Research Article

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Cleaner Production: Analysis of the Role and Path of Green Finance in Controlling Agricultural Nonpoint Source Pollution

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Abstract: This study evaluates the impact of green finance (GF) on agricultural nonpoint source pollution (ANPSP) control and emission reduction in 30 Chinese provinces from 2005 to 2021. Utilizing the entropy value method and the unit survey inventory method, the research measures the levels of GF development and ANPSP. It employs a mediation effect model to empirically assess the pollution control efficacy of GF and to elucidate the mechanisms underlying its influence. The findings indicate that GF development significantly curtails ANPSP emissions. It achieves this through government environmental regulation (ER) and land transfer mechanisms. Heterogeneity test results show that GF has a stronger impact on ANPSP in regions with lower economic development level and GF reform policies. Therefore, the study suggests strengthening the GF infrastructure in rural areas, aligning GF policies with ER, promoting large-scale land operations, and implementing tailored strategies for regions with different levels of economic development and GF reform policies.

Keywords: green finance, ANPSP, government environmental regulation, land transfer, mediation effect, entropy evaluation method

JEL classification numbers: Q56, G28, O13

1 Introduction

The prevention and control of agricultural nonpoint source pollution (ANPSP) is one of the effective ways to realize the green development of agriculture and enhance the supply capacity of agricultural ecological products. According to the data from the China Pollution Source Census, ANPSP has become an important factor endangering China's ecological environment, especially in terms of the degree of water pollution. With people's increasing attention to water environment, scientific assessment and exploration of ANPSP are receiving more and more attention. The control of ANPSP requires the support of green finance (GF). GF invests funds in low-carbon, clean energy, and environmental projects through tools such as green loans, green bonds, and other financial mechanisms (Ge & Zhu, 2022). This promotes the transition of capital from high-polluting industries to low-polluting industries, increases the return on investment of green industries, improves the availability of funds, and reduces pollution emissions (Guo et al., 2024; Tian et al., 2022). The 20th National Congress of the Communist Party of China (CPC) emphasized the important role of financial support for green development. It advocates for rational allocation of resources, promoting the transfer of resources to green and low-carbon projects, facilitating the transition of traditional industries to ecological practices, and developing new green industries. In this context, ANPSP, as an important driving factor of systemic environmental pollution, plays a crucial role in achieving sustainable agricultural development and ensuring human health and safety (Fan et al., 2024).

According to the 2022 China Ecological Environment Statistical Bulletin, the chemical oxygen demand (COD) emissions from agricultural sources were 17.857 million tons, accounting for 68.8% of the total emissions from all sectors. The total nitrogen (TN) emissions are 1.744 million tons, accounting for 55.0% of the total emissions of all departments. The total phosphorus (TP) emissions are 277,000 tons, accounting for 80.2% of the total emissions of all departments. These data indicate that the situation of ANPSP remains severe and urgently needs to be fundamentally addressed to improve the health level of agricultural production environment quality. ANPSP, a significant contributor to systemic environmental pollution, is vital for achieving

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sustainable agricultural development and ensuring human health and safety (Fan et al., 2024). Despite robust policy and financial backing for controlling ANPSP, the inherently dispersed, concealed, and delayed nature of ANPSP challenges effective management, often rendering fiscal policies administratively dysfunctional and necessitating increased governmental financial intervention. The designation of "green financial standardization construction" as a key initiative during the "13th 5-Year Plan," coupled with guidelines from the CPC Central Committee and the State Council to enhance ecological environmental protection, underscores China's commitment to advancing GF standardization. With the ongoing positive development of the financial market, financial backing has emerged as a pivotal force in managing ANPSP and advancing ecological civilization (Shen et al., 2023).

Although GF yields positive effects in managing ANPSP, it faces numerous bottlenecks and challenges, including the imbalance and inadequacy of China's financial development. Hence, in this context, it is essential to examine the impact of GF on the governance of ANPSP in China. Does it effectively support pollution management? What mechanisms does GF employ in managing ANPSP? This paper aims to address these questions by exploring scientific issues, developing an assessment of the impact mechanism of GF on managing ANPSP, providing decision-making guidance for the government to promote ecological construction, and offering reference significance for other developing countries' pollution management efforts. This research aims to contribute to the improvement of the green financial system and achieve dual benefits in financial and environmental domains.

2 Literature Review

The concept of GF, emerging from global concerns about environmental protection and sustainable development, represents a novel paradigm in financial theory and practice. Often referred to as environmental finance or sustainability finance, GF restructures the operational concepts, management policies, and business processes of the financial industry through an environmental lens, aiming to facilitate sustainable development (Zhang et al., 2019). In recent years, the Chinese government has actively promoted the establishment of a green financial system through various measures, including the introduction of green credit, green bonds, and support for green project development and implementation (Li et al., 2023a). China GF policy extends beyond urban environmental issues to include the agricultural sector, specifically targeting the challenge of agricultural surface source pollution.

Agricultural surface source pollution refers to the contamination of the ecological environment due to excessive chemical inputs in the planting industry and improper treatment of crop straws and livestock manure in the farming industry. It is driven by factors such as rainfall, topography, and a variety of influencing factors, making its monitoring challenging. With the rapid development of agriculture since the twenty-first century, China's major lakes and rivers have been increasingly affected by surface pollution, leading to the dangerous problem of eutrophication (Li et al., 2023b). Similarly, foreign countries also face agricultural surface source pollution due to extensive chemical fertilizer (CF) use and intensified modern agricultural practices (Shortle et al., 2012).

There are two main methods for measuring agricultural surface source pollution. The experimental method involves selecting representative farms to test and measure pollutants discharged using modeling and monitoring methods (Shen et al., 2020). The source strength estimation method, used for macro calculations, estimates pollutant loads per unit area from farmland fertilizers, livestock and poultry farming, farmland solid waste, and rural life (Ding et al., 2023). In terms of governance instruments, two broad categories exist: "Pegu's instruments," dominated by government macro-control, and "Coase's instruments," driven by market regulation mechanisms (Ren et al., 2018). Peguy's approach advocates top–down government intervention to reduce environmental pollution by taxing polluters or subsidizing environmental protection efforts. Under the pressure of economic growth targets, the negative externalities of pollution in China conflict with environmental pollution control efforts (Pang & Xie, 2024). Conversely, Coasean means rely on clear property rights definitions to transform environmental goods into private goods, thereby preventing the tragedy of the commons phenomenon and optimizing societal interests (Shen and Zhang, 2022). In this regard, enterprises in polluting industries and other relevant entities should take more actions to reduce pollutant emissions and adopt green technologies, which are crucial for sustainable development under environmental protection (Wei & Zhao, 2024).

As the financial system continues to evolve, market-led green financial support has become an important tool for managing ANPSP. Political uncertainty and other factors may lead to changes in stock prices in financial markets (Xu et al., 2022). Regarding this, financial institutions can influence the environmental protection capacity of the production sector by incorporating environmental values into their financial products or services, thereby directing social funds to participate in pollution management, particularly in less-developed areas (Jiang et al., 2019). Measures such as promoting organic fertilizers, improving livestock and poultry management, and supporting eco-agriculture not only reduce pollution but also enhance agricultural production efficiency, achieving economic and environmental benefits (Bah et al., 2020; Wen et al., 2024). However, the application of GF in agriculture still faces numerous challenges. Scholtens (2017) suggested that the imbalance in financial resource allocation can hinder efforts to combat ANPSP. Factors such as capital scarcity, technological limitations, and the immaturity of financial products and services may inhibit farmers' adoption of ecological practices for soil and water conservation (Muthukannan et al., 2020; Spearing et al., 2022).

Overall, research on GF and ANPSP appears to be both systematic and comprehensive, yielding significant findings across various dimensions. Nonetheless, as investigations advance, certain limitations in existing studies have become evident. In response, this paper utilizes panel data from 30 mainland Chinese provinces between 2005 and 2021. It constructs a GF index employing the entropy value method and assesses emissions from seven categories of agricultural nonpoint source pollutants (agricultural fertilizers, livestock and poultry farming, aquaculture, crops, rural life, pesticides, and agricultural films (AF)) using the inventory method. Moreover, the paper performs empirical analyses of the pollution control and emission reduction impacts of GF by developing a mediation effect model.

The significant contributions of this study are threefold. First, it innovatively consolidates GF and ANPSP within a unified framework. This approach facilitates an in-depth examination of the influence of GF on ANPSP. It also delves into the role of government environmental regulation (ER) and the extent of land transfer in this dynamic. This integration not only sheds light on the interaction between these elements but also provides empirical evidence supporting the development of an optimized green financial system. Such a system is instrumental in enhancing pollution and carbon reduction efforts. Second, this study broadens the analytical scope of ANPSP by employing an extensive set of indicators, thereby offering a more systematic and thorough evaluation of its comprehensive impacts in China. Third, the research deepens our understanding of variations in both GF development and ANPSP. It investigates the differing dynamics between these two elements across various economic levels. Collectively, this study addresses existing gaps in the literature, furnishing more scientifically robust and comprehensive insights for enhancing the efficacy of GF in pollution control and emission reduction. Concurrently, it serves as a valuable reference for more effectively managing and preventing ANPSP.

3 Theoretical Analysis and Research Hypotheses

3.1 Direct Effect of GF on ANPSP

GF is a novel financial mechanism designed to support environmentally sustainable investments and projects (Fu et al., 2023), significantly impacting the prevalence of ANPSP. This influence manifests in several key ways. First, GF enhances the sustainability of agricultural production by reallocating resources, thereby addressing the environmental impacts of agriculture at its source. For example, green credit, a primary instrument of China's green finance, enforces strict environmental criteria for borrowers and underscores comprehensive credit assessments. This approach indirectly escalates financing costs for high-polluting and energy-intensive enterprises, thereby curbing their financial resources. Moreover, green credit restricts funding to such enterprises, explicitly bans support for prohibited or newly established projects, increases the risk of exit for high-polluting firms, sends market selection signals, and establishes barriers to entry for potential polluters. Additionally, GF supports the management of ANPSP through the promotion of technological advances. It encourages the adoption of eco-friendly agricultural technologies, such as soil testing, precision fertilization, the use of commercial organic fertilizers, and integrated water and fertilizer management systems. By fostering the research and development initiatives of enterprises, GF enhances the technological capabilities within the agricultural sector. This advancement leads to a transformation of farming operations into more large-scale, industrialized, and modern green agricultural practices, improving both the efficiency and quality of agricultural development, fostering sustainability, and alleviating the impacts of ANPSP. Based on these considerations, this paper proposes the following hypothesis:

Hypothesis 1 (H1): GF helps to curb ANPSP.

3.2 Mechanism Channel of GF to Reduce ANPSP

3.2.1 The Role of Government ER

Existing research suggests that although intensifying government ER may initially reduce resource utilization efficiency (Boyd & McClelland, 1999), it plays a pivotal role in enhancing the effectiveness of environmental pollution control (Bu et al., 2022). This influence is evident in two primary ways: first, ER imposes environmental taxes that escalate production costs in high-pollution sectors, effectively reducing their competitive advantage due to their limited capacity for short-term technological innovation. Conversely, sectors engaged in green agriculture benefit from inherent green competitive advantages, mitigating environmental costs through optimized resource allocation and accelerated technological progress (Czyżewski et al., 2020). Second, ER stimulates technological innovation and supports the green transformation of the agricultural industry. This dynamic enhances the quality of factor inputs, phases out obsolete production capacities, and fosters the emergence of technological leaders, promoting the diffusion of innovative agricultural technologies and advancing regional agricultural development. Based on these considerations, this paper proposes the following hypothesis:

Hypothesis 2 (H2): GF inhibits the development of ANPSP through ER.

3.2.2 The Role of Land Transfer

GF can significantly impact ANPSP through the mechanism of land transfer, operating across three dimensions: 1. Optimization of Land Resource Allocation. GF, supported by financial mechanisms, encourages agricultural stakeholders to adopt more efficient farming techniques, reducing the reliance on extensive land and decreasing the use of inefficient inputs such as chemical fertilizers and pesticides. This strategic optimization helps mitigate the negative externalities associated with traditional agricultural practices, thereby enhancing pollution control and emission reduction efforts. 2. Economic Incentives for Land Transfer. By offering economic incentives, GF encourages land transfers to agricultural producers who engage in sustainable practices. Enhanced financial terms such as lower financing costs and more favorable loan conditions support this transition, promoting environmentally friendly agricultural production (Zang et al., 2022). 3. Investment in Agri-Environmental Technologies. GF also encompasses investments in environmentally friendly agricultural technologies. This financial support enables producers to acquire advanced tools like conservation irrigation systems and eco-fertilizers, which further alleviate ecological pressures on the land. Based on these considerations, this paper proposes the following hypothesis:

Hypothesis 3 (H3): GF inhibits the development of ANPSP through the degree of land transfer.

Building on these premises, this paper develops a theoretical model to examine the impact of GF on ANPSP. Within this framework, GF is conceptualized as the “knowledge bandwagon,” with ANPSP as the outcome variable. The model incorporates ER and the mediating effect of land transfer to elucidate the underlying mechanisms, as depicted in Figure 1. This comprehensive analysis aims to provide a robust understanding of the pathways through which GF influences ANPSP, guiding policy formulation and strategic interventions in sustainable agricultural development.

4 Study Design and Data Source

4.1 Empirical Model

4.1.1 Benchmark Regression Model

This study conducts a preliminary test to evaluate the effectiveness of GF in promoting pollution control and emission reduction in ANPSP. The framework for the basic model is outlined as follows:

$$\text{ANPSP}_{it} = \alpha_1 + \beta_1 \text{GF}_{it} + \theta_1 \text{Controls}_{it} + \sigma_t + \nu_i + \varepsilon_{it}. \quad (1)$$

In equation (1), ANPSP_{it} denotes the level of ANPSP emissions, GF_{it} is the level of GF development; Controls_{it} is the set of control variables, σ_t is the time fixed effects,

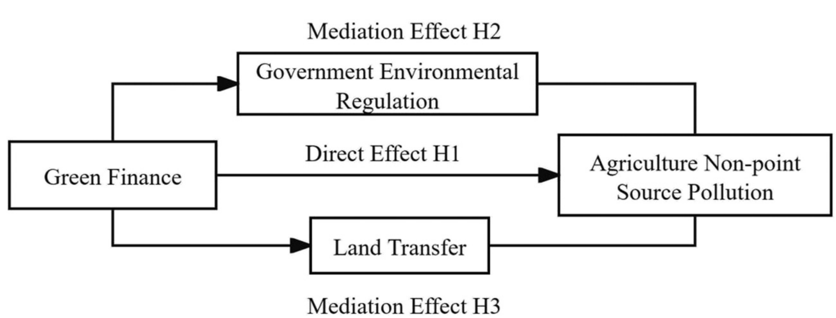

Figure 1: Theoretical analytical framework for the impact of GF on ANPSP.

v_i is the individual fixed effect, ε_{it} is random error term, subscript i denotes the provincial individual, and subscript t denotes the year.

4.1.2 Mediating Effects Modeling

Building upon prior analysis, it is posited that GF can influence ANPSP both directly and indirectly, through the promotion of ER and the facilitation of land transfer. This paper advances the basic model (1) to model (2), aiming to explore the mediating roles of ER and land transfer degree in the nexus between GF and ANPSP. The specific formulation of the model is presented as follows:

$$\mathrm{ANPSP}_{it} = \alpha_1 + \beta_1 \mathrm{GF}_{it} + \beta_2 \ln \mathrm{MED}_{it} + \theta_1 \mathrm{Controls}_{it} + \sigma_t + \varepsilon_{it}. \quad (2)$$

In equation (2), $\ln \mathrm{MED}_{it}$ is the mediating variable after taking logarithm, including two variables of ER and the degree of land transfer. The rest of the variables are the same as in equation (1).

4.2 Variable Selection

4.2.1 Explained Variable

Agricultural nonpoint source pollution: Different from pollutant emissions from the same point source pollution, ANPSP is mainly composed of soil and sediment particles, nutrients such as nitrogen and phosphorus, pesticides, and various atmospheric particles (Luo et al., 2023). It mainly enters the water, soil, or atmosphere through the way of surface runoff, soil erosion, and farmland drainage, thus causing environmental pollution. Chemical fertilizers, pesticides, agricultural plastic films, and diesel used in agricultural mechanization are the main sources of pollutants in agricultural production. It can be considered that yes, as long as there is the application of agricultural production factors such as fertilizers, pesticides, agricultural plastic films, and diesel, no matter whether it is overused or not absorbed by crops, it will directly become the direct source of water pollution, soil pollution, and other nonpoint source pollution characteristics under multiple effects of rainfall, sediment and irrigation. In this study, representative emissions of pollutants produced in the production and life of the agricultural sector were used as proxy variables to measure agricultural pollution. Agricultural production generates various forms of surface source pollution, predominantly consisting of TN, TP, COD, carbon emissions, and residues from pesticides and AF. This pollution impacts the soil environment directly and also reaches water bodies through a combination of precipitation, topography-driven runoff (both surface and subsurface), and plant interception (Sun et al., 2012). To measure agricultural pollution, this study employs the inventory analysis method based on unit surveys. This method encompasses pollution from both aquaculture and the use of pesticides and AF. It estimates ANPSP across seven dimensions: agricultural fertilizers, livestock and poultry farming, aquaculture, crops, rural population, pesticides, and agricultural plastic films. The index information of this study to measure ANPSP is shown in Table 1.

The emission intensity of ANPSP is calculated as:

$$\mathrm{ANPSP} = E_{\mathrm{TP}} + E_{\mathrm{TN}} + E_{\mathrm{COD}}, \quad (3)$$

$$E = \sum_{i}^{n} \mathrm{EU}_i \rho_i \theta_i. \quad (4)$$

In equation (3), TE is the total emission of ANPSP, E_{TP}, E_{TN}, and E_{COD} are the total emission of TN, TP and COD, respectively. In equation (4), the EU_i is the statistic of the pollution unit i, ρ_i is the pollution production coefficient of the pollution unit, and θ_i is the emission coefficient or loss rate. The pollution intensity of various units differs due to distinct influencing factors. For the calculation of emissions from ANPSP, the coefficients for the seven pollution units are utilized as follows:

Agricultural fertilizers: The primary pollutants from agricultural fertilizers include nitrogen, phosphorus, and compound fertilizers. This paper employs the output coefficient method to account for the variances in fertilizer loss rates due to different planting methods. Since the focus is on TN and TP pollution from fertilizer inputs, and the phosphorus fertilizer inputs in statistical yearbooks are indicated as phosphorus pentoxide (P_2O_5), these inputs are adjusted by multiplying them by 43.66%. Additionally, in line with recent domestic fertilizer practices and prior research findings, the compound fertilizer is converted to TN at 40% and P_2O_5 at 32%. The fertilizer loss coefficient is derived by averaging the results from different regional samples, based on existing studies (Wang et al., 2019). This specific accounting approach is in accordance with the methods used in the second national pollution source census.

Livestock and poultry farming: The pollution emissions are calculated as the product of the total quantity of livestock and poultry (in stock or slaughtered), multiplied by both the pollution discharge coefficient and the wastage coefficient. The discharge coefficients for feces and urine of livestock and poultry are sourced from SEPA data (2022). The formula applied is: Livestock and poultry pollution intensity (kg per head per annum) = Rearing cycle × Fecal (urine) emission factor × Fecal (urine) pollutant excretion coefficient. In this study, livestock and poultry statistics encompass cattle, sheep, and pigs. For cattle and sheep, which have a rearing period of more than 1 year, the total breeding amount is based on the year-end stock. For pigs, due to their rearing period of less than 1 year, the total breeding amount is determined by the current year's output.

Aquaculture: ANPSP primarily arises from bait residues, aquaculture excreta, and chemicals. The extent of this pollution is contingent on the aquaculture type and method. The China Statistical Yearbook classifies aquaculture production into marine and freshwater categories. Given that artificial aquaculture is a significant pollution contributor, this paper exclusively utilizes data from freshwater aquaculture for its analyses. The primary aquaculture species include freshwater fish, crustaceans, shellfish, and other aquatic organisms. The production and discharge coefficients for aquaculture are derived from the First National Pollution Source Census: Handbook of Production and Discharge Coefficients for Pollution Sources in Aquaculture, supplemented by additional literature (Feng et al., 2023).

Crops: The primary pollutants from crops include residues, vegetable wastes, and other debris from agricultural production (Norse, 2005). Given the diverse range of crops, this paper focuses on the seven most representative ones for analysis: rice, wheat, maize, beans, potatoes, oilseeds, and vegetables. The estimation of surface source pollution from agricultural solid waste involves calculating the crop residue yield based on the grass-to-grain ratio and determining the TN, TP, and COD content from the nutrient composition of the straw. Recognizing the varied straw utilization methods in rural areas, each with different nutrient loss rates, the final emission formula for farmland solid waste pollution is: Emissions (tons) = Total crop production (tons) × Production coefficient × Straw utilization structure × Straw nutrient loss rate, where the production coefficient equals the grass-to-grain ratio multiplied by the straw nutrient content (Ma et al., 2019).

Rural life: Pollution in rural life primarily comprises domestic sewage and human feces. The annual production coefficients per capita for COD, TN, and TP in domestic wastewater are 5.84 kg/person, 0.584 kg/person, and 0.146 kg/person, respectively, with an emission factor of 100%. For human feces, the corresponding coefficients are 19.8 kg/person, 3.06 kg/person, and 0.64 kg/person, respectively, with an emission factor of 10% (Luo et al., 2019).

Pesticides: Pesticide residues are calculated as the amount of pesticides applied multiplied by a residue factor of 0.5.

Table 1: Indicator set for ANPSP

Categories	Elements of pollution production	Survey indicators	Unit	Pollutants
Agricultural fertilizers	Nitrogen fertilizer, phosphorus fertilizer, compound fertilizer	Refractive index of application	10,000 tons	TN, TP
Livestock and poultry breeding	Pigs, cows, sheep	Inventory/output	10,000 heads	TN, TP, COD
Aquaculture	Freshwater fish, crustaceans, shellfish, and others	Total production	10,000 tons	TN, TP, COD
Farm crops	Rice, corn, wheat, beans, potatoes, oilseeds, vegetables	Total production	10,000 tons	TN, TP, COD
Rural life	Rural domestic sewage	Agricultural population	10,000 persons	TN, TP, COD
Pesticides	Pesticides	Utilization amount	10,000 tons	Pesticide loss
Agricultural plastic film	Agricultural plastic film	Utilization amount	10,000 tons	Agricultural plastic film loss

Agricultural film: The amount of AF residue is determined by multiplying the quantity of AF used by a residue factor of 0.1.

4.2.2 Explanatory Variable

Green finance: GF primarily aims to adhere to market economy principles while focusing on building an ecological civilization. It employs a range of financial tools, including credit, securities, insurance, and funds, to foster energy conservation, reduce consumption, and achieve a harmonious balance between economic resources and the environment. In the realm of existing literature, methodologies such as principal component analysis, the entropy value method, and hierarchical analysis are commonly used to determine the weights of GF development indicators. Following the approach of Li and Shao (2022), this paper develops indicators in seven domains: green credit, green investment, green insurance, green bonds, green support, green fund, and green rights and interests. These indicators are then integrated using the entropy method to formulate a GF index, which assesses the level of GF development. For this assessment, raw data is initially standardized, followed by the computation of the indicators. The detailed measurement methodology is presented in Table 2.

4.2.3 Mediator Variables

Environmental regulation: The selection of the ER variable follows the methodology of Chen et al. (2018). This approach utilizes the frequency of terms related to "environmental protection" in local government work reports compared to the total word count of the report as an indicator. A higher frequency indicates a stronger commitment to environmental governance, thus reflecting the intensity of ER and addressing endogeneity concerns. Relevant terms include ecology, green, low-carbon, pollution, energy consumption, emission reduction, sewage, sulfur dioxide, and carbon dioxide. As local government work reports are typically published early in the year, they predate and thus are not influenced by that year's environmental conditions, further mitigating endogeneity issues.

Land transfer: For the degree of land transfer (LT), this paper adopts the rate of agricultural land transfer (calculated as the total area of family-contracted arable land transferred divided by the total area of family-contracted arable land operated) as the proxy variable. This rate is an effective measure of agricultural land transfer levels and is widely used in inter-provincial level studies.

4.2.4 Control Variables

In alignment with existing literature (Abid et al., 2022), this study selects seven indicators as control variables: industrial structure (IS), economic development (ED), fixed investment (INV), research and development (R&D) intensity (RD), marketization level (MAR), human capital (HC), and openness to foreign trade (FT). The specific methodologies for these measures are detailed in Table 3.

4.3 Data Sources

To ensure data availability and continuity, this study utilizes panel data from 30 provinces, autonomous regions, and municipalities in China, excluding Tibet, Hong Kong, Macao, and Taiwan, for the period of 2005–2021 for empirical

Table 2: Comprehensive evaluation system of GF indicators

Name	Norm	Measurement
Green credit	Percentage of credits for environmental projects	Total credit for environmental projects in the province/total credit in the province
Green investment	Investment in environmental pollution control as % of gross domestic product (GDP)	Investment in environmental pollution control/GDP
Green insurance	Extent of promotion of environmental pollution liability insurance	Environmental pollution liability insurance income/total premium income
Green bonds	Extent of green bond development	Total green bond issuance/total all bond issuance
Green support	Percentage of fiscal expenditure on environmental protection	Financial environmental protection expenditures/financial general budget expenditures
Green fund	Percentage of green funds	Total market capitalization of green funds/total market capitalization of all funds
Green equity	Green equity development depth	Carbon trading, energy rights trading, emissions trading/total equity market transactions

Table 3: Control variable measurement procedure

Variable name	Measurement
Industrial structure	Value added of tertiary industry
Economic development	GDP per capita
Fixed investment level	Regional fixed investment volume
R&D intensity	Regional R&D expenditures
Level of marketization	Obtained from the Fan Gang China Marketization Index report
Human capital	Average years of schooling
Foreign trade	Total exports and imports of goods

analysis. The primary data sources include the CSMAR and Wind databases, the Green Patent Database of the China Research Data Service Platform, and various annual publications such as the China Statistical Yearbook, China Demographic Statistical Yearbook, China Science and Technology Statistical Yearbook, China Energy Statistical Yearbook, China Financial Yearbook, China Rural Statistical Yearbook, China Industrial Statistical Yearbook, and China Agricultural and Forestry Management Statistical Yearbook. To address any minor data gaps, linear interpolation was employed, and logarithmic transformations were applied to all variables to mitigate heteroskedasticity bias arising from data extremes. Descriptive statistics of the empirical data are presented in Table 4.

5 Empirical Results and Analysis

5.1 Result Analysis

This study used a two-way fixed effects model for multiple regression analysis, and the benchmark regression results are shown in Table 5. The analysis in column (1) of Table 5 shows that when control variables are not included, the estimated coefficient of GF on ANPSP is significantly negative at the 5% significance level. This emphasizes the significant inhibitory effect of GF on the development of ANPSP, thus verifying hypothesis H1 in this article. Subsequently, the test in column (2) of Table 5 showed that after incorporating control variables, the GF estimation coefficient on ANPSP remained at −0.446, with significance at the 5% level. The research results indicate that even after considering other influencing factors, GF still has a significant inhibitory effect on ANPSP. This article believes that there may be several reasons. First, GF policy is an important component of the policy system of strengthening agriculture, benefiting agriculture, and enriching agriculture. Effective capital investment and credit support are the primary focus of China's agricultural green development. Using financial policies to concretize ER measures, financing behavior can help solve environmental pollution problems, especially green credit can effectively compensate for market failures. Second, at the micro level, traditional farmers lack the enthusiasm to adopt environmentally friendly technologies. GF promotes the adoption of environmental protection technologies in agricultural production by providing financial support. It can not only increase crop yields, but also significantly reduce the excessive use of fertilizers and pesticides, thereby directly reducing the generation of ANPSP.

Table 4: Descriptive statistics of variables

Variable	Mean	Median	Standard deviation	Min	Max
ANPSP	−1.472	−1.270	0.785	−4.787	−0.135
GF	−1.939	−1.964	0.507	−3.121	−0.120
ER	9.776	9.791	0.199	8.533	10.715
LT	−1.789	−1.572	0.998	−4.301	−0.093
STR	0.009	−0.069	0.412	−0.694	1.667
GDP	9.261	9.142	0.487	8.091	10.781
INV	9.084	9.186	1.052	5.745	11.041
RD	14.345	14.365	1.496	9.677	17.505
MAR	2.005	2.031	0.259	1.212	2.517
LAO	2.180	2.181	0.114	1.853	2.548
FT	16.995	16.846	1.656	12.335	20.532

5.2 Results of the Mechanism Test

The traditional three-step approach to mediating effects is widely used in psychology research, yet its reliability in economic studies is questioned due to issues like endogeneity bias and unclear channel identification. Therefore, this paper adopts the research approach proposed by Liu

Table 5: Benchmark regression results

Variable	(1) ANPSP	(2) ANPSP	(3) ER	(4) LT
GF	−0.390**	−0.446**	−1.040*	0.406***
	(0.175)	(0.191)	(0.537)	(0.033)
Individual fixed effect	Yes	Yes	Yes	Yes
Time fixed effect	Yes	Yes	Yes	Yes
Control Variables	No	Yes	Yes	Yes
N	510	510	510	510

Note: ***, **, and * indicate significance at the 1, 5, and 10% levels, respectively. Standard error is reported in parentheses.

and Mao (2019) to examine the mechanism by assessing the impact of core independent variables on mediating variables. The theoretical mechanism section has already elucidated the effects of ER strength and the degree of land transfer on ANPSP, and the testing steps of these mechanisms are presented in Table 5, columns (3) and (4).

From columns (3) and (4) of Table 5, it can be observed that the regression coefficients of GF on ER and LT are −1.040 and 0.406, respectively, and have passed the significance tests at the 10 and 1% levels, respectively. This conclusion indicates that first, GF contributes to the implementation of stricter environmental regulatory measures. This may be because GF has increased the marginal benefits of environmental governance by increasing funding support, tilting the equilibrium point of maximizing total social welfare towards higher environmental quality. From the theoretical analysis in the previous text, it can be concluded that the strengthening of ER has a significant inhibitory effect on ANPSP. Therefore, GF enhances the ER strength, thereby reducing ANPSP. Second, with the increase of GF, the efficiency of land transfer and utilization has been improved. This may be because GF reduces the marginal cost of landowners changing land use by providing support such as credit, incentivizing landowners to use their land for environmentally friendly agricultural activities. From the theoretical analysis in the previous text, it can be concluded that the strengthening of LT has a significant inhibitory effect on ANPSP. Therefore, GF increased LT, thereby reducing ANPSP.

In general, ER and LT are important mechanism variables of GR affecting ANPSP. Strengthening ER can mitigate ANPSP, whereas an increase in the degree of land transfer may have an adverse effect. This analysis provides a deeper understanding of the impact mechanism of GF on ANPSP.

5.3 Robustness Test

To ensure the reliability of the empirical findings, this study employs three robustness testing methods. The first method is to change the measurement method and index system of ANPSP. According to the practice of the existing literature (Jiang et al., 2017), this study will use a simpler weight index and measurement system. The methodology follows the idea of drawing on the same weights used by the United Nations Human Development Index and the Economic Vulnerability Index to calculate the composite index. Specifically, the weights of the four production factors of CF, pesticide (PE), AF, and agricultural diesel oil (DO) were set at 0.25, and then the information on agricultural seeding area in different provinces was used to measure agricultural pollutant emission intensity. Compared with the inventory survey method, the advantage of this method is that it makes full use of the concept and generation mechanism of ANPSP, and weights the major nonpoint source pollution sources such as fertilizers, pesticides, agricultural plastic film, and DO. Therefore, it can avoid the interference of generalization indicators and fit the connotation and characteristics of ANPSP to the greatest extent. In terms of weight setting, the equal weighting of all nonpoint source pollution factors can ensure the consistency of all pollution sources in the overall dimension, which is conducive to describing the overall level law and revealing the general characteristics. The method of remeasuring ANPSP is shown in equation (5). The second approach is to eliminate the potential endogeneity of the regression equation using instrumental variables and performing a two-stage least square (2SLS) method. In economics-related research, thorough analysis and examination of the causal relationship between two variables is extremely important. Unlike correlations at the statistical level, economic research requires the elimination of measurement errors, reverse causality, and the threat of missing important variables in order to obtain a causal relationship between economic things. Based on the published literature (Liu et al., 2023), this study constructs an instrumental variable from the practical level. Specifically, it mainly takes advantage of the time lag term of GF. Lastly, additional control variables are introduced. Given the multitude of objective factors influencing ANPSP, controlling for the regional agricultural disaster rate through the ratio of affected crop area to sown crop area (Gao et al., 2015; Li and Wang, 2024).

$$\mathrm{ANPS} = (0.25 \times \mathrm{CF} + 0.25 \times \mathrm{PE} + 0.25 \times \mathrm{AF} + 0.25 \times \mathrm{DO}) / \mathrm{SA}. \tag{5}$$

The regression outcomes in Table 6 consistently demonstrate significantly negative coefficients of GF on ANPSP following these robustness tests, aligning with previous empirical findings. This underscores the robustness of the paper's conclusions across diverse model specifications and control variables, indicating high reliability. Specifically, model (5) reports that GF has a significantly negative effect on ANPSP, with a coefficient of −0.201 and at the 1% significance level, underscoring its robustness. The results in column (6) show that after the endogeneity was eliminated by the method of instrumental variables, the negative effects of GI on ANPSP still exist and are statistically significant. Finally, the results in column (7) show that after adding more external control variables, the regression coefficient of GF to ANPSP is still significantly negative. The results of all the above three methods show that the results of GF in the benchmark regression model can mitigate ANPSP are robust.

Table 6: Robustness test results

Variable	(5) Change the explained variable	(6) 2SLS	(7) Adding control variables
GF	−0.201*	−0.866***	−0.400**
	(0.047)	(0.128)	(0.190)
Individual fixed effect	Yes	Yes	Yes
Time fixed effect	Yes	Yes	Yes
Control variables	Yes	Yes	Yes
N	510	480	510

Note: *, ** and *** are significant at the levels of 10%, 5% and 1% respectively; Robust standard error is reported in parentheses.

5.4 Heterogeneity Analysis

5.4.1 Heterogeneity of Economic Development Level

To investigate whether regional economic disparities influence the effectiveness of GF in mitigating ANPSP, this study calculated the average per capita GDP across 30 provinces within the sample year. By comparing each province's total per capita GDP against the average value of 12078.75, the sample was divided into two groups: high and low economic development. The high economic development group consists of ten provinces: Beijing, Tianjin, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Hubei, Guangdong, and Chongqing. In contrast, the low-economic development group includes 20 provinces: Hebei, Liaoning, Anhui, Jiangxi, Henan, Hunan, Sichuan, Shaanxi, Shanxi, Inner Mongolia, Jilin, Heilongjiang, Guangxi, Hainan, Guizhou, Yunnan, Gansu, Qinghai, Ningxia, and Xinjiang. As shown in Table 7, a comparison of the estimated coefficients' magnitude and significance reveals that GF's impact on ANPSP is only pronounced in regions of low-economic development and is notably positive. In these areas, agricultural practices may rely more on outdated technologies and methods, which are typically less environmentally sustainable. Furthermore, these regions might lack efficient resource allocation mechanisms, leading to suboptimal use of GF for pollution reduction. Additionally, areas with lower economic development often have weaker ER and enforcement, posing challenges to effective implementation of environmental protection measures, even with GF support (Wang & Wang, 2023).

5.4.2 Heterogeneity Analysis of GF Policy Support

Considering the heterogeneity of GF standards, development levels, policy arrangements, and regulatory policies in the GF Reform and Innovation Pilot Zone, there are significant differences in the implementation effectiveness of GF. This study further explores the differential impact of GF on ANPSP across provinces within the policy framework of GF reform and innovation pilot zones. According to the Overall Plan for the Construction of Green Financial Reform and Innovation Pilot Zone jointly issued by seven ministries and commissions including the People's Bank of China in 2017 and the Overall Plan for the Construction of Green Financial Reform and Innovation Pilot Zone in Lanzhou New Area of Gansu Province approved by the State Council in 2019, 30 provinces are divided into green financial reform and innovation pilot zones and nongreen financial reform and innovation pilot zones, of which the provinces of green financial reform and innovation pilot zones include Zhejiang, Guangdong, Jiangxi, Guizhou, Xinjiang, Gansu, and Chongqing.

The regression results in Table 7 indicate that in policy-supported provinces, GF and ANPSP are negatively correlated, with a GF coefficient of −1.340, which is

Table 7: Results of heterogeneity test

Variable	Heterogeneity of economic development level		Heterogeneity of policy support	
	High-economy group	Low-economy group	Nonpolicy group	Policy group
GF	0.282	0.270*	−0.026	−1.340***
	(0.565)	(0.143)	(0.146)	(0.230)
Individual fixed effects	Yes	Yes	Yes	Yes
Time fixed effect	Yes	Yes	Yes	Yes
Control Variables	Yes	Yes	Yes	Yes
N	170	340	391	119

Note: * and *** are significant at the level of 10% and 1% respectively; Robust standard error is reported in parentheses.

significant at the 1% level. However, in nonpolicy-supported regions, GF and ANPSP are not significant. This indicates that GF policies have effectively promoted the improvement of environmental quality in policy-supported provinces, while the effect is not significant in nonpolicy-supported provinces. The possible reason is that in nonpolicy-supported areas, the incentive mechanism and policy support for GF are insufficient, resulting in low efficiency in financial resource allocation and thus failing to fully stimulate the enthusiasm of the market and enterprises to support green development.

6 Conclusions and Policy Implication

6.1 Conclusions

This paper examines the significant impact of GF on reducing industrial pollution and explores its direct effects and mechanisms on ANPSP at a theoretical level. Utilizing panel data from 30 Chinese provinces from 2005 to 2021, the study applies panel fixed effect and intermediary effect models to assess the impact and influence mechanisms of GF on agriculture pollution emissions from a multi-dimensional perspective. The key findings are: (1) GF notably suppresses ANPSP. (2) It achieves pollution control and emission reduction in ANPSP through ER and land transfer. (3) The heterogeneity analysis results indicate that in provinces with lower levels of economic development and regions with GF reform measures, the role of GF is significant.

6.2 Policy Implication

Strengthening GF in rural areas: To maximize the impact of GF on addressing ANPSP, it is imperative to clearly define the strategic direction and functional roles of financial institutions in supporting rural ecological civilization. This involves enhancing the provision of green credit by small and medium-sized banks, expanding the scope of financial subsidies, and increasing incentives for investments in GF, particularly in areas of taxation and technological innovation. These measures aim to effectively curb the financial constraints associated with managing ANPSP. Additionally, optimizing the policy framework for the growth of agriculture-related GF is essential. This includes offering preferential treatment to green credit products and prioritizing compensation rights for green bonds and other financial instruments. Furthermore, the development and reinforcement of legal and regulatory measures to address financial, credit, and moral risks in rural enterprises are crucial. These measures are intended to mitigate the risks of sunk and opportunity costs arising from ineffective agricultural green financial instruments.

Harmonizing GF and ER Policies: Creating synergies between GF policies and ER is vital for effectively tackling ANPSP. First, governments and regulatory bodies should establish and enforce transparent, equitable ER, including the implementation of environmental administrative agreements. These agreements should recognize the equal standing of governments and entities responsible for ANPSP, ensuring clear communication during negotiations to balance economic and environmental benefits. Second, enhancing environmental support through initial lenient ER policies encourages innovation that improves the efficiency of ANPSP control. Specific measures include offering subsidies, loans, or other financial aid for technological upgrades and industrial transformation to meet new environmental standards. Lastly, financial institutions must innovate green financial products and services in line with the requirements of ER.

Optimizing land transfer policies: To encourage farmer participation in land transfer and facilitate large-scale agricultural land management, government departments must enhance the rural land transfer system and environment. This includes refining the mechanism to incentivize practices that reduce ANPSP, implementing and improving the "three-rights partition" system of agricultural land, and establishing an efficient and reliable platform for agricultural land transfer and trading. A focus should be placed on ensuring an orderly transfer of agricultural land through a standardized process and effective legal frameworks. Additionally, increasing awareness and trust among farmers in land transfer policies through enhanced public outreach is crucial.

Adjust policies to address regional economic and policy heterogeneity: By tailoring policies according to the different economic and policy environments in each region, GF's effectiveness in managing ANPSP can be significantly improved. GF has shown a significant impact in areas with lower levels of economic development, and efforts should be focused on strengthening local financial infrastructure. This approach includes enhancing the ability of local financial institutions to provide green credit and utilizing tax incentives to promote investment in sustainable agricultural practices. At the same time, in areas lacking specific policy support, the relationship between GF and ANPSP is not as significant as in policy-supported regions, and the guiding role of policies should be enhanced by increasing policy transparency and setting specific policy objectives. By establishing a special fund to support green development in nonpolicy-supported areas. Encourage public–private partnership models to enable governments, financial institutions, and nongovernmental organizations to jointly participate in the funding support and implementation of green projects.

6.3 Research Limitations and Future Prospects

There are still some limitations in this paper, and these limitations are the direction of future research: first, at the level of data selection, due to the availability of data, this paper only selects data at the provincial level in China. In the future, the study could be further refined to the prefecture level for further research. Second, in the calculation of indicators, although the calculation of indicators of agricultural surface pollution in this paper uses the list method to select more than 10 kinds of indicators for comprehensive measurement, the factors affecting agricultural surface pollution also cover other factors such as climate and water source. Future research can use SWAT, ANSWERS, and other hydrological models for combined analysis. Third, this paper does not assess how the effectiveness of GF and pollution control policies might vary across different political systems. Given the distinct governance structures, regulatory practices, and financial systems worldwide, the methods and conclusions drawn from the Chinese context may not be universally applicable. Future research should therefore compare the impact of GF on ANPSP in various political environments to identify both global strategies and localized solutions.

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