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An Investigation into the Repercussions of Environmental Regulation on the Green Total Factor Productivity within Corporate Entities

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Abstract: Consequently, environmental regulation possesses significant theoretical and practical significance for improving the green total factor productivity of corporations. Despite the prevailing literature's predominant focus on the macroeconomic impacts of environmental regulations, this study narrows its scope to the microeconomic level, specifically investigating how corporate-level environmental regulations affect green total factor productivity. The analysis utilizes data from publicly listed companies from 2011 to 2022. In this context, the paper employs machine learning algorithms to construct a dictionary of environmental regulations and evaluates the text of these companies' annual reports to formulate an index of corporate environmental regulatory levels. Findings indicate that environmental regulations exert a substantial positive effect on green total factor productivity, a result that withstands a series of robustness tests. This discovery not only contributes to a deeper comprehension of the nexus between micro-level corporate environmental regulation and the enhancement of green production efficiency but also offers valuable insights for enterprises seeking to foster the advancement and refinement of environmental regulatory frameworks.

Keywords: Listed Company; Regulations of Environment; GTFP; Text Analysis

1. Research Background

The natural environment is the foundation of mankind survival and sustainable development, but the current environmental problems are prominent, and global climate change, air and water pollution, soil pollution, etc. have a substantial effect on human health and overall quality of life. In addition, biodiversity loss and overexploitation of resources also pose a threat to the ecological balance. In light of the swift expansion of Chinese economy, environmental problems have become more prominent, with 2023 data showing that 40.1% of cities have substandard ambient air quality, reflecting the detrimental effects of environmental degradation on society and the economy. To address these environmental challenges, China has advocated a new path of industrialization since 2002 and attaches great importance to the construction of ecological civilization. Since 2017, the state has proposed to shift to high-quality development, promote green economy, emphasize the harmonious coexistence of man and nature, and incorporate environmental pollution prevention and control, carbon peaking and carbon neutrality into the national strategy, and gradually form a policy system focusing on carbon reduction. In this context, as an important subject of economic development, enterprises' environmental protection responsibilities are increasing. Under appropriate environmental regulations, enterprises can incentivize technological innovation and enhance market competitiveness, thereby enhancing green total factor productivity and fostering a win-win scenario for both economic and environmental benefits. Consequently, investigating the impact of environmental regulation on the green total factor productivity of businesses is crucial for facilitating green transformation, optimizing resource allocation, and advancing the development of ecological civilization in the modern era.

Combined with the current status of relevant research and the research content of this paper, the incremental value of this research is chiefly demonstrated in two key areas: in the first place, the innovation of study perspective. The

majority of current studies on this topic focus on the framework of capital and labor factor inputs and macroeconomic indicators (such as GDP, per capita GDP, total factor productivity, etc.), and this paper aims to examine the effect of environmental regulation on green total factor productivity at the micro-enterprise level, a critical metric for characterize the quality and transformation degree of green economic growth of enterprises. Secondly, innovation in research methods. Based on the yearly reports of publicly traded companies, the research uses Python software to analyze the text of corporate annual reports, so as to quantify environmental regulations. These innovative methods and perspectives provide new ideas and empirical evidence to gain a clearer insight into the connection between environmental regulation and corporate green development.

2. Literature Review

2.1 Environmental Regulation Definition and Level Measurement

Environmental regulation is a dynamically evolving concept, and its definition has been enriched with the deepening of academic research. Initially, it was seen as a state-enforced statute that reflected the state's "coercive power". Dasgupta (1980) [1] emphasizes the central role of government in environmental regulation, aiming to balance economic development and the ecological environment. In the late 1980s and 90s, scholars recognized that environmental regulation should involve both direct and indirect interventions, including administrative and economic instruments such as emissions taxes and permit systems. Since the beginning of the 21st century, scholars have generally believed that environmental regulation is a coercive force to protect the environment and safeguard rights and interests, based on tangible institutions or latent consciousness [2]. In recent years, the consensus is that environmental regulation is the sum of government policy measures and the binding impact of social organizations and the public on polluters [3], and intervenes in the atmosphere, water, soil pollution and noise to achieve resource conservation and sustainable development [4], so as to improve environmental quality and foster the advancement of a green economy.

Due to the lack of a unified index system and measurement methods, scholars choose different indicators according to their research objectives. At present, there are mainly the following types: the selection of indicators characterized by a single index, such as industrial "three wastes" emissions [5], industrial "three wastes" emissions per unit of output value[6], etc.; A comprehensive index is constructed based on multiple types of indicators, including the rate of industrial smoke and dust removal, the overall utilization rate of industrial solid waste, and the rate of industrial wastewater treatment [7], as well as the ratio of total investment in urban industrial pollution source management to the total emissions of regional industrial sulfur dioxide, industrial wastewater, and industrial smoke (dust) [8]. The alternative indicators were selected based on other characteristics: the ratio of the number of words related to animal husbandry in the government work report to the word count of each report on the work of the government [9], along with the ratio of environmental terminology to the total word count in the work reports of prefecture-level cities [10].

2.2 Definition and Measurement Method of GTFP

In 1957, Robert · Solo first proposed the notion of "Total Factor Productivity" (TFP), which measures the efficiency of the transformation of total input into output in economic development and reflects the role of technological progress on economic growth [11]. However, the traditional TFP model does not fully consider natural resources and environmental factors. In the 20th century, with the growing concern about resource scarcity and environmental issues, scholars systematically improved TFP. In 1983, Pittman introduced the expenses associated with environmental pollution and quantified the environmental contamination in the production process as a cost, laying the foundation for the integration of environmental factors into TFP research [12]. In 1996, Mohtadi proposed "Green Total Factor Productivity" (GTFP), which treats energy consumption as an input and incorporates environmental pollution to make up for the shortcomings of traditional TFP [13]. With the diversification of the economy and industry, a favorable environment

is gradually regarded as an important factor in economic growth. GTFP emphasizes an environmentally friendly development model and aims to avoid excessive consumption and environmental damage. In recent years, scholars have redefined the calculation of economic growth by treating energy consumption as an input and pollutant emissions as an undesirable output, focusing on the quality and sustainability of growth, and achieving a mutually beneficial scenario for the economy, society, and ecological environment [14].

GTFP calculation methods are mainly divided into parametric approach and non-parametric approach. The parametric approaches consist of the Solow residual technique, the production function method and the stochastic frontier production function method, all of which have advantages and disadvantages, and all of them depend on the setting of the production function. In contrast, non-parametric methods are more widely used, including data envelopment analysis (DEA), Malmquist index, Luenberger productivity index, non-radial relaxation SBM, and SML index. These methods do not need to preset production functions, and can effectively handle a variety of inputs and outputs, and decompose advancements in technology and shifts in efficiency, offering a more thorough GTFP calculation tool.

2.3 Literature Review

Through literature reading, it is found that the relevant achievements have been quite abundant, which provides valuable methods and ideas for the research of this paper. However, there is still room for further discussion in the existing literature.

First of all, there is no unified evaluation standard for scholars when it comes to measuring environmental regulation. Some studies use qualitative indicators, some use quantitative indicators such as pollutant emissions and pollution control investment, and some studies construct composite indexes, but the indicators selected are different, making it difficult to make direct comparisons between the studies. Based on the previous research practice, this paper will use Python software to segment the provincial government work reports and count the frequency of key words related to environmental regulation. This approach can alleviate the endogenous problem between economic growth and environmental regulations, and improve the practical significance of the research results. Secondly, in terms of measuring GTFP, most of the existing studies use DEA approach and ML indicator, but the traditional DEA method cannot effectively address the issue of "undesired output". In this paper, we will use a non-radial SBM model to measure the GTFP of listed companies. In addition, the current body of research mostly focuses on the meso-level of macro-provincial or single industries, and pays little attention to the impact of enterprises as a whole. Based on micro-enterprises, this paper comprehensively discusses the link between environmental regulation and eco-friendly total factor productivity, so as to enrich the theoretical basis of this research direction and provide reference for optimizing the implementation of environmental regulation.

3. Study Design

3.1 Model Settings

Based on theoretical analysis, this paper constructs the following model based on the selection of indicators (1):

$$GTFP_{it} = \alpha + \beta_1 ER_{it} + \theta CON_{it} + \lambda_i + \lambda_t + \varepsilon_{it} \quad (1)$$

In this context, the subscript i denotes the enterprise, while t indicates the time period. The variable GTFP signifies the green total factor productivity of the enterprise, ER represents the level of environmental regulation for the enterprise, and CON refers to the control variable, λ_i indicates the fixed effect associated with the enterprise industry, λ_t represents the time fixed effect, ε_{it} is the random perturbation term, and α, β, and θ are the parameters that need to be estimated within the model.

3.2 Data Sources and Variable Construction

3.2.1 Data source

In this study, 14,137 firm-annual observations were obtained from 2011 to 2022 with the initial sample of listed companies in China as the initial sample. The specific screening steps include: (1) excluding financial enterprises; (2) Eliminate the sample of enterprises with missing statistical data; (3) Exclusion of samples of non-arm's length trading enterprises (ST, ST*); (4) For the revised annual report, the statistical sample of word frequency before

the amendment is excluded. The sample data comes from the annual reports of listed companies on the Juchao Information website, as well as the basic information and financial indicators of enterprises from the databases of CSMAR, Wind and China Securities Securities.

3.2.2 Explanation of the main variables

The explanatory variable in this study is the green total factor productivity (GTFP) of enterprises, and the evaluation system incorporates the environmental pollution of these enterprises. The GTFP was calculated using the non-radial SBM index. The explanatory variable in this paper is the level of enterprise environmental regulation, and its construction is the key work. At present, there is no standardized measurement method for assessing the level of environmental regulation at the enterprise level, which is usually divided based on macro regions, and the environmental regulation indicators are constructed based on indicators such as regional pollution emissions and treatment investment. However, this can lead to deviations in the level of corporate environmental regulation at the micro level. Considering that the reports issued by publicly listed companies comprehensively reflect the operation and development of enterprises, this paper uses machine learning algorithms to construct a dictionary of corporate environmental regulation, and constructs an index of the level of corporate environmental regulation based on the annual report data. The detailed steps are as follows:

(1) Data acquisition

This paper selects the Juchao information website as the data source of the annual reports of listed companies, and finally obtains 41,628 annual reports from A-share listed companies in Shanghai and Shenzhen covering the years 2011 to 2022.

(2) Generate a dictionary of environmental regulations

Drawing on the practice of Chen Shiyi et al. [15], this study extracted 15 seed words about environmental regulation from government reports, such as "environmental protection" and "emission reduction", as the basis for keywords. Subsequently, the Skip-gram model of Word2vec was utilized to train the text content of the annual report of listed companies, and the cosine similarity was calculated between the seed words and the resulting words was calculated to screen out the words with the closest semantism. Finally, a total of 95 words were obtained by eliminating repetitive, irrelevant and words with too low or too high word frequency, and the environmental regulation dictionary of this paper was formed.

(3) Construction of corporate environmental regulation indicators

This study utilizes the well-known open-source Python module "jieba" for segmenting the text of the annual reports of listed companies. In the analysis of Chinese text, issues arise such as segmentation granularity, ambiguous word identification, and recognition of new terms [16]. For example, "environmental protection", as the core term of environmental regulation, may be divided into "environment" and "protection". In order to address these challenges, this study incorporated the created environmental regulation dictionary as a proper noun dictionary into "jieba", and counted the number of environmental regulation words in the annual report. Subsequently, the number of environmental regulation keywords was added by 1 to take the natural logarithm (Lwd) to smooth out the processing and use it as a measurement index of corporate environmental regulation.

3.3 Endogeneity Discussion

A firm's green total factor productivity (GTFP) is affected by a variety of factors, including firm characteristics, market demand, human resources, management practices, capital investment, and technological innovation. Without considering these factors, the regression coefficient of the impact of environmental regulation on GTFP may be biased, presenting endogeneity problems. In order to solve this problem, this paper constructs the corporate environmental regulation equation based on the GTFP equation and uses the Simultaneous Equation Model (MLE) to mitigate the potential endogenous impact. This method not only improves the estimation accuracy, but also provides a more reliable empirical basis for the analysis of the true impact of environmental regulation on GTFP, and enhances the academic rigor of the research.

Referring to Greene's (2018) Econometric Analysis [17], this paper uses the MLE simultaneous equation system estimation method to construct the enterprise

environmental regulation equation on the basis of the green total factor productivity equation, as shown in equation (2):

$$\begin{cases} GTFP_{it} = \alpha + \beta_1 ER_{it} + \theta CON_{it} + \varepsilon_{it} \\ ER_{it} = \beta_2 ISO_{it} + controls_{it} + \mu_{it} \end{cases} \quad (2)$$

A two-dimensional normal distribution with the assumed and obeyed mean vectors u and the variance matrix is Σ, i.e.:

$$\begin{pmatrix} \varepsilon \\ \mu \end{pmatrix} \sim N_2(u, \Sigma) \quad (3)$$

Thereinto:

$$u = \begin{pmatrix} 0 \\ 0 \end{pmatrix}, \Sigma = \begin{bmatrix} \sigma_1^2 & \rho\sigma_1\sigma_2 \\ \rho\sigma_1\sigma_2 & \sigma_2^2 \end{bmatrix} \quad (4)$$

Assuming that there are N enterprises, construct the log-likelihood function lnL, as shown in Eq. (5):

$$ln\, L_i = -\frac{M}{2} ln\, 2\,\pi - \frac{1}{2} ln\, |\Sigma| - \frac{1}{2} \gamma_i^{'} \Sigma^{-1} \gamma_i \quad (5)$$

In this study, the fully informed maximum likelihood estimation (MLE) is implemented by the constructed likelihood function to alleviate the estimation bias caused by the endogeneity problem, so as to obtain more accurate and reasonable estimation coefficients. For the variables in the environmental regulation estimation equation, the selection criteria are similar to those of instrumental variables (IV), but relative exogeneity is the main requirement for MLE to identify variables. This advantage makes MLE more flexible in the selection of identifying variables, which is helpful to effectively capture the complex relationship between different variables, and provides a solid theoretical basis for in-depth analysis of the impact mechanism of environmental regulation on the green total factor productivity of enterprises. In this paper, the identification variable selected is the enterprise environmental management system certification, and the ISO9001 certification index is used as the proxy variable.

4. Empirical Analysis

4.1 Descriptive Statistics

Table 1 shows the descriptive statistical results of the main variables. The mean value of GTFP was 10.136, the standard deviation was 0.896, the minimum value was 8.268, and the maximum value was 11.759, indicating that the overall performance of enterprises during the study period was good, but there were differences. The mean value of the environmental regulation level is 2.705 and the standard deviation is 1.154, indicating that there is a significant difference in the environmental regulation of enterprises. The natural logarithmic mean of the number of employees is 7.928 and the standard deviation is 1.155, reflecting significant heterogeneity in enterprise size. The natural logarithmic mean of average wages was 11.579 and the standard deviation was 0.478, indicating a significant difference in wage levels. The average asset-liability ratio was 0.414, and the average proportion of fixed assets was 0.233, indicating that the financial structure of the enterprise was relatively stable, but there were obvious differences. The average size of the board of directors is 2.122, and the average shareholding ratio of management is 14.178%, both of which show that there are large differences in corporate governance. In terms of market value, the average book-to-market ratio is 0.599, and the average shareholding ratio of institutional investors is 43.727%, reflecting the significant differences in market value and investor structure of the sample companies. The above statistical results provide a basis for the follow-up analysis and verify the rationality and reliability of the study. The distribution of control variables is within a reasonable range.

Table 1. Descriptive Statistics of the Main Variables

VarName	Obs	Mean	SD	Median	Min	Max
gtfp	14137	10.136	0.896	10.166	8.268	11.759
lwd	14137	2.705	1.154	2.773	0.000	6.669
FirmAge	14137	2.897	0.332	2.944	1.099	4.174
ListAge	14137	2.142	0.756	2.197	0.693	3.434
Employee	14137	7.928	1.155	7.849	3.178	13.253
BM	14137	0.599	0.245	0.592	0.008	1.468
Board	14137	2.122	0.190	2.197	1.386	2.890
Indep	14137	37.609	5.624	33.330	16.670	80.000
Lev	14137	0.414	0.184	0.414	0.008	0.993
Mshare	14137	14.178	19.598	1.615	0.000	89.177
INST	14137	43.727	24.733	45.380	0.000	231.846
FIXED	14137	0.233	0.135	0.209	0.000	0.810
lnpwage	14137	11.579	0.478	11.560	6.843	13.719

4.2 Baseline Regression

Table 2 shows the benchmark regression results of environmental regulation and corporate green total factor productivity. The results of column (1) show that there is a significant positive relationship between environmental regulation and green total factor productivity (regression coefficient of 0.231) when only the year and industry are controlled. The regression results of column (2) after the introduction of the main control variables showed that the relationship was still significant (regression coefficient of 0.230). Further analysis shows that the regression coefficient in column (3) is also significantly positive (0.230) after considering the size of the firm, indicating that the size of the firm affects this relationship to a certain extent. The subsequent regression results in columns (4), (5) and (6) showed that the regression coefficients were 0.228, 0.222 and 0.220, respectively, which were significantly positive at the 1% significance level, despite the addition of variables such as enterprise technology type, ownership and location. This results show that the positive impact of corporate environmental regulation on green total factor productivity is still significant under different enterprise characteristics. In addition, the regression coefficient decreases gradually, reflecting that these characteristics may affect the relationship between environmental regulation and green total factor productivity through multiple channels.

Table 2. Regression Results of Environmental Regulation and Corporate Green Total Factor Productivity

	(1)	(2)	(3)	(4)	(5)	(6)
	m01	m02	m03	m04	m05	m06
ER	0.286***	0.231***	0.230***	0.228***	0.222***	0.220***
	(61.02)	(51.56)	(51.51)	(51.50)	(50.58)	(50.11)
Control variables	NO	YES	YES	YES	YES	YES
Enterprise size	NO	NO	YES	YES	YES	YES
Type of Technology	NO	NO	NO	NO	YES	YES
Enterprise Ownership	NO	NO	NO	NO	YES	YES
Location	NO	NO	NO	NO	NO	YES
Year fixed effect	YES	YES	YES	YES	YES	YES
Industry fixation	YES	YES	YES	YES	YES	YES
Sample	14137	14137	14137	14137	14137	14137
Adjust R2	0.586	0.682	0.683	0.691	0.697	0.699

Note: The t-values in parentheses, ***, **, and * indicate significant at the 1%, 5%, and 10% levels, respectively.

4.3 Endogeneity Issues

In this paper, a simultaneous equation model is used to analyze the potential endogeneity problem by using the Complete Information Maximum Likelihood Estimation (MLE) method. The results are shown in column (2) of Table 3, which shows that the correlation coefficient between the residuals of the two equations is -0.642, indicating that there is a significant negative correlation between the explanatory variable and the residual term. This suggests that the use of OLS regression may have the bias of missing variables, which leads to the underestimation of the impact of environmental regulation on the green total factor productivity of enterprises. After using the MLE simultaneous equation method to deal with endogeneity, the coefficient of environmental regulation is significantly positive at the 1% significance level, which further verifies the positive impact of environmental regulation on the green total factor productivity of enterprises. Based on this, the follow-up research in this paper will focus on the MLE simultaneous equation model, aiming to deeply explore the relationship between environmental regulation and corporate green total factor productivity.

Table 3. Control for Endogeneity Regression Results

	(1)	(2)	
	OLS	MLE	
variable	GTFP	GTFP	ER
ER	0.220***	0.618***	
	(50.11)	(33.53)	
ISO			0.195***
			(9.65)
Control variables	YES	YES	YES
Industry fixation	YES	YES	YES
Year fixed effect	YES	YES	YES
correlation coefficient		-0.642***	
		(-37.82)	

Sample	14137	14137
Estimates of maximum likelihood		-28512.849

4.4 Robustness Test

In order to enhance the robustness of the research results, this paper examines the impact of corporate environmental regulation on green total factor productivity through a variety of methods. Substitution of core explanatory variables: In order to verify the reliability of the research results, the core explanatory variables were replaced by the E score in the corporate green investment and CSI ESG scores, as shown in columns (1) and (2) of Table 4. According to the method of Zhang Qi et al. (2019), the green investment data of listed companies is collated, and the environmental protection investment data in the annual reports of listed companies are sorted out, and the data are returned after standardization. The regression results show that the coefficients of the substitution variables are positive at the 1% significance level, which is consistent with the benchmark results, indicating that environmental regulation significantly promotes green total factor productivity. Tail shrinking method: The sample data was 1% tail shrinking, as shown in column (3) of Table 4, the regression coefficient of the regression results was 0.622, which was still significantly positive at the 1% significance level, slightly higher than the benchmark regression result of 0.618, indicating that the extreme value had little impact on the estimation results and enhanced the robustness of the study. Changing the sample interval: 50% of the samples were randomly selected for regression, as shown in column (4) of Table 4, the environmental regulation coefficient obtained was 0.588, which was still significantly positive at the 1% significance level, which verified the robustness of the research conclusions. This phenomenon reveals the influence of sample selection and firm characteristics on the regression estimation results, and provides ideas for follow-up research.

Table 4. Robustness Test Results

	(1)	(2)	(3)	(4)
Equation 1	GTFP	GTFP	GTFP	GTFP
Green investment	0.361***			
	(4.27)			
China Securities E score		0.931***		
		(9.64)		
Tail reduction			0.622***	
			(33.61)	
Replace the sample interval				0.588***
				(12.85)
Control variables	YES	YES	YES	YES
Year fixed effect	YES	YES	YES	YES
Industry fixation	YES	YES	YES	YES
Equation 2	lnER1	lne	lwd_w	lwd
ISO	0.217*	0.085**	0.195***	0.184***
	(1.74)	(2.18)	(9.74)	(5.81)
Control variables	YES	YES	YES	YES
Year fixed effect	YES	YES	YES	YES
Industry fixation	YES	YES	YES	YES
correlation coefficient	-0.998***	-0.761***	-0.639***	-0.579***
	(-957.65)	(-18.61)	(-37.52)	(-12.15)
Sample	1417	1417	14137	7069
Estimates of maximum likelihood	-7067	-2349	-28354	-14433

In summary, after a series of robustness tests, the regression results are significant at the significance level of 1%, indicating that the level of corporate environmental regulation significantly improves the green total factor productivity of enterprises, which verifies the conclusion of benchmark regression, and the results are robust.

5. Conclusions and Policy Implications

Enterprises are the source and living water of economic development, and environmental

regulation has a strong driving force in improving the green total factor productivity of enterprises and promoting economic growth. This paper analyzes the text mining of the annual reports of listed companies, uses machine learning methods to generate environmental regulation dictionaries, and then constructs enterprise-level environmental regulation indicators. Through descriptive statistics and empirical analysis, this paper draws the following conclusions: (1) Environmental regulation significantly promotes the green total factor productivity of enterprises. The regression coefficient was 0.231 when controlling for year and industry variables, and the effect was still significant (0.230) even after the introduction of other control variables. (2) Even after controlling for technology type, ownership and location, the regression coefficients were still significantly positive (0.228, 0.222, 0.220, respectively) under different characteristics, indicating that the impact was stable. (3) The decreasing regression coefficient shows that the relationship between enterprise characteristics affecting environmental regulation and green total factor productivity through multiple channels can be analyzed in depth. (4) After controlling for other factors and alleviating endogeneity, each standard deviation improvement in the level of environmental regulation will increase the green total factor productivity of enterprises by 0.80 standard deviations. And after a series of robustness tests, the conclusion is still robust.

Based on the above conclusions, the following policy suggestions are put forward: (1) Strengthen environmental supervision policies. The government should further strengthen environmental regulations to ensure that enterprises comply with environmental standards to promote the improvement of green total factor productivity. Policies may include raising environmental standards and enforcement, and imposing penalties on companies that do not meet standards. (2) Support the development of large-scale enterprises. For smaller firms, especially those with weak resources and technology, it is recommended to provide incentives to encourage them to scale up, so as to enhance their ability to cope with environmental regulations and improve green total factor productivity. (3) Promote the application of green technologies. In order to enhance the ability of enterprises to adapt to environmental regulations, it is recommended that the government and relevant institutions provide technical support and financial subsidies to encourage enterprises to invest in green technologies and innovations, so as to reduce environmental impact and improve production efficiency. (4) Differentiated policy formulation. Taking into account the different characteristics of enterprises, it is recommended to develop more targeted policies. For example, support policies can be designed to encourage environmental protection and productivity improvement efforts of various enterprises, depending on the industry, technology level and form of ownership.

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