thiel index [45] is introduced here, which was earlier used to measure regional income disparity,

$$TL_{i,t} = \sum_{i}^{n}\left(\frac{Y_i}{Y}\right)ln\left(\frac{Y_i}{L_i}/\frac{Y}{L}\right) \tag{7}$$

The Thiel index is 0 when the economy is in equilibrium. Meanwhile, the Thiel index introduces the idea of weighted average, which takes into account the weight of output value relative to GDP, so it can better measure the *IR* compared with industrial deviation. Since the industrial rationalization index is a negative indicator. To prevent the minimum value from being 0, the following method is adopted [46].

$$IR_{i,t} = \max(TL_{it}) + \min(TL_{it}) - TL_{it} \tag{8}$$

The model is set up as follows, where $IR_{i,t}$ denotes the industrial rationalization index of province i in year t and the rest are constant.

$$IR_{i,t} = \alpha_0 + \alpha_1 lnGc_{i,t} + \sum \eta X_{i,t} + \nu_i + \mu_t + \varepsilon_{i,t} \tag{9}$$

To initially test the robustness, where no control variables for column (1) and control variables for column (2) of Table 7. The results show that green credit significantly improves the rationalization of local industrial structure regardless of whether control variables are included or not. Hypothesis 1 is proven. Thus, the first mechanism is established: green credit issuance promotes economic growth by improving the rationalization of industrial structure.

Table 7. Mechanism of impact of green credit on economic growth—*IR*.

	(1)	(2)
	IR	***IR***
Gc	0.329 ***	0.180 ***
	(0.039)	(0.036)
Constant	−0.368 ***	−0.112
	(0.020)	(0.243)

Table 7. *Cont.*

	(1)	(2)
	IR	***IR***
Control variables	-	Yes
N	390	390
R^2	0.636	0.715
Region	Yes	Yes
Year	Yes	Yes

Note: This table reports the relationship between green credit and industrial rationalization. *** indicates statistical significance at the 1% level.

6.1.2. Green Total Factor Productivity

To verify the impact of green credit on GTFP (hypothesis 2), we measure the GTFP based on the method by Bin Li [47], in which he used provincial indicators for the calculation. The approach is shown in the Appendix A. The model is set up as follows, where $Gtfp_{i,t}$ denotes the green total factor productivity of province i in year t, and $lnGc_{i,t}\_2$ denotes the square of green credit issuance, which is added to measure the non-linear relationship between GTFP and green credit.

$$Gtfp_{i,t} = \alpha_0 + \alpha_1 lnGc_{i,t} + \alpha_2 lnGc\_2_{i,t} + \sum \eta X_{i,t} + \nu_i + \mu_t + \varepsilon_{i,t} \tag{10}$$

Similarly, column (1) of Table 8 does not include the squared term and control variables, while column (2) of Table 8 adds the control variables. To verify the "U" type relationship between the green credit and GTFP, the squared term "Gc_2" is introduced based on column (2). It turns out that the relationship between them is not significant until the squared term is added. From column (3) of Table 8, the green credit issuance suppresses the GTFP of enterprises in the first period, while in the long run, it seems to promote it, and hypothesis 2 is proven. Thus, the impact mechanism is established: green credit issuance improves economic growth in the long run by promoting GTFP.

Table 8. Mechanism of the impact of green credit on economic growth—*GTFP*.

	(1)	(2)	(3)
	Gtfp	**Gtfp**	**Gtfp**
Gc	0.193	−0.447	−3.612 **
	(0.318)	(0.351)	(1.710)
Gc_2			3.353 *
			(1.922)
Constant	1.603 ***	0.339	−0.323
	(0.147)	(2.026)	(2.241)
Control variables	-	Yes	Yes
N	390	390	390
R^2	0.366	0.471	0.479
Region	Yes	Yes	Yes
Year	Yes	Yes	Yes

Note: This table reports the relationship between green credit and green total factor productivity. *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively.

6.2. East-Middle-West Heterogeneity Analysis

From Table 9, the economic effect of green credit issuance is greater in the west than in the east and central regions. This is shown by the fact that each 1% increase in green credit issuance leads to a boost in local GDP of about 0.21% in the west, while it is not significant in the east and central region. The reason for this may be related to several aspects. First, the diminishing marginal effect [42]. In the country, especially in the east-central region, the development of industrial structure, technical level and financial system are way more ahead of those in west [48]. The scale of green credit is also relatively larger, and the economic effect of green credit in the eastern region has also reached saturation first. In contrast, the full implementation of green credit can better promote the development of the local economies in the western region, where the level of financial development is less perfect. That is, the economic effect of green credit is greater in the less developed financial regions than in the more developed financial regions. The second reason is related to the "pollution sanctuary hypothesis" [44]. The eastern region due to a long period of stronger local government environmental regulation (the average environmental regulation index in the east reaches 0.716, while in the west it is only 0.223). This will result in the migration of polluting enterprises to provinces and cities outside the country, mainly in the western region where environmental regulation is weaker. However, as the implementation of green credit is a national policy of environmental regulation, it is difficult for western polluters to continue to flee and find new sanctuaries, so they can only make changes for themselves. Combined with mechanisms, this has led to industrial restructuring and GTFP improvements. The economy in the West is likely to be improved more broadly. Finally, consider the expectations. The level of government regulation is significantly stronger in the east than in the west [44], and polluting enterprises are more likely to flee to the west than to "stay" in the central region, where they expect to suffer from environmental regulation in the future. As a result, the adjustment of green credit for polluting enterprises in the central region is small. The effect on the local industrial structure is relatively small, and so as the economic effect of green credit, thus the impact is not significant.

Table 9. Sub-regional regression results.

	(1)	**(2)**	**(3)**
	lnGDP-East	**lnGDP-Central**	**lnGDP-West**
Gc	0.034	0.588	0.210 **
	(0.181)	(0.373)	(0.103)
Constant	5.801 ***	15.405 **	−2.153 ***
	(0.685)	(2.832)	(0.579)
Control variables	Yes	Yes	Yes
N	156	117	117
R^2	0.992	0.691	0.993
Region	Yes	Yes	Yes
Year	Yes	Yes	Yes

Note: This table reports the result of heterogeneity analysis, grouped by east, central and west. "Region" here is to control the fixed effects of the eight economic regions of the country, including the northeast, northern coast, eastern coast, southern coast, middle Yellow River, middle Yangtze River, southwest and northwest in China. **, and *** indicate statistical significance at the 5%, and 1% levels, respectively.

7. Discussion

To find out the economic impact of green credit, we use regional data and design experiments to find out the positive effects of green credit on the economy and to validate the mechanisms from the perspective of industrial structure improvement and green total factor productivity.

First, we enrich the study of the impact of green credit on regional economies. Unlike studies conducted from firms [17,18,49], we found a positive impact of green credit on the economy from a macro perspective, which is consistent with the findings of these studies [35,37]. This result demonstrates that green credit is in line with its original purpose of issuance, i.e., to improve the environment while delivering a boost to the economy. Empirical findings provide empirical evidence for developing countries that are currently facing environmental and economic issues, namely, that to a certain extent economic problems are not incompatible with environmental problems. Making the case for the environment does not mean sacrificing the economy. As more and more countries are currently delaying or withdrawing from carbon peaking and carbon neutral programs

(In August 2022, Germany chooses to eliminate its goal of carbon neutrality by 2035), our findings may provide a new way of thinking.

Second, the mechanism analysis extends the study of green credit on industrial structure and green total factor productivity. For industrial structure, we find that green credit has a positive relationship on the rationalization of industrial structure. In some previous literature, the adjustment of green credit on industrial structure is mostly at the stage of theoretical analysis due to imperfect data and lack of green credit measurement indicators [22,24]. We capture the positive impact on industrial restructuring by constructing related indicators. This implies that green credit improves industrial structure by means of credit priority, a finding that is consistent with such studies [9,16], from which we differ in the measurement of industrial structure. For green total factor productivity, we find that the effect of green credit on total factor productivity is not a simple linear relationship, but rather a "U" shaped one, i.e., a short-term inhibition and a long-term promotion. This is an innovation from previous studies that showed a positive relationship simply [48]. Since green credit can also be seen as an indirect environmental regulation policy, we also prove Porter's hypothesis that appropriate environmental regulation can promote total factor productivity [14].

Finally, the heterogeneity analysis completes the study on the economic effects of green credit differ across regions with different features. In the case of this paper, these features may include prior green credit issuance level, financial development, intensity of local environmental regulations, etc. The existence of heterogeneity in green credit is consistent with theses literatures [5,10,11,19]. Through the model of Equation (2), we also found that which provincial features may affect its issuance. This conclusion is lacking in current research related to green credit.

At the same time, there are some international implications in our study. China was not the first country to develop green credit. The Federal Republic of Germany established the world's first policy-oriented environmental bank in 1974. The United States also published and distributed the Berdith Principles in May 1989 by the Investment Group of the Environmentally Responsible Economic Alliance, and used the Berdith Principles as a practical guide to green credit. Soon after, the United Nations also issued corresponding laws and regulations applicable to the banking industry to regulate the development of green credit. As a result, a large number of countries other than China have implemented green credit policies. With the intensification of global environmental problems and the economic downturn, both developing and developed countries need to address both environmental and economic issues at the same time, and the sacrifice of either will not be worth the loss. The positive effects of green credit on industrial restructuring, productivity improvement, and economic growth can be determined by national governments according to their own conditions.

8. Conclusions and Policy Recommendations

8.1. Conclusions

This paper explores the influencing factors and regional distribution of green credit issuance using panel data from 2008 to 2020 from 30 provinces across China. In particular, we systematically assess the impact of green credit on regional economic growth, its mechanisms and regional heterogeneity. The results show that provinces with higher FDI, R&D and financial development, lower urbanization rate and government fiscal expenditure have a higher share of green credit issuance. At the regional level, the eastern part is higher than the central and western. Moreover, green credit issuance can significantly boost regional economies: for a whole country, every 1% increase in the share of green credit raises local GDP by an average of about 0.482%. The mechanism analysis shows that green credit issuance boosts the local economy by increasing IR and GTFP, where green credit suppresses GTFP in the short term and boosts it in the long term, not in a simple linear relationship, but a "U" shape. For the sub-regional scenario, a 1% increase in the share of green credit issuance in the west raises local GDP by 0.210% on average, while it is not significant in the east-central region. The differences across regions are related to diminishing marginal effects and the escape of polluters, as well as their expectations. The endogeneity of the model is mitigated by constructing instrumental variables from the frictional costs and the degree of competition by considering the number of local financial institutions and firms, yielding consistent findings.

8.2. Policy Recommendations

From this study, we make the following policy recommendations for the continued implementation of green credit policies in China.

First, the issuance of green credit has effectively boosted local economic growth, which is based on the rationalization of industrial structure and the improvement of green total factor productivity, which is more in line with the sustainable development strategy. Although China has become the world's largest green credit issuer, there is still a lot of room for improvement in the central and western regions. And along with the phenomenon of "polluting enterprises fleeing", the economic effect of green credit in the western regions is more obvious. Therefore, we need to formulate corresponding credit support policies for the western region to accelerate the technological transformation and upgrading of polluting enterprises and enhance the rationalization of local industrial structure.

Secondly, the number of local financial institutions and industrial enterprises exert some impact on the issuance of green credit, and the policy to facilitate the issuance of green credit can appropriately increase the number of local financial institutions and coordinate the allocation of industrial enterprises to reasonably reduce the difficulty of obtaining credit and the competition level of local enterprises.

Thirdly, the role of green credit in promoting industrial structure upgrading and green total factor productivity enhancement should be given full play to boost the development of regional economy. On the one hand, according to the principle of "lending priority", green credit can guide the flow of credit loans to green industries such as new energy, energy-saving and environment-friendly industries, support the development of these industries, and restrict the "two high and one surplus" industries, so as to promote the transformation of industrial structure. On the other hand, the government should also lead credit to innovative projects of traditional processes and technological innovation, encourage the development of green projects and mitigate the risk of innovation, promote technological progress and improve the green total factor productivity.

Author Contributions: Formal analysis, C.C.; Investigation, Y.B.; Data curation, Y.Z.; Writing—review & editing, S.Z.; Supervision, S.Z. All authors have read and agreed to the published version of the manuscript.

Funding: This research was supported by the Principal's Fund Project of Minnan Normal University (sk22008) and the Fujian Provincial Social Science Planning Project (FJ2021BF038).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data is obtained from the China Statistical Yearbook for Industry, Urban City, and the Environment (2008–2020).

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Appendix A.1. The Calculation of Ec

The calculation was first standardizing each indicator to remove the effect of the magnitude,

$$S'_{i,j,t} = \frac{S_{i,j,t} - min(S_{i,j})}{max(S_{i,j}) - min(S_{i,j})} \tag{A1}$$

where $S'_{i,j,t}$ denotes the value of the indicator of pollutant category j in province i after normalization at time t. $max(S_{i,j})$ denotes the maximum value in the indicator of pollutant category j in province i, and $min(S_{i,j})$ denotes the minimum. The weights are then determined according to the entropy weighting method. The principle of this approach is to objectively determine the weights based on the variability of the indicators, rather than the subjective assignment of weights. The variability of the index is measured by the information entropy, and the smaller the value of information entropy, the greater the dispersion of the index, the more information is provided, and the greater the weight, and vice versa [47].

The specific steps are as follows, assuming that the standardized values of the indicators in group m

$$X_1, X_2, \ldots X_m \tag{A2}$$

Find the weight of the nth value in the X_n indicator, or calculate the size of the variation of the indicator,

$$p_{mn} = \frac{X_{mn}}{\sum_{i=1}^{n} X_{mn}} \tag{A3}$$

According to the definition of information entropy in information theory, the information entropy of a set of data is that,

$$E_m = -ln(n)^{-1} \sum_{i=1}^{n} p_{mn} ln p_{mn} \tag{A4}$$

where $E_x \geq 0$, if $p_m = 0$, define $E_m = 0$.

According to the formula of information entropy, calculate the information entropy of each index, and determine the weight of each index,

$$w_m = \frac{1 - E_m}{k - \sum E_m} (j = 1, 2, \ldots, m) \tag{A5}$$

where k is the number of indicators, which include emissions of industrial wastewater, SO_2 and smoke, so k = 3.

Finally, based on the weights determined by the entropy weighting method, the environmental regulation intensity index of each region at different time is calculated.

$$EC_{i,t} = \sum_{j}^{3} w_j S_{i,j,t} \tag{A6}$$

Appendix A.2. The Calculation of GTFP

This is calculated as follows: define the matrix $X = (x_{i,t}) \in R^{+}_{n*m}$, which denotes the input factor vector. And $Y^g = \left(y^g_{i,t}\right) \in R^{+}_{n*m}$ denotes the desired output vector. $Y^b = \left(y^b_{i,t}\right) \in R^{+}_{n*m}$ denotes the non-desired output vector. The desired output is the 2004 provincial GDP at constant prices, the undesired output is the "three industrial wastes", and the input factors are capital, labor and energy. Using the data envelope approach, environmental technologies are modeled as

$$P(x) = \{(x, y^g, y^b) | x \geq X\lambda, y^g \leq Y^g\lambda, y^b = Y^b\lambda, \sum_{i=1}^{n} \lambda = 1, \lambda \geq 0\} \tag{A7}$$

where λ denotes the weight of the cross-sectional observations. If $\sum_{i=1}^{n} \lambda = 1$, it indicates variable payoffs for scale (VRS). Define undesired output. For a particular $DMU_0\left(x_0, y^g_0, y^b_0\right)$, The SBM model considering non-desired outputs i.e., solving the following linear programming model.

$$\begin{aligned} min\rho^* &= \frac{1-\frac{1}{n}\sum_{i=1}^{n}\frac{s_i^-}{x_{i0}}}{1+\frac{1}{u+v}\left(\sum_{j=1}^{u}\frac{s_j^g}{y_{j0}^g}+\sum_{j=1}^{v}\frac{s_j^b}{y_{j0}^b}\right)} \\ s.t.x_0 &= X\lambda + s^-, y_0^g \\ &= Y^g\lambda + s^b, \lambda, s^g, s^b, s^- \\ &\geq 0 \end{aligned} \tag{A8}$$

where $s^- \in R^n$ and $s^b \in R^v$, denotes too much input and undesired output respectively. While $s^g \in R^u$ denotes insufficient expected output. The numerator and denominator of ρ^* denote the average shrinkable and average expandable ratios of actual inputs and outputs of the production decision unit relative to the production technology frontier.

Environmental technology $P(x)$ is the possible frontier of output after taking environmental factors into account, which is the basis for measuring green total factor productivity. In this paper, we introduce the directional distance function based on the set of environmental technologies, i.e., for a specific province k, the directional distance function for year t can be obtained by the following linear programming.

$$\begin{aligned} &\overrightarrow{D}_0^t\left(x^t, y^t, b^t; g_y - g_b\right) = max\beta \\ &s.t.\sum_{k=1}^{n} z_k^t y_{kj}^t \geq y_{k'j}^t + \beta g_{yj}^t, j = 1,2,\ldots,u \\ &\sum_{k=1}^{n} z_k^t b_{ks}^t \geq b_{k's}^t - \beta g_{bs}^t, s = 1,2,\ldots,v \\ &\sum_{k=1}^{n} z_k^t x_{ki}^t \leq x_{k'i}^t, i = 1,2,\ldots,n \end{aligned} \tag{A9}$$

where z_k^t denotes the weight value in period t, k = 1,2, … ,n. After the directional distance function is obtained by solving linear programming, the Gtfp from period t to period t + 1 can be obtained as,

$$Gtfp_t^{t+1} = \left\{\frac{1+\overrightarrow{D}_0^t\left(x^t, y^t, b^t; g^t\right)}{1+\overrightarrow{D}_0^t\left(x^{t+1}, y^{t+1}, b^{t+1}; g^{t+1}\right)} \times \frac{1+\overrightarrow{D}_0^{t+1}\left(x^t, y^t, b^t; g^t\right)}{1+\overrightarrow{D}_0^{t+1}\left(x^{t+1}, y^{t+1}, b^{t+1}; g^{t+1}\right)}\right\}^{1/2} \tag{A10}$$

Appendix A.3. Variable Definitions

The definitions and calculation methods of all variables used in this paper are shown in the following table:

Table A1. Variable definitions.

Type	Variable	Description	Measurement
Explained Variables	$\mathrm{lnGDP}_{i,t}$	GDP of each province	Natural logarithm of (GDP of each province), Q25-lnGDP, Q50-lnGDP, Q75-lnGDP, Q90-lnGDP are the 25%, 50%, 75% and 90% quantile points of lnGDP
	$\mathrm{lnPergdp}_{i,t}$	GDP per capita	Natural logarithm of (GDP of each province/the total population of each province)
Explanatory Variables	$\mathrm{Gc}_{i,t}$	The volume of green credit issuance	[1 − (Interest disbursements for six high-energy industries/Industrial interest expenditure)] × 100%

Table A1. *Cont.*

Type	Variable	Description	Measurement
Control Variables	$FDI_{i,t}$	Foreign direct investment	Natural logarithm of (FDI of each province)
	$R\&D_{i,t}$	Research and development expenditure of each province	Natural logarithm of (Research and development expense of each province)
	$FP_{i,t}$	Fiscal spending of each province	Natural logarithm of (Fiscal spending of each province)
	$Edu_{i,t}$	Year of education	The proportion of population with no education $\times$ 0 + the proportion of population with elementary school education $\times$ 6 + the proportion of population with junior high school education $\times$ 9 + the proportion of population with senior high school education $\times$ 12 + the proportion of population with college education or above $\times$ 16
	$Urban_{i,t}$	Urbanization rate of each province	Urban registered population as a percentage of the permanent population
	$Findex_{i,t}$	The degree of financial development	The balance of deposits and loans of financial institutions in each province divided by GDP
	$Ec_{i,t}$	Environmental regulation intensity	The index is calculated based on emissions of industrial wastewater, SO_2 and smoke (Appendix A.1)
Instrumental Variable	$IV_{i,t}$	Constructed by local financial institutions and enterprises	Natural logarithm of (the number of local financial institutions of each province)/the number of local industrial enterprises of each province
Mechanism Variables	$IR_{i,t}$	Industrial Rationalization	Thiel index calculated by labor and income, Equations (8) and (9)
	$Gtfp_{i,t}$	Green total factor productivity	Calculated by desired output (GDP of each province), undesired output (three industrial wastes) and input (capital, labor and energy) (Appendix A.2)

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