Pol. J. Environ. Stud. Vol. XX, No. X (XXXX), 1-19
DOI: 10.15244/pjoes/187137 ONLINE PUBLICATION DATE:

Original Research

The Effects of Environmental Regulation on Environmental Equity: Evidence from China

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Received: 5 February 2024
Accepted: 13 April 2024

Abstract

Sustainable development plays a decisive role in achieving the Chinese government's goal of "carbon peaking and carbon neutrality". Taking panel data from 31 provinces in China from 2003-2021, we constructed a fixed-effects econometric model to study the effect of environmental regulation (ER) on environmental equity (EE). The link between ER and EE was explored. The results show that the ER indeed has a beneficial effect on EE and exhibits significant regional and individual characteristics heterogeneity. Particularly, the effect of ER on EE is stronger in Chinese eastern and middle regions and in provinces with lower incomes, higher tax costs, and higher innovation levels. In addition, mechanism analysis reveals that the favorable effect of ER on EE is affected in three ways: government greening services, energy industrial investment, and public environmental attention. Finally, our findings provide an important decision-making reference for advancing the development of ecological civilization and implementing the new development philosophy of a green economy.

Keywords: environmental regulation, environmental equity, environmental pollution, SO_2 emissions, fixed effects model

Introduction

"Reducing inequalities" is one of the 17 sustainable development goals set by the United Nations 2030 Agenda for Sustainable Development. As a part of social equity, environmental equity (EE) is not only the key to maintaining social harmony and stability, but also a prerequisite for building an eco-civilized society and a decisive condition for achieving sustainable development.

EE is a concept that every individual in the same area bears fair environmental risks and enjoys environmental benefits [1]. According to data released by the WHO in 2022, 99% of the world's population breathes unhealthy air, which is caused primarily by the burning of fossil fuels. Specifically, people living in nations with low or middle incomes are more vulnerable to air pollution and poor air quality. In most developing countries, air pollution imposes a huge burden on social development, health, and the economy [2]. For instance, China's rapid economic growth has resulted in a variety of environmental and social costs [3], especially

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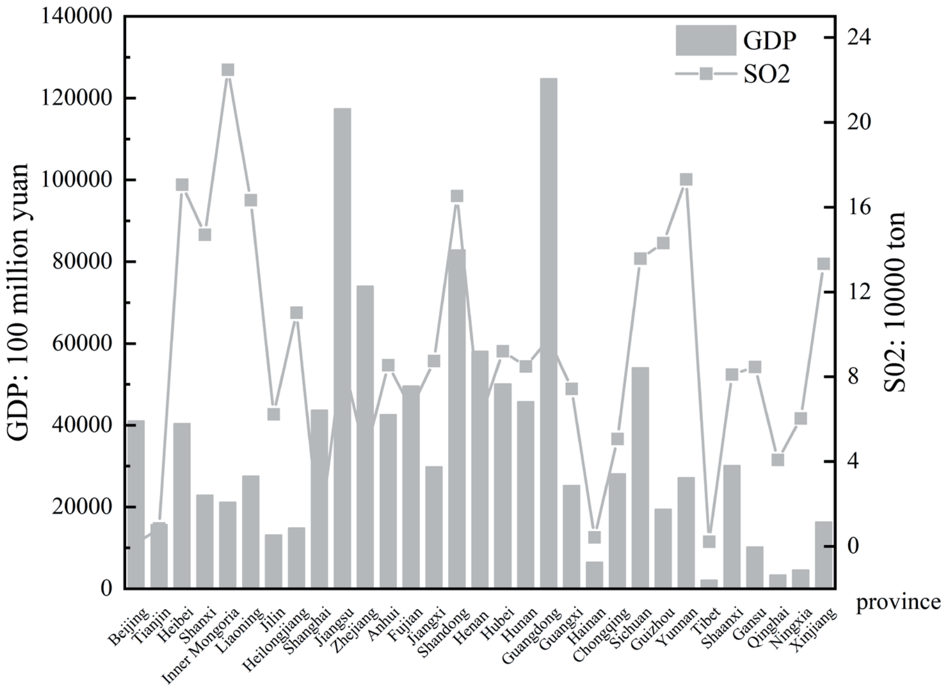

Fig. 1. GDP and SO_2 emissions by the province in China in 2021.

the environmental pollution problems caused by the excessive emissions of CO_2, SO_2, and fine particulate matter [4].

As shown in Fig. 1, in 2021, the SO_2 emissions in the middle and western provinces of China (e.g., Inner Mongolia, Shanxi, etc.) are much more than those in the eastern provinces (e.g., Jiangsu, Zhejiang, etc.). In contrast, the GDP situation is the opposite. In particular, the emissions of Inner Mongolia, the highest SO_2 emissions province, are over 160 times that of Beijing, but its GDP is only about half of Beijing. This manifests clearly that regional economic and environmental inequality within China is extremely serious [5-7]. This severe economy-ecology imbalance has not only caused regional environmental and welfare inequality, but also deviated from the Chinese government's sustainable development doctrine, which holds that "Lucid Waters and Lush Mountains Are Invaluable Assets" [8]. Furthermore, that poses a serious risk to social stability and environmental security at home and greatly hinders China's excellent economic transformation and progress [9].

Thus, the risk of air pollution exposure varies widely across countries and populations, and environmental inequality is becoming a widespread occurrence globally. [10], whereby the most disadvantaged regions or groups tend to bear the greatest proportion of environmental pollution risk [11]. This not only widens the gap in health costs across regions and populations, but can also trigger social unrest, disrupt social order [12-14], and stunt economic growth [15]. As a basic human right, clean air is not only necessary for the health and productivity of society, but also a "fueling station" for tens of thousands of lives. Therefore, we are going to examine the environmental inequity caused by air pollution, which is of great relevance for building an economy and society focused on human well-being.

ER (ER), the most straightforward and effective means to resolve environmental pollution problems [16, 17], produces ecological impact directly and economic effect indirectly [18], which has an inestimable role in promoting the coordinated development of ecological civilization and economic growth and building a welfare society of EE. However, few studies have put ER and EE together. Therefore, our paper will start from the perspective of ER to study EE in China. The study covers three main areas: firstly, from the overall macroscopic perspective, exploring the causal relationship between ER and EE; secondly, examining the heterogeneities in the effect of ER on EE; and thirdly, identifying the specific paths through which ER affects EE.

Our research contributes to several strains of the literature. First, from the perspective of ER, we provide a more comprehensive examination of its effects on EE and offer a new thought for improving EE. Second, by the heterogeneity analysis and the mechanism testing, we comprehend the directions of avoiding environmental inequity and the ways of improving EE. That offers the Chinese government more detailed policy-making guidance. Third, the in-depth study of EE in China will not only provide useful references for the majority of developing countries, but also contribute to Chinese solutions to improve global welfare.

Fig. 2 illustrates the research framework of our paper. The rest of this paper is organized as follows: Section 2 is the theoretical analysis and research hypothesis. In

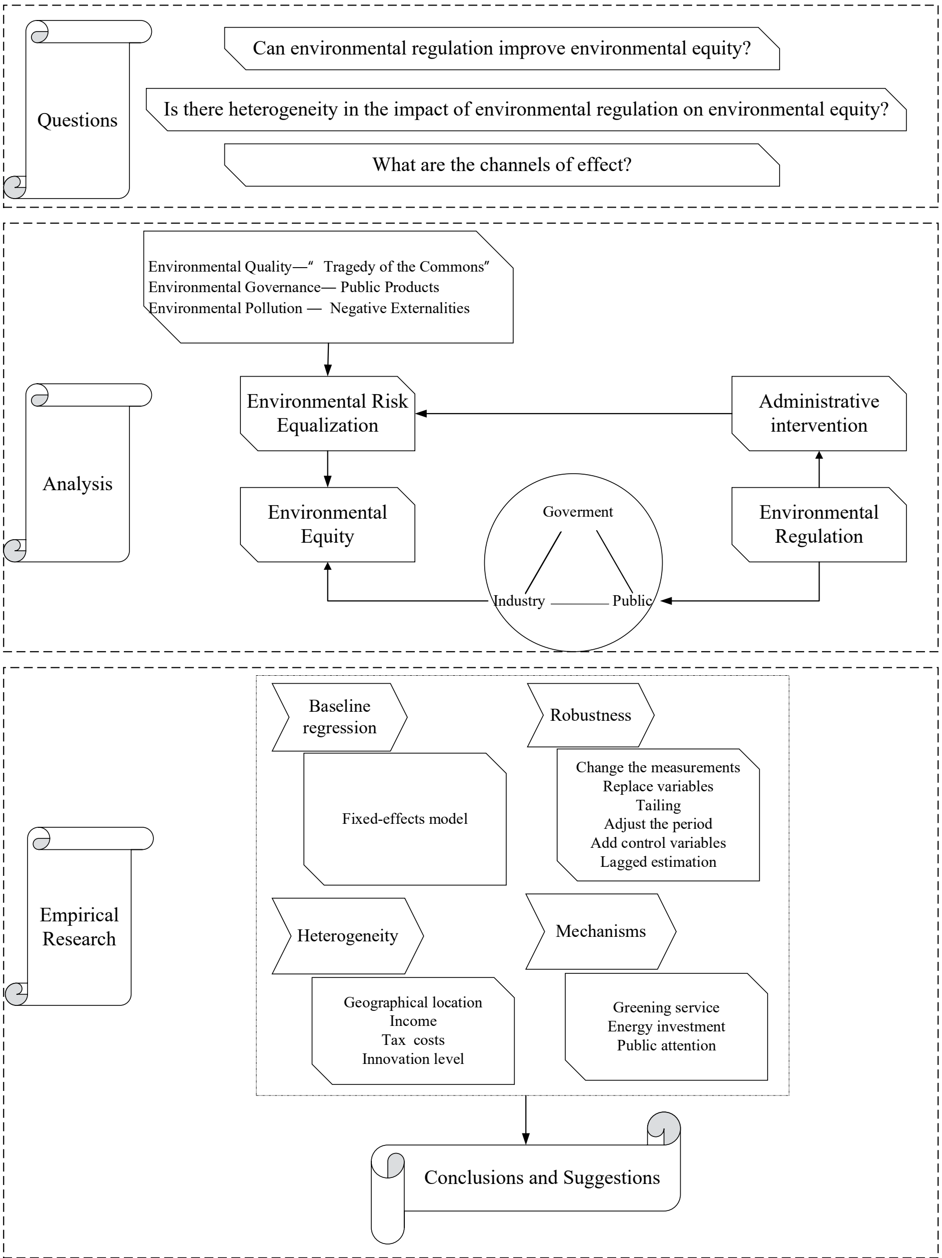

Fig. 2. Research framework diagram.

Section 3, the empirical model is constructed and the data are described. In Section 4, the principal empirical findings are presented. Section 5 tests the impact mechanism. The last section concludes and makes recommendations.

Review and Hypotheses

ER, the primary means of controlling environmental pollution and improving air quality, is inherently linked to EE. However, previous studies have not systematically examined the two in the same framework. In light of this, the purpose of this work is to elucidate the effects of ER on EE and to identify the heterogeneity and mechanisms of its effects.

Baseline Hypotheses

According to the claim of welfare economics, "the more equal the distribution, the greater the social welfare", which is also suitable for the concept of environmental equity. Specifically, the more equal the distribution of environmental benefits or risks, the greater the ecological welfare of the whole society (under the premise that environmental pollution has significantly reduced). That is crucial for promoting sustainable development and striking a balance between social, economic, and environmental advancement. On the one hand, public resources, such as air, are not sufficiently protected by the market, but rather give rise to the phenomenon of "tragedy of the commons" due to the motivation of economic benefits. On the other hand,

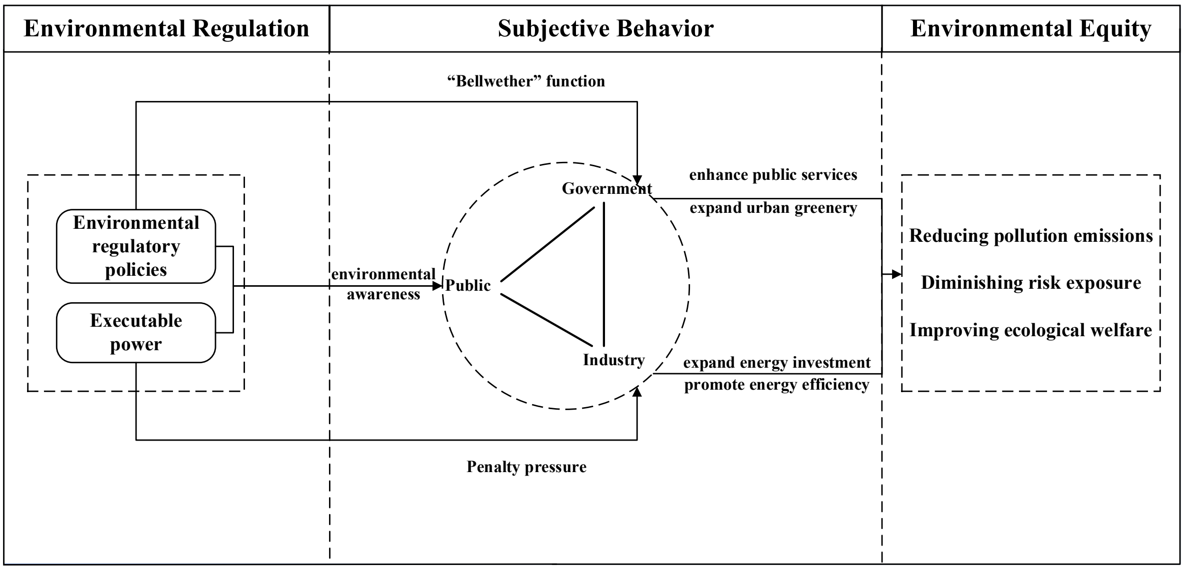

Fig. 3. Logical mechanism.

the public goods character of environmental governance and the negative externality of environmental pollution will lead to market failure, and it is unrealistic to rely on market mechanisms alone to improve EE.

First and foremost, environmental pollution in China mainly comes from industrial pollution, including industrial waste gas (SO_2, PM2.5, and so on), industrial wastewater, and industrial smoke and dust. The adverse effects of SO2 on the urban environment have long been overlooked by the public and government, who have placed too much attention on fine particle pollution. This has indirectly contributed to China's ongoing environmental pollution problem and led to the unreasonable deployment of instruments for environmental pollution prevention and control. This, coupled with the differences in the level of economic development and public demand for environmental protection, has led to increasing disparities in environmental pollution across the country, exacerbating the problem of environmental inequality in China. Besides, the primary target of ER is industrial pollution, which has an immediate effect on limiting corporate emissions, especially in reducing pollutants like SO_2 and industrial wastewater. That will not only improve the quality of the ecological environment, but also enhance eco-efficiency [19], which has a positive effect on promoting environmental equity. This is in line with the findings of Zhang et al. (2021), who contend that local environmental policies can significantly promote EE by reducing regional disparities in environmental pollution. We put out the following first hypothesis in light of the study above:

Hypothesis 1: ER can curb industrial pollution emissions and reduce regional differences in pollutant emissions and exposure, thereby improving EE.

Mechanisms Hypothesis

In terms of environmental governance, the government is generally responsible for formulating and implementing environmental policies, industrial sector enterprises are the emitters of pollution and the objects of restraint, and the public is the expressers and supervisors of environmental demands. The efficiency of environmental governance and EE will unavoidably be impacted by the behavioral decisions of the public, industries, and government, the three subjects of ER.

It has been proven that ER can act directly to reduce pollution and emissions while indirectly influencing environmental quality in different ways, like affecting urban ecological welfare [20], industry investment [21], and public environmental attention [22]. That contributes to improving EE. Fig. 3 is the mechanism diagram.

Government Greening Services

Environmental inequity arises because people do not face the same environmental risks or gain the same environmental benefits in their daily lives. The government can improve environmental inequity by increasing the environmental welfare of the people [23]. In reality, the environmental welfare that people feel most deeply and directly is undoubtedly urban greening, which happens to be one of the government's public services.

The area of green land is not only an important manifestation of improving the sustainability of cities and the environmental welfare of the population [24], but also one of the main solutions to air pollution and plays a non-negligible role in air purification and climate regulation [25]. Therefore, when the green area is increased, the photosynthesis of plants can largely reduce environmental pollution and improve air quality, thus reducing the environmental risks faced by people and improving regional EE. In addition to environmental benefits, the area of urban green land can also generate good socioeconomic as well as health benefits [26-28]. Firstly, they can reduce the negative effects of life stress and environmental pollution on people. Secondly, the living environment of greening can also have a positive impact on people's physical and mental well-being [29]. When ER is strengthened, it means that the government's focus is biased towards environmental governance. By increasing the area of greening in the region, the government can enhance the ecological purification capacity, reduce air pollution and environmental risks, and improve the environmental interests of the residents, that is EE. This paper argues that the government can reduce environmental pollution and the environmental risks faced by the population by improving greening services and then playing a role in improving EE.

Energy Industry Investment

The "compliance cost" and "innovation compensation" hypotheses state that ER adds to a company's short-term cost burden [30]. However, over time, ER promotes the technological progress of clean production in industrial enterprises, allowing them to receive a series of benefits, such as improved product quality, lower production costs, and enhanced market competitiveness. Thus compensating for the previous additional cost caused by acting up to the orders of ER [31].

The primary target of ER is the energy sector, because it uses large amounts of fossil energy and emits many harmful gases such as SO_2 and PM2.5, especially in heavy industries. Therefore, under the pressure of ER, companies in the energy industry will inevitably need to make changes, which will lead to certain cost increases. In order to avoid the environmental protection cost brought by ER, industrial enterprises may enhance investment to improve the level of industrial technology production or adopt more energy-efficient and advanced production equipment. This strategic approach aims to achieve the objectives of energy conservation and emission reduction. In energy-polluting enterprises, end-of-pipe treatment and source control are the two most commonly used methods [32, 33]. For one thing, the end-of-pipe treatment is that enterprises replace cleaner production equipment so as to reduce environmental costs. Although the initial investment will bring about an increase in costs, this problem will be effectively solved by its immediate environmental effects and permanent technological effects [34]. For another thing, by source control, industrial enterprises have the potential to simultaneously decrease pollution levels and enhance operational efficiency. This may be achieved through the advancement of product technology and the reduction of energy intensity [35-37]. Reducing fossil energy consumption and elevating energy utilization efficiency, in the prerequisite of ensuring constant output, can save environmental costs, enhance corporate competitiveness, and promote green production transformation [38, 39]. So, this study argues that the penalty effect and cost pressure of ER will motivate industrial enterprises to make decisions to expand investment for replacing clean equipment or improving production efficiency before promoting the green upgrading of production processes and reducing pollution emissions. That will lead to positive results of narrowing regional differences in emissions, improving environmental quality, reducing environmental risks [40, 41], and ultimately impacting EE.

Public Environmental Attention

With an increasing number of air pollutants, the public's attention to pollution and the demand for refreshing air quality have evidently risen to the surface [42, 43]. The augment of residents' material living conditions is accompanied by an increase in environmental health risks. Air pollution, such as haze, can directly affect people's health [44]. A large amount of fine respirable particles will give rise to many diseases, like respiratory tract infections, asthma, and chronic blockage of the pulmonary. That adds to the odds of falling ill and the burden of health treatment costs [45-47]. In order to defend environmental rights, a growing number of people are expressing their concentrations about air pollution and demanding to optimize air quality via the Internet and the new media [48]. Through the media network, the rapid spread of pollution even makes more people pay attention to the current environmental problems. Consequently, this has generated public opinion pressure, compelling the government to prioritize environmental governance, strengthen the implementation of environmental policies, urge the industrial sector to reduce pollution emissions, and facilitate the transition towards green production [49]. Therefore, our study argues that the rise in public environmental attention can bolster the successful execution of ER by local authorities while compelling polluting enterprises to actively mitigate pollution and emissions. Thus, the rising of people’s attention to the environment will have the result of improving environmental quality, reducing the risk of pollution exposure, and inhibiting the deepening of environmental inequity.

According to the analysis provided above, we put forward the second hypothesis as follows:

Hypothesis 2: ER can improve EE by influencing government greening services, energy industry investment, and public environmental attention.

Material and Methods

Variable Material

Dependent Variable: EE (Equity)

The main components of air pollution include sulfur dioxide (SO_2), solid particulate matter (PM2.5 and PM10), nitrogen oxides (NO_x), etc. SO_2, the most common and irritating sulfur oxide, is one of the regular indicators for measuring urban environmental quality. However, compared with fine particle pollutants, people have long paid less attention to SO_2, which may lead to bias in pollution control and prevention and thus leave the environmental problem unresolved effectively. In addition, SO_2 also has adverse effects on the physical and mental fitness of residents. It has long been listed as a key target for environmental pollution management. Since 2000, due to SO_2 emissions, the annual loss of life in China has been around 180,000, and the related treatment costs exceed 300 billion yuan per year. In 2021, SO_2 emissions in China still reached 2747,810 tons. Among them, the emissions from industrial are 2.532 million tons, accounting for nearly 80% (data source: Ministry of Ecology and Environment of China).

Therefore, we utilize the industrial SO_2 emissions from prefecture-level cities in China to calculate the provincial environmental Gini coefficients, which are used to represent EE. Besides, due to the fact that Beijing, Tianjin, Shanghai, and Chongqing are municipalities that fall directly under the jurisdiction of the central government, as well as Tibet, Qinghai, and other prefecture-level cities, industrial SO_2 data are missing, thus the surface SO_2 mass concentration is used instead.

Independent Variable: ER (Envreg)

For ER, most scholars commonly refer to variables such as the pollution treatment investment as a percentage of GDP, the amount of investment in industrial pollution treatment, the amount of investment in industrial pollution treatment as a percentage of total industrial output value, and so on [50].

Whether it is a single indicator or a composite indicator, it involves the completion of investment in industrial pollution treatment, which can not only directly reflect the efforts and costs of local governments in industrial pollution control, but also reflect the efforts and determination of the government in environmental governance. There is a widely held belief that increasing the investment in industrial pollution treatment is more likely to facilitate the role of ER. This is attributed to the availability of sufficient funds for environmental protection, which can be allocated towards the acquisition of advanced pollution treatment equipment and technology. That can effectively alleviate environmental pollution issues, reduce environmental exposure risk, and improve EE. Moreover, the use of a single indicator can also avoid some of the irrationality of composite indicators; therefore, this paper adopts the "real completed investment of industrial pollution treatment" to measure ER, and its price deflator and logarithmic processing.

Control Variables

Environmental inequality is not intentionally caused by a single act, but is the result of the interaction of many factors [51]. Therefore, referring to previous research [52-54], industrial structure, o**pening up**, educational input, consumption level, urbanization rate,

Table 1. Variable descriptions.

Variables	Indicators	Variable Description
Dependent variable	Equity	Gini SO_2
Independent variable	Envreg	Real completed investment in industrial pollution treatment (100 million yuan), taking logarithmic forms
Control variables	Structu	Value-added of the tertiary industry / Value-added of the secondary industry (%)
	Openup	The investment of foreign-invested enterprises / GDP (%)
	Educat	The financial expenditure on education / the general budget of local finance (%)
	Consum	Real consumption expenditure per capita (yuan), taking logarithmic forms
	Urban	Urban resident population / resident population at year-end (%)
	Service	Public toilet seats / resident population at year-end, taking logarithmic forms
	Econom	Real GDP (100 million yuan), taking logarithmic forms
	Securit	The social security and employment expenditures / the general budgets of local finance (%)

Table 2. Descriptive statistics of main variables.

Variable	N	mean	p50	sd	min	max
Equity	589	0.3329	0.3251	0.1390	0.0549	0.6650
Envreg	589	2.3104	2.5276	1.4997	-3.2442	5.2841
Structu	589	1.1006	0.9148	0.5914	0.5408	4.1653
Openup	589	0.0044	0.0024	0.0051	0.0006	0.0373
Educat	589	0.1600	0.1624	0.0263	0.1035	0.2122
Consum	589	8.9957	8.9738	0.2610	8.5346	9.6814
Urbaniz	589	0.5290	0.5242	0.1499	0.2192	0.8927
Service	589	-0.1139	-0.1000	0.6176	-2.1643	1.3578
Econom	589	8.9989	9.1690	1.1244	5.8228	11.1235
Securit	589	0.1188	0.1229	0.0436	0.0187	0.2549

public service, economic development level, and social security are selected as control variables, as shown in Table 1.

Data Sources

The data samples are panel data from 2003-2021. The volume of industrial SO_2 emissions of prefecture-level cities was used to calculate the dependent variable EE. the rest of the provincial panel. All data are obtained from *CEIC*, *CSMAR* Dataset, and China Statistical Yearbook. Except for the ratio variables, the other variables were logarithmized, and the variables involving values were deflated. In addition, we use linear interpolation and moving averages to make up for missing values.

Methods

For the purpose of investigating the causal impact of ER on EE, we specify the following econometric estimation model:

$$Equity_{it} = \beta_0 + \beta_1 Envreg_{it} + CX_{it} + \delta_t + \theta_p + \varepsilon_{it} \tag{1}$$

Where i and t denote respectively province and year; $Equity_{it}$ is the dependent variable, denoting provincial Gini SO_2, based on the industrial SO_2 emissions of prefecture-level cities; $Envreg_{it}$ is the independent variable, denoting the ER of the province, measured by the real completed investment of industrial pollution treatment (100 million yuan), taking logarithmic forms; X_{it} denotes the set of control variables. δ_t denotes the regional fixed effect, θ_p denotes the year fixed effect; ε_{it} is the random disturbance term. The descriptive statistics of specific variables are described in Table 2.

Results and Discussion

Baseline Regression

This paper conducts estimation based on the full sample to examine the effect of ER on environmental equity, and the results of the baseline regression align with the anticipated outcomes outlined in this study. Table 3 displays the regression results. The findings of the fixed effects model are analyzed and deliberated below.

Columns (1) ~ (5) of Table 3 display the stepwise regression results. It can be seen that the coefficients of Envreg are all negative, significant at least 5% level. Corroborating Hypothesis 1, this result indicates that there is indeed a distinct improvement effect of ER on EE.

As the column (5) shows, the estimated coefficient of Envreg is -0.4887 at the 1% significance level. The estimated coefficient indicates that with the strengthening of ER, EE in China has improved significantly, i.e., environmental inequality has gradually declined. With a 1% rise in ER leads to a drop of around 4.9% in environmental inequality.

As for the control variables, the estimated coefficient of Structu is -0.0305 at the 5% significance level. This demonstrates that with the transformation and upgrading of industrial structure and the declining share of secondary industry, the problem of environmental inequality will be alleviated to some extent. With a 1% improvement in Structu, environmental inequality declines by about 3.1%. The estimated coefficient of Openup is -2.2594 at the 5% significance level, indicating that the degree of openness to foreign will have a binding effect on the pollution emissions of enterprises. The "halo effect" of opening up to the world not only fosters the economic growth of the region, but also brings advanced production technology. This might potentially have a beneficial impact on energy conservation and the reduction of emissions for enterprises. In addition,

Table 3. Baseline regression results.

	(1)	(2)	(3)	(4)	(5)
Envreg	-0.0932**	-0.1232**	-0.1313**	-0.1292**	-0.4887***
	(0.0454)	(0.0528)	(0.0528)	(0.0554)	(0.1103)
Structu		-0.0071	-0.0132	-0.0157	-0.0305**
		(0.0144)	(0.0145)	(0.0145)	(0.0149)
Openup		-2.9905***	-2.6919***	-2.4139**	-2.2594**
		(0.9558)	(0.9593)	(0.9593)	(0.9516)
Educat			0.2226	0.2836	0.2420
			(0.2765)	(0.2801)	(0.2777)
Consum			-0.4141**	-0.3625**	-0.4424***
			(0.1625)	(0.1633)	(0.1635)
Urbaniz				0.1521**	0.0796
				(0.0643)	(0.0670)
Service				-0.0168	-0.0104
				(0.0109)	(0.0109)
Econom					0.3252***
					(0.0895)
Securit					-0.2623
					(0.1801)
_cons	0.4863***	0.5479***	4.1492***	3.6219**	2.2546
	(0.0617)	(0.0792)	(1.4319)	(1.4437)	(1.5191)
Province-Fix	Y	Y	Y	Y	Y
Year-Fix	Y	Y	Y	Y	Y
N	589	589	589	589	589
R^2	0.0871	0.1044	0.1172	0.1300	0.1542

Note: ***, **, and* indicate 1%, 5%, and 10% significance levels, respectively; t-values in parentheses.

to build a good international image in international trade, China will naturally try to improve the green contributions of its products. This also contributes to the reduction of environmental inequality. With a 1% increase in Openup, environmental inequality declines by about 230%. The estimated coefficient of Consum is -0.4424 at the 1% significance level, indicating that as the level of consumption increases, people's ability to resist risk increases, and thus they are better able to cope with the inequality caused by environmental pollution. In addition, people's concepts of green consumption are also being strengthened, which in turn improves environmental inequality. A 1% increase in Consum, environmental inequality declines by about 44.2%.

The estimated coefficient of Econom is 0.3252 at the 1% significance level, indicating that the disparities in economic development between regions can increase environmental inequality. The extensive development mode can rapidly promote economic development, but at the same time, it will bring a series of environmental pollution costs, which is also in line with the development of China in recent decades. The excessive consumption of energy resources, on the one hand, led to the rapid development of the economy. On the other hand, it has also caused a large amount of environmental pollution, and the ecological pressure has soared, which in turn aggravates environmental inequality. A 1% increase in Econom, EE declines by about 32.5%.

The estimated coefficients on the rest of the control variables are not significant. Specifically, the estimated coefficient of Educat is 0.2420, but it is not significant. The more education is invested, the higher the proportion of education in local fiscal expenditures becomes, which may crowd out government expenditures on environmental governance, thus weakening environmental protection and ultimately leading to environmental inequality. This effect is not significant and may be due to the direct relationship between education and the environment, which is not so obvious. The estimated coefficient of Urbaniz is 0.0796, but not significant. An increase in the rate of urbanization, on the one hand, increases population concentration and, on the other hand, contributes to an increase in the consumption of various types of energy. This significantly increases the probability of people being exposed to the risk of environmental pollution, thus reducing environmental equity. However, there are also many beneficial aspects of urbanization, which in turn counteracts the tendency to increase environmental inequality and so leads to a non-significant coefficient for Urbaniz. The estimated coefficient of Service is -0.0104, but not significant. The improvement of government public services has a clear beneficial effect on social equity and people's sense of well-being. The higher the level of public services, the more social welfare people enjoy. EE, as a kind of social welfare, is obviously positively affected by public services. However, since public services focus more on safeguarding and facilitating the basic material living conditions of the population, its effect on improving EE is not obvious. The estimated coefficient of Securit is -0.2623, but not significant. EE is part of social equity, and social security undoubtedly promotes social equity and naturally has a positive effect on enhancing EE. The fact that social protection covers such a wide range of social and livelihood aspects, rather than just environmental governance alone, has resulted in this impact not being significant.

Robustness Tests

To ensure the robustness of the above consequence, a sequence of robustness tests was conducted: instrumental variables, replacing the dependent and independent variables, ending processing, changing the time interval, and adding control variables. The details are as follows:

Instrumental Variable

In this study, we take the real completed investment of industrial pollution treatment as a quantitative indicator of ER rather than constructing a quasi-natural experiment based on a specific environmental policy. The Gini coefficient of SO_2 emissions as a quantitative indicator of EE. The potential correlation between the two indicators is one of the main reasons for the endogeneity problem. The amount of completed investment in industrial pollution treatment reflects the government's attitude and determination toward environmental governance. That will certainly influence the enterprises' emission behavior. Similarly, the deterioration of environmental quality due to excessive emissions of industrial enterprises will also draw the government's great attention, thus forcing the government to focus more on environmental protection. The possibility of a causal relationship between the two is extremely high, which may lead to biased baseline regression results.

The instrumental variables method is one of the main solutions to the endogeneity problem. It has the ability to efficiently address the estimation bias resulting from endogeneity. The selection of instrumental variables is based on two conditions. One is “correlation”, and the other is “exogeneity” [55]. Draw on previous research methods [56]. We choose the quantity of domestic garbage collected and transported (Garbage,100,000 tons) and the area of road sweeping and cleaning (Scroad, 10,000 m^2) as instrumental variables 1 and 2, and use the two-stage least squares method (2SLS) to test endogeneity and run regression again. Based on the above, Garbage and Scroad can effectively reflect the intensity of local ER. For one thing, the two instrumental variables can directly reflect the degree of implementation of ER, which meets the correlation conditions for use as an IV in our research. For another thing, they and industrial SO_2 are obviously not related, which also satisfies the exogeneity criteria to be used as

Table 4. IV-2SLS regression results.

Variables	(1)	(2)	(3)
	Second	second	second
Envreg	-1.5887***	-0.9879**	-0.3220**
	(-2.6773)	(-2.5330)	(-2.1652)
Controls	Y	Y	Y
LM statistic	18.536***	34.821***	327.708***
F statistic	18.864***	36.539***	851.782***
N	589	589	558
R^2	-0.289	-0.046	0.056
Number of province	31	31	31

Note: ***, **, and* indicate 1%, 5%, and 10% significance levels, respectively; t-values in parentheses.

Table 5. Robustness estimation results.

	(1)	(2)	(3)	(4)	(5)
Envreg	-0.5689***		-0.4510***	-0.3414*	-0.4206***
	(0.1703)		(0.1453)	(0.1886)	(0.1108)
Envreg1		-0.0191*			
		(0.0100)			
Controls	Y	Y	Y	Y	Y
Infras	N	N	N	N	-0.0004
					(0.0005)
Medica	N	N	N	N	-0.0011
					(0.0196)
Burden	N	N	N	N	0.3908***
					(0.1061)
_cons	2.6606	3.4516**	0.6811	2.8193	1.4987
	(2.3453)	(1.5120)	(1.7785)	(2.7058)	(1.5244)
Province-Fix	Y	Y	Y	Y	Y
Year-Fix	Y	Y	Y	Y	Y
N	589	589	589	186	589
R^2	0.1380	0.1289	0.1391	0.1744	0.1772

Note: ***, **, and* indicate 1%, 5%, and 10% significance levels, respectively; t-values in parentheses.

an IV. The results are shown in columns (1) and (2) of Table 4.

In addition, the utilization of one-stage lag is a frequently employed approach for addressing the issue of endogeneity [21]. In order to ensure the robustness of the test results, we tested Envre_lag of Envreg as instrumental variable 3, and the results are shown in column (3) of Table 4.

Table 4 shows the regression results of two-stage least squares (2SLS). According to the F-statistics of the first-stage regressions, it is observed that all of the F-statistics exceed the threshold value as determined by the 10% bias of the weak instrumental variables test (>10). This finding suggests a strong correlation between the chosen instrumental variables and the endogenous explanatory variables, which can rule out the "weak instrumental variable" problem. From the second-stage regression results in columns (1) - (3), it can be seen that the strengthening of ER can significantly reduce environmental inequality, which is consistent with the baseline findings and confirms Hypothesis 1.

New Measurement of EE

The most common method to measure inequality is the Gini coefficient. However, it is only sensitive to changes in the median value of an indicator, not to changes in the maximum and minimum values. It can only reflect the overall gap in a general way, but cannot accurately measure the differentiation of the gap. That may lead to the problem of overestimation or underestimation of the measurement results. On the contrary, the Theil index, calculated by using the concept of "entropy" in information theory, can not only accurately measure the overall gap, but also be more sensitive to the changes of the two poles of the index [57]. Therefore, to avoid measurement error, we use Theil Index to re-measure EE in place of the original dependent variable for robustness testing. As shown in column (1) of Table 5, the results of the empirical regression using different methods of measuring EE remain significant.

Replace the Independent Variable

Most of the ER indicators used in the previous literature focus on capturing a particular aspect of government environmental governance costs, which may not be enough to embody the whole aspects of government environmental governance. For one thing, these indicators are largely endogenous and arise from economic development phases, which is prone to bring the endogeny. For another thing, due to the externalities and public goods features of environmental governance, informal ER, such as market-regulated and public-participatory ones, may suffer from market failures. To this end, we refer to previous scholars [58, 59] and take the frequency of environment-related terms in government work reports to replace ER. The environmental word frequency share can comprehensively measure the strength of local government environmental governance. Because government work reports generally announced at the beginning of the year, the economic situation of that year cannot reverse influence the pre-determined government work reports, thus mitigating the endogeneity arising from the adoption of this indicator. Then the result is shown in column (2) of Table 5. The estimated regression coefficient remained significant.

Ending Processing

In order to mitigate the potential influence of extreme values in the sample data on the findings of the study, we perform a bilateral tailing process on the original data. That not only ensures sufficient sample data, but also effectively addresses the influence of maximum and minimum values. The treatment process is to replace the quantile values before 1% and after 99% for all variables, which can control the influence of outliers on the estimation results. The effect of ER on EE is then empirically tested again. As shown in column (3) of Table 5, the result remains significant.

Reclassifying the Sample Interval

Environmental regulatory policies take a long time to come into effect and be implemented. In particular, the goals of environmental protection and resource conservation require sustained effort to achieve. The inability of environmental policies and their goals to be fully adjusted within one year is more evident in continuous panel data [60]. In order to test the robustness of the baseline results, the original data sample is reclassified by a 4-year cut-off, drawing on Anderson and Yotov (2016). Specifically, the original sample from 2003-2021 is reclassified, i.e., a total of six years from 2003, 2007, 2011, 2015, 2019, and 2021 are selected for the regression. As shown in column (4) of Table 5, the results remain significant.

Added Control Variables

It has been noted that children, youth, and poor households face the highest levels of pollution exposure [61]. Considering the demographic and social conditions of different regions, this paper, to avoid omitted variable bias, uses the method of adding other control variables for robustness testing and alleviates the endogeneity problem. Specifically, we added three control variables, including population burden, infrastructures, and medical conditions, characterized by the ratio of the number of non-working-age population to the number of working-age population, the gas penetration rate, and the number of hospital beds per capita, respectively. As shown in column (5) of Table 5, the regression result remained significant.

In Table 5, all regression coefficients of Envreg are negative at least at the 10% significance level, which is in line with the baseline regression results. These results also fully prove the robustness of this paper's conclusion that the enhancement of ER can significantly improve EE.

Heterogeneity Analysis

The above regression analysis based on the full sample only reflects the average effect of ER on EE. However, the discrepancies in regional characteristics and socioeconomic conditions may lead to discrepancies in the behavioral choices of local government agents, thus making the effect of ER on EE vary across regions. Therefore, we further examine the heterogeneous effects of ER on EE in four aspects: geographical location, income level, tax costs, and innovation level.

Geographical Location Heterogeneity Analysis

First, China is a geographically expansive nation characterized by variations in natural geographical endowments among its regions. The characteristics of geographical impact undoubtedly the ecological environment. Moreover, environmental regulatory policies are subject to obvious geographical differences in implementation, which may affect the effect of ER on EE. So, we divided the sample data into eastern, middle, and western regions by geographic location and conducted empirical tests, respectively [62].

Columns (2), (4), and (6) in Table 6 show the estimated results of ER on EE in the eastern, middle, and western regions, respectively. The estimated coefficient of the eastern is -0.8837 at the 5% significance level, and the estimated coefficient of the middle is -0.4783 at the 1% significance level. In contrast, the estimated coefficient of the western is still negative, but non-significant. This indicates that there is indeed heterogeneity in the effect of ER on improving EE. Among them, the effect of the middle is the most obvious, followed by the eastern, while the western is not obvious. The reason behind this may be that most of China's industrial industries are located in the middle provinces, where industrial pollution is particularly problematic. The role of ER in reducing pollution emissions and improving environmental quality is obvious to all. Therefore, when ER is strengthened, the middle region, where heavy industries are concentrated, has the most obvious effect of improving environmental quality, and the risk of environmental exposure is greatly reduced, thus optimizing the improvement of EE. Secondly, the eastern part of China is mostly developed provinces, and the economic development model is gradually transforming and upgrading to a sustainable and high-quality direction, and the requirements for environmental protection are also continuously strengthened. The implementation of ER policies may force the eastern provinces to transfer

Table 6. Geography heterogeneity estimation results.

	Eastern		Middle		Western	
	(1)	(2)	(3)	(4)	(5)	(6)
Envreg	0.0037	-0.8837**	-0.1830*	-0.4783***	0.0978	-0.2608
	(0.0835)	(0.3994)	(0.0971)	(0.1544)	(0.0813)	(0.1841)
Controls	N	Y	N	Y	N	Y
_cons	0.2620	-16.6269***	0.5922***	6.1785	0.4206***	1.1632
	(0.1771)	(4.6743)	(0.1448)	(5.1020)	(0.0469)	(2.1783)
Province-Fix	Y	Y	Y	Y	Y	Y
Year-Fix	Y	Y	Y	Y	Y	Y
N	209	209	152	152	228	228
R^2	0.0745	0.2008	0.2072	0.4243	0.2543	0.3224

Note: ***, **, and* indicate 1%, 5%, and 10% significance levels, respectively; t-values in parentheses.

Table 7. Income heterogeneity estimation results.

	Low income		High income	
	(1)	(2)	(3)	(4)
Envreg	-0.0863	-0.9418***	-0.1476**	0.0434
	(0.0700)	(0.1606)	(0.0739)	(0.2871)
Controls	N	Y	N	Y
_cons	0.4809***	6.2672***	0.6159***	9.2376**
	(0.0856)	(2.1910)	(0.1243)	(4.5691)
Province-Fix	Y	Y	Y	Y
Year-Fix	Y	Y	Y	Y
N	368	368	221	221
R^2	0.0990	0.2727	0.2392	0.3517

Note: ***, **, and* indicate 1%, 5%, and 10% significance levels, respectively; t-values in parentheses.

heavy polluting industries to the western provinces, which can reduce the environmental pollution and at the same time complete the transformation and upgrading of the industries, thus improving the environmental quality to a greater extent and enhancing the EE. The largest regression coefficient for the eastern also just proves this point. As for the western region, because it is located deep in the land, the transportation accessibility is not high, which leads to less commercial trade and a lower level of economic development. In order to accelerate economic development, the western provinces have undertaken a large number of foreign polluting industries, which have caused serious damage to the local ecological environment [63]. Although ER has obvious effects in improving environmental quality, in the western region, where the "economy comes first", ER may be a mere formality that does not play its proper policy role, resulting in a less obvious suppression of regional environmental inequality.

Income Level Heterogeneity Analysis

Second, multiple studies have demonstrated a highly significant correlation between socio-economic status and environmental pollution. To detail, the groups with low socio-economic status tend to be more exposed to air pollutants and toxic substances. Which in turn adversely affects their health and exacerbates social inequalities in the health aspects of air pollution [64]. In this paper, the real per capita disposable income of the entire population was selected to present the level of income. The sample was divided into two groups, high and low, according to their mean values. The results are shown in Table 7.

Columns (2) and (4) show the empirical results of Envreg on Equity for the low-income groups and the high-income group, respectively. For the low-income groups, the effect of ER on EE is -0.9418 at the 1% significance level. For the high-income group, the estimated coefficient of Envreg is 0.0434, and non-significant. The reason behind this may be that owing to higher income, people can afford to relocate from places with poor environmental quality to places with good environmental quality. They can also afford to spend on medical care for health damage caused by pollution. In other words, the higher income groups are able to use the economic advantage of "voting with their feet" to keep themselves in a relatively high state of EE. Therefore, the effect of ER on EE is inverse in provinces with high per capita income. On the contrary, low-income people cannot afford the cost of relocation and medical expenses. So, they can only reduce their expenses by choosing to live in environmentally polluted areas, resulting in more exposure to environmental risks. This is in line with previous scholars [65]. In this case, the implementation of ER by the government has a significantly improving effect on EE in provinces with low per capita income.

Tax Cost Heterogeneity Analysis

Third, China's industrial energy consumption, at present, is primarily reliant on fossil fuels like coal and oil, which release significant amounts of polluting gases and deteriorate environmental quality. For this reason, the Chinese government has been advocating the environmental policy of "energy saving and open source", encouraging the industrial sector to economize on the use of fossil energy, actively use new energy sources, and take the road of green and low-carbon development. Taxation, as a crucial financial tool employed by the government, holds considerable importance in shaping the trajectory of industry development. Therefore, in this paper, the proportion of resource tax revenue to total fiscal tax revenue is selected to present tax costs. The sample is divided into high and low groups according to their mean values for testing, and the results are shown in Table 8.

Columns (2) and (4) show the regression results of Envreg on tax expenditure cost for different regions, respectively. Although the estimated coefficients of Envreg are significantly negative at the 1% level in both groups, the coefficient values are much larger in the high tax cost group than in the low tax cost group. The reason behind this is that when the cost of taxation is higher, the cost of using fossil energy fuels in industrial enterprises will be higher, and the expenditure will be higher. This not only puts pressure on the capital flow of enterprise development, but also has an adverse impact on the environment and ecology, which is not conducive to the maintenance of the image of the enterprise. Therefore, under the high tax expenditure, industrial enterprises will actively seek new and cleaner energy sources so as to achieve the sustainable development goals of saving energy, reducing costs, and improving efficiency. On the contrary, when the tax cost is lower, the principle of externality suggests that manufacturers who seek to maximize profits do not need to pay too much extra cost for the environmental pollution caused by their production activities while obtaining great benefits. As a result, firms will use fossil energy for related production activities without restraint in order to gain more economic profits. To sum up, when the cost of taxation is higher, the improvement effect of ER on environmental inequality is more obvious, and the government should fully and rationally utilize the fiscal policy of taxation to match the effect of ER on EE.

Innovation Level Heterogeneity Analysis

Finally, the path of sustainable development cannot be separated from innovation, and energy conservation

Table 8. Tax-cost heterogeneity estimation results.

	Low tax-cost		High tax-cost	
	(1)	(2)	(3)	(4)
Envreg	-0.0396	-0.3760***	-0.2112**	-2.2328***
	(0.0603)	(0.1321)	(0.0876)	(0.6161)
Controls	N	Y	N	Y
_cons	0.4044***	0.3414	0.6539***	-7.4509*
	(0.0894)	(2.3844)	(0.1036)	(4.3397)
Province-Fix	Y	Y	Y	Y
Year-Fix	Y	Y	Y	Y
N	418	418	171	171
R^2	0.0716	0.1403	0.2131	0.4558

Note: ***, **, and* indicate 1%, 5%, and 10% significance levels, respectively; t-values in parentheses.

Table 9. Innovation level heterogeneity estimation results.

	Low innovation		High innovation	
	(1)	(2)	(3)	(4)
Envreg	-0.0151	-0.3181**	-0.2037***	-0.5088***
	(0.0675)	(0.1567)	(0.0618)	(0.1400)
Controls	N	Y	N	Y
_cons	0.3730***	0.8412	0.6555***	4.2179*
	(0.0909)	(1.9394)	(0.0854)	(2.2777)
Province-Fix	Y	Y	Y	Y
Year-Fix	Y	Y	Y	Y
N	329	329	260	260
R^2	0.1288	0.1972	0.2058	0.3341

Note: ***, **, and* indicate 1%, 5%, and 10% significance levels, respectively; t-values in parentheses.

and emission reduction likewise cannot be separated from innovation, which is the first driving force for development. Through green innovation, cleaner production technologies can be improved, the efficiency of production can be increased, pollution emissions can be reduced, and environmental quality can be improved, and thus EE can be enhanced. In our study, the ratio of the numbers, domestic patent grants for invention originated to patent applications for invention originated, is selected to present innovation level. The sample is divided into two groups of high and low, respectively, according to their mean values, and the results are shown in Table 9.

Columns (2) and (4) show the regression results for provinces with different levels of innovation. When the innovation level is different, the effect of ER on EE is heterogeneous. Specifically, when the level of regional innovation is high, the inhibitory impact of ER on environmental inequality is -0.5088 at the 1% significance level, while when the level of regional innovation is low, the impact of ER on environmental inequality is -0.3181 at the 5% significance level. In other words, the promotion effect of ER on EE is larger and more obvious for those provinces with higher innovation levels. Innovation can significantly promote and optimize industrial structural upgrading and green transformation. It will convert technological advantages into economic and environmental advantages, and green and clean production technology can not only change the crude development mode, but also further reduce pollution emissions, promote sustainable development, and benefit the whole society.

Mechanisms

The aforementioned empirical results have provided evidence that ER can significantly depress regional environmental inequity. The mechanisms proposed in the research hypothesis section (shown in Fig. 3) need to be further discussed and validated.

To this end, in this section, we use, respectively, greening services, energy investment, and public environmental attention as explained variables to test hypothesis 2, referring to the practice of previous scholars [53]. Particularly, the greening rate of built-up areas, the proportion of energy industry investment to industry value added, and the Baidu environmental pollution search index[1] in PC (logarithmic) were used to indicate greening services (Green), energy investment (Invest), and public environmental attention (Public), respectively. Taking the following empirical regression model, we also investigate the influence mechanisms of ER on EE as follows:

$$\text{Mechanisms}_{it} = \beta_0 + \beta_1 Envrg_{it} + CX_{it} + \delta_t + \theta_p + \varepsilon_{it} \tag{2}$$

where M_{it} represents the potential influence mechanism variables through which the ER can affect EE, including Green, Invest, and Public; the rest variables are the same as before.

The estimated results are shown in Table 10. In column (1), the estimated coefficient of Envreg is significantly positive at the 5% level, which indicates that ER can improve EE by increasing green spaces. The area of green land not only affects people's living environment objectively, but also impacts people's living feelings subjectively. By increasing the construction of green spaces and improving the level of environmental welfare, the government can largely eliminate the local environmental inequality problem and enhance EE.

1 Baidu Haze Environmental Index has been published since 2011.

Table 10. Mechanism test.

	(1)	(2)	(3)
	Green	Invest	Public
Envreg	9.0009**	1.2328***	1.6957*
	(3.7269)	(0.2492)	(0.9930)
Controls	Y	Y	Y
_cons	72.6666	-2.2601	31.4544**
	(51.3379)	(3.4333)	(14.0153)
Province-Fix	Y	Y	Y
Year-Fix	Y	Y	Y
N	589	589	341
R^2	0.6742	0.2137	0.6852

Note: ***, **, and* indicate 1%, 5%, and 10% significance levels, respectively; t-values in parentheses.

In column (2), the estimated coefficient is significantly positive at the 1% level, which indicates that ER can affect EE by influencing energy industry investment. On the one hand, the increase in energy industry investment makes more clean equipment and facilities to be inputted into the production process, which reduces pollution emissions, reduces environmental risks, and ultimately improves EE. On the other hand, ER can also force enterprises to advance production technology and boost energy utilization efficiency, which will diminish emissions and thus have a positive impact on EE.

In column (3), the estimated coefficient of Envreg is significantly positive at the 10% level. With the strengthening of ER, public attention on environmental pollution is also increasing. Which in turn raises environmental demands to improve environmental quality to defend their environmental rights. That plays an active role in realizing EE. Public concern can not only force enterprises to add their investment in environmental conservation, but also enhance the intensity of regional ER by pushing local authorities to increase expenditure in environmental governance. This can play a role in improving environmental quality and optimizing regional ecological welfare performance. Therefore, the active participation of people in activities to improve environmental quality should be strongly advocated and thus inject new vitality into enhancing regional EE and socio-ecological welfare.

In summary, ER can indeed play a role in improving EE by promoting government greening services, influencing energy industrial investment, and raising public attention. Hypothesis 2 is confirmed.

Conclusions and Discussion

Main Findings

Sustainable development and ecological civilization construction have always been vital topics for the government and the public and also one of the most popular research contents in environmental economics. At the new inflection point of China's economic transformation and ecological construction development, green development has undoubtedly become the focus of attention of the whole society. Nowadays, safeguarding environmental interests and improving environmental inequity have become two of the most urgent issues to be solved.

Taking ER and EE as the research objects, we conduct empirical analysis by constructing a fixed-effects model and initially reveal the causal relationship and mechanism pathways between them. Our findings majorly include the following: (1) The strengthening of ER does play a positive role in improving regional ecological welfare and enhancing EE. This is highly aligned with the results of existing literature [7]. (2) There is heterogeneity in the impact of ER on EE. Specifically, the suppressive effect of ER on environmental inequity is more pronounced in eastern and middle provinces with lower incomes, higher tax costs, and higher innovation levels. This is in line with existing literature [66]. (3) The mechanisms test finds that ER affects EE by acting on different channels. For the government, they can improve the ecological welfare of residents and regional EE by boosting its own public greening services. This is in line with previous scholars [67]. For the industrial sectors, by increasing energy investment to replace clean production equipment or advance production efficiency, they can accomplish the dual goals of mitigating pollution and saving cost, and thus improve EE. For the public, their serious concern for environmental quality can express their own environmental rights and interests, as well as urge the government and enterprises to actively carry out environmental prevention and governance work. This is in line with the findings of previous scholars [68]. The above three channels have significant positive meaning for improving EE.

In conclusion, our findings are highly consistent with those of previous literature. The majority of prior research has mostly concentrated on the fact that pollution abatement is conducive to improving EE, without considering the reasons behind that. From the perspective of ER, which is the most effective and direct way to reduce environmental pollution, we demonstrate its role in promoting EE, expanding the scope of research in this field, and contributing solution ideas to promote sustainable green development of society and improve the environmental rights of the people.

Suggestions

The results of our study have significant policy ramifications for advancing the development of ecological civilization in countries around the world and achieving the "win-win" goal of high-quality economic transformation and green sustainable progress.

Firstly, improving the system of government environmental governance and reinforcing the implementation of ER on the ground. From the findings, it is utterly clear that the lower the proportion of secondary production and the higher the degree of openness, human capital, and residents' consumption, the stronger the inhibiting effect of ER on environmental inequity. Therefore, it is necessary to fully channel these favorable factors and incorporate them into the system of ER. Specifically, in the first place, adjusting the industrial structure to optimize and upgrade, reducing the scale of high pollution industries, and increasing the investment in green technology innovation. In the second place, improving continuously the openness to foreign businesses, optimizing the threshold and standard of foreign business entry, and giving full play to the technology diffusion effect of FDI. In these ways, it can weaken the negative influence of the crude utilization of foreign capital on the effect of ER. Moreover, the government should accelerate the process of urbanization, enhance the consumption ability of residents, promote the concept of green consumption, and support green products.

Secondly, constructing composite ER policies and executing differential ER according to local conditions. Since there is heterogeneity in the influence of ER on EE, the ability of different regions to undertake environmental policies varies greatly [69, 70]. Therefore, when formulating environmental policies in order to ensure their effectiveness, it is necessary to select scientific and appropriate regulatory tools and implement differentiated regulatory instruments according to the geographical location, and the regional level of social and economic development. Besides, for the development of ecological civilization and economic growth, enhancing interregional cooperation in environmental governance is crucial to establishing a novel framework. Specifically, on the one hand, it can reduce the population burden of the regional environment by accelerating the construction of suburban areas and evacuating the population size of core cities, creating good conditions for improving regional EE. On the other hand, the living environment of low-income residents should be improved to enhance their ability to prevent environmental risks, and the healthcare protection system of residents should be improved to reduce the burden of health costs on vulnerable groups. In addition, it is imperative to fully leverage the subjective initiative of the government. By increasing fiscal expenditure on science and technology, the government could guide enterprises to actively carry out green technology innovation. In addition, via the rational utilization of financial means, such as the implementation of tax incentives to reduce enterprise costs, the authority also provides a good context for enterprises to innovate. The combination of subjectivity and objectivity should be truly achieved to effectively improve environmental quality and EE.

Thirdly, giving full play to the role of participating subjects of environmental governance. First and foremost, to enhance people's sense of well-being, the government should actively fulfill its public service obligations, expand urban greening spaces, and improve ecological carrying capacity and residents' environmental welfare. Further, under the pressure of ER, enterprises should take the initiative to promote pollution reduction and emission reduction actions, replace clean production equipment, and improve energy utilization efficiency. Finally, the public should also actively participate in expressing environmental demands through the Internet, new media, environmental petitions, etc. to defend their own environmental rights and interests. They can also give some advice to the government on environmental policies and urge enterprises to embrace green transformation. The above actions can build a good mass foundation for the construction of a welfare society in EE.

Shortcomings and Prospects

The findings of our study hold substantial practical implications for the field of environmental governance in China, but there are some shortcomings. First, the research level needs to be further deepened. Limited to the calculation method of the Gini coefficient and the availability of county data, we calculate the EE index at the provincial level through city-level pollution data, which may have some bias in the measurement of regional environmental inequality in China. Second, there is no fine-grained classification of ER, only a comprehensive measure of ER. There are many ways to categorize ER, such as command control, market incentive, and public participation. In view of the above shortcomings, subsequent research can further try to make breakthroughs in research level and data updating and explore more mechanisms to improve EE so as to put forward more specific and applicable recommendations.

Acknowledgments

This research was funded by the Innovation Project of School of Economics and Management, Guangxi Normal University (JG2022006).

Conflicts of Interest

The authors declare no conflict of interest.

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