The Inverted U-Shaped Effect of Economic Policy Uncertainty on Corporate ESG Performance: A Study Based on Machine Learning Models and Micro Data

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Abstract: In this paper, we first use the traditional econometric models to examine the impact of economic policy uncertainty (EPU) on enterprises' Environmental, Social and Governance (ESG) performance in the economy using a sample of all A-share listed firms from 2007 to 2020. Then, we apply the Python Machine Learning model to further explore the real nonlinear impact of EPU on corporate ESG performance. Our estimation results indicate that the nexus between EPU on enterprises' ESG performance is inverted U-shaped, and the results remain robust after endogeneity treatment and robustness checks. By further investigating the heterogeneous effects of EPU in ESG performance, we find that the inflection point of the effect of EPU on ESG performance is larger for firms in more market-oriented regions and non-state enterprises. For large-scale firms, EPU shows a positive linear relationship with ESG performance rather than an inverted U-shaped relationship. The results of the machine learning model analysis show that the importance of EPU on the impact of corporate ESG is more prominent compared to traditional factors. There is a significant non-linear relationship between the two. Compared with the traditional econometric model, the machine learning model fits better. Our study provides policy insights for policy economic policy implementation and for promoting high-quality economic development.

1 INTRODUCTION

Since it is impossible to know exactly if, when, and how current economic policies will change, there is a high degree of uncertainty about the potential direction and intensity of the economic policy for economic entities, which is called Economic Policy Uncertainty (EPU) in general (Baker et al., 2016; Gulen and Ion, 2016). Firms, as the main micro-objects of economic policy, are inevitably affected by economic policy uncertainty. It has been found that EPU is a "double-edged sword" for firms (Segal et al., 2015). Enhancing corporate reputation by improving social environment performance has been proved to be an effective way for firms to hedge against potential negative shocks ((Kruger, 2015). At present, China is in the stage of high-quality development led by a green economy, and environmental issues are widely emphasized. As the basic unit of economic and social operation, enterprises bear more responsibilities. In this context, the performance of corporate social and environmental responsibility (CSR) and its motivation have become one of the focal points of academic research, and many research results have been accumulated (Yoo and Managi, 2022). However, the system of CSR fulfilment in China is still in the exploration stage. Companies have more freedom to decide whether and to what extent to exercise their social responsibility, which is both determined by internal factors and the external macro environment (Wu and Memon, 2022). Therefore, we should further discuss enterprises' social and environmental behaviours in the context of a larger macroeconomic environment. From this perspective, clarifying the nexus between EPU and corporates' Environmental, Social and Governance (ESG) performance is significant for the implementation of economic policies and the improvement of corporate social and environmental governance.

However, the existing literature so far has been silent on the potential effect of EPU on enterprises' ESG performance despite its importance. Given that, this paper first systematically explore the impact of EPU on corporate ESG performance using traditional econometric model and the panel data of all A-share listed enterprises in China from 2007 to 2020, and further explores how the impact of EPU on ESG performance varies by ownership nature, firm size, and market environment, respectively. Then, we further apply a Machine Learning model to explore the potential nonlinear effects of EPU on corporate ESG performance to reveal the true relationship between the two.

This paper extends the growing body of literature in the following aspects. First, the existing studies on the relationship between EPU and CSR mainly explore the one-way impact of EPU on corporate performance behaviour, ignoring the non-consistent effect of varying degrees of EPU on firms' ESG performance. This paper confirms the inverted U-shaped nexus between EPU and corporate ESG performance, which may contribute to the research on the nexus between EPU and corporate social environmental performance. Second, this paper further explores the external and internal conditions that motivate firms to fulfil their ESG responsibilities under EPU in three dimensions: regional marketization, firm ownership, and firm size, which enriches the study of firms' motivation to fulfil their social and environmental responsibilities. Third, this paper finds that EPU presents heterogeneity in corporate ESG performance across market environments as well as corporate characteristics, which helps guide the government to introduce more targeted macroeconomic policies to encourage corporate to take social and environmental responsibility. Finally, this paper broadens the research approach by combining computer models with economic models to study the nonlinear relationship between EPU and ESG. Machine learning models, as an important frontier research result in the field of artificial intelligence, are applicable to the study of nonlinear problems. Compared with causal inference, machine learning models focus more on the combined effect of an explanatory variable influencing the explanatory variable under the action of multiple factors, which is of great significance to better fit the complex economic system and improve the decision-making predictability of enterprises. Therefore, the machine learning model can better reveal the true nonlinear

influence trend of EPU on enterprise ESG performance.

We proceed as follows. Section 2 briefly summarizes the views of existing studies. Section 3 describes the empirical strategy and the data. Section 4 presents the empirical results. Section 5 concludes and proposes policy implication.

2 LITERATURE REVIEW

Economic policies as well as macro-environmental changes are the basis for corporate social and environmental behavior decisions that cannot be ignored (Ilyas et al., 2021). Research on the nexus between EPU and corporate ESG performance is still in its infancy, and the existing studies have conflicting views that have not yet been agreed upon. On the one hand, EPU deteriorates the information environment of enterprises. Firms will be more prudent in their financial decisions for precautionary purposes (Yang et al., 2020). For enterprises, CSR fulfillment is a special kind of long-term asset investment with long payback period and high uncertainty of return (Zhao et al., 2020). In the face of strong external environmental uncertainty, the value of investment options possessed by firms rises (Bernanke ,1983). Investing more liquid resources in social and environmental activities such as pollution reduction may negatively affect the short-term financial performance of firms by crowding out limited resources, putting them in a financing constraint dilemma (Ho and Wu, 2021). As a result, firms may neglect to fulfill their social and environmental responsibilities in the face of stronger EPU. Several studies provide empirical evidence for it. For example, Zhao et al. (2020) find that when EPU significantly inhibits the fulfillment of corporate social and environmental responsibility, which is more pronounced for state-owned enterprises.

On the other hand, high EPU significantly increases enterprises' external risks (Pastor and Veronesi, 2013). In the Chinese economic environment, active social responsibility is an effective measure to help firms reduce their external risks (Krüger, 2015). For companies, active social and environmental responsibility can reduce the information asymmetry problem between them and their stakeholders, enhance shareholders' and bondholders' investment confidence, and thus facilitate companies' access to scarce competitive assets and core resources (Hartzmark and Sussman, 2019). Moreover, good social and environmental

performance helps firms to establish a quality image in the capital market and create a reputational insurance effect, which in turn improves firms' ability to cope with and mitigate risks and reduces the impact of negative events (Dyck, 2019). There is a body of research that directly or indirectly provides empirical evidence for the positive nexus between EPU and enterprises' ESG performance. For example, Rjiba et al. (2020), Ahsan and Qureshi (2021) find that corporate social and environmental responsibility activities can alleviate the adverse impact of EPU on firm value. Ilyas et al. (2022) find that companies will cushion the negative impact of uncertainty by improving their social environment performance in times of high EPU, similar conclusion has also been reached by Yuan et al. (2022).

In sum, there is no consensus on whether economic policy uncertainty has an "incentive effect" or a "disincentive effect" on the fulfillment of corporate social and environmental responsibility. Putting aside the contradictory results of existing studies, there are still many puzzles. Is there only a one-way effect of EPU on corporate social and environmental behavior? Or does the relationship between the two show non-consistency with changes in economic policy uncertainty? These questions remain to be explored. In this study, we try to answer this question by empirically investigating the non-linear nexus between EPU and corporate ESG performance.

3 DATA AND METHODOLOGY

3.1 Classical Econometric Model

To examine the non-linear relationship between EPU and firm ESG performance, this paper constructs the following benchmark regression model by referring to Zhou et al. (2022).

$$
\begin{aligned}
ESG_{it} = {} & \alpha_0 + \alpha_1 EPU_t + \alpha_2 EPU_t^2 \\
& + \beta X_{it} + \lambda_j + \gamma_i + \theta_t + \varepsilon_{it}
\end{aligned}
\tag{1}
$$

Where, i denotes enterprise, j denotes industry, and t denotes year. The explained variable ESG_{it} is the comprehensive score of corporate social environmental responsibility in year t, which measures the degree of fulfillment of corporate social environmental responsibility. The higher the ESG score, the higher the degree of corporate social and environmental responsibility fulfillment. EPU_t is the core explanatory variable, which refers to the degree

of economic policy uncertainty in year t. In this paper, we use the Chinese EPU index developed and compiled by Baker et al. (2016) using textual data mining method. We draw on the arithmetic mean method proposed by Zhao et al. (2021) to convert the monthly index into the annual one after taking logarithms. X_{it} is a set of control variables in firm-level. Drawing on existing research (e.g., Ilyas et al., 2022), we add a series of control variables to the benchmark model that may affect firms' ESG performance, including the enterprise's total asset net profit rate (ROA), firm age (Age), asset liability ratio (Lev), the proportion of independent directors ($Dire$), and the cash flow rate ($Cashflow$). Also, firm individual-fixed effects γ_i, industry-fixed effects λ_j and year-fixed effects θ_t are included in the model to control for the characteristics of individual heterogeneity of firms that do not vary over time and the potential influences over time. ε_{it} is the random error perturbation term.

3.2 Machine Learning - Random Forest Model

This paper applies the Machine Learning-Random Forest model to the basic data set to further verify the nonlinear impact of EPU on enterprise ESG performance. On the one hand, the idea of splitting a variable in the random forest model is more consistent with the investigation of the importance of variables, which also facilitates us to compare the contribution of EPU with the classical variables that affect the enterprise ESG performance. On the other hand, compared with the traditional econometric models, machine learning models can make full use of the data information of variables in order to improve the accuracy of prediction, and find a more realistic form of complex functions. Referring to Wang et al. (2022), we set the following stochastic forest nonlinear function model.

$$
ESG_{it} = \phi(EPU_t, Controls_{it}, \gamma_j, \theta_t, \varepsilon_{it})
\tag{2}
$$

Where ESG_{it} is the enterprises' ESG performance score. EPU_t is the core explanatory variable, which refers to the degree of economic policy uncertainty. $Controls_{it}$ is a set of control variables, consistent with those in section 3.1. γ_j and θ_t represent industry dummy variable and time dummy variable respectively. ε_{it} is the residual item. $\phi(\cdot)$ is a nonlinear model constructed by Random Forest

method. Since the model is a black box function without analytic expression, we further solve the partial dependence function $\hat{\phi}(\cdot)$ (e.g. $\hat{\phi}(x_1)$ is the partial function of the explained variable to the dependent variable x_1) to further characterize the marginal effect of EPU on the enterprise's ESG performance. Finally, the sample mean is used to estimate the overall mean, as shown in Equation (3).

$$\hat{\phi}(x_1) = \frac{1}{n}\sum_{j=1}^{n} f(x_1, x_{j2}, ..., x_{jp}) \tag{3}$$

3.3 Data Source

This paper selects the ESG scores of all Chinese A-share listed companies from 2007 to 2020 as the research object to study the impact of China's EPU on corporate ESG performance. To ensure the robustness and validity of the results, samples labelled ST, *ST, PT and with more missing data were excluded, and enterprises included in the financial and insurance industries were also excluded. Finally, 9594 valid samples were obtained. Drawing on the measurement method of economic uncertainty proposed by Baker et al. (2016), this paper uses the Economic Policy Uncertainty Index jointly published by the University of Chicago and Stanford University to measure EPU in China. The index is based on the number of articles in the South China Morning Post that contain the words "uncertainty", "China" and "economic policy" as a proportion of the total number of articles in the same month. Some existing studies have also confirmed the applicability of this indicator to measure China's economic policy uncertainty (e.g. Zhao et al., 2021; Ilyas et al., 2022). ESG data are obtained from Bloomberg Databases, which contains index values for three primary indicators: corporate environmental disclosure, social responsibility disclosure, and corporate governance disclosure. It is also a widely used database in the research on determinants and impacts of enterprise ESG performance. The basic information and financial data of the A-shared listed companies involved in the empirical study are obtained from the CSMAR database and the WIND database. The marketability index is obtained from Wang et al. (2017).

4 EMPIRICAL RESULTS

4.1 Basic Results

We first use a two-way fixed panel regression model to preliminarily examine the nexus between EPU and firm ESG performance. Column (1) of Table 1 reports the regression results, which indicates that there is a significant positive nexus between EPU and firm ESG, which is consistent with the research results of Yuan et al. (2022). However, from the previous review of the literature, there is no consensus on whether EPU has an "incentive" or "disincentive" effect on the ESG performance of firms. On the one hand, according to the pecking order theory, On the one hand, referring to the theory of pecking order theory, when facing the potential risks brought by the uncertainty of economic policies, fulfilling social environmental responsibility can be regarded as the insurance paid in advance by enterprises in order to buffer risks. The active engagement in ESG activities can send positive signals to stakeholders and win their confidence, enhance corporate reputation and moral capital, thus alleviate financing constraints to smoothly pass the risk period. On the other hand, based on real options theory, when faced with higher external uncertainty, companies tend to hold off on their current investment decisions, especially investment in social and environmental activities, which is considered a special long-term investment with long payback cycles and high uncertainty of returns. Therefore, when economic uncertainty continues to rise, companies may reduce the fulfillment of their socio-environmental responsibilities.

Based on the above analysis, the nonlinear setting of the effect of EPU on corporate ESG performance may be more accurate. Therefore, we estimate Equation (1) to capture this nonlinear effect. Columns (2) and (3) of Table 1 report the results without and with the introduction of control variables, respectively. The results show that EPU exhibits a significant inverted U-shaped nexus on firm ESG performance at the 1% confidence level, validating the nonlinear nexus between them. This finding suggests that when EPU is at a low level, firms' ESG performance increases as EPU increases. However, when EPU rises and reaches a relatively high level, firms' motivation to engage in ESG activities decreases significantly. The value of this inflection point is 158.9116.

Table 1: Baseline Results.

	(1)	(2)	(3)
EPU	0.2456***	0.8917***	0.7577***
	(0.0055)	(0.1387)	(0.1399)
EPU^2		-0.0028***	-0.0024***
		(0.0006)	(0.0006)
Constant	-7.0547***	-42.4797***	-36.1088***
	(1.9671)	(7.7560)	(7.8133)
Break point			158.9116
Controls	Y	Y	Y
Firm-fixed effect	Y	Y	Y
Industry-fixed effect	Y	Y	Y
Year-fixed effect	Y	Y	Y
Observations	9594	9594	9594
R^2	0.390	0.390	0.395

Note: Robust standard errors are presented in parentheses, ***, ** and * indicate the significance at 1%, 5% and 10%, respectively. The same in Table 2 and Table 3.

4.2 Robustness Tests

Although the uncertainty of economic policy is relatively exogenous for micro enterprises, the performance of micro enterprises is also the motivation and basis for some macroeconomic policy adjustments. Therefore, there may be an inverse causal relationship between EPU and corporate ESG performance. To address this potential endogeneity issue, this paper uses the US EPU index as an instrumental variable for 2SLS estimation. On the one hand, in the context of economic globalization, the effects arising from economic policy changes in one country may be transmitted to another country through activities such as international trade. For example, China's interest rate and exchange rate will soon be affected by changes in U.S. monetary policy. From this perspective, EPU in the U.S. is closely related to that in China. On the other hand, corporate ESG activities belong to the category of corporate social responsibility and are directly influenced by domestic environmental regulation policies as well as institutional culture. Foreign economic policies do not directly constrain the social and environmental behavior of Chinese enterprises. Therefore, we can conclude that EPU in the US is not directly related to Chinese firms' ESG performance. The regression result after introducing the instrumental variables is reported in column (1) of Table 2. After using instrumental variables, there is no under-identification and weak instrumental variables, and the impact of EPU on enterprises' ESG performance remains consistent with the baseline result, indicating the reliability of the results of this paper.

In addition to addressing potential endogeneity issues, this paper also tests the robustness of the benchmark results by replacing the explanatory variables as well as by winsorizing the variables. Specifically, we first replace the arithmetic mean in the benchmark regression with the monthly median value of the EPU index and run the regression again. The regression results are shown in column (2) of Table 2, which remains consistent with benchmark results after replacing the annual EPU index measure. Then, in order to avoid confounding the findings by outliers on a larger scale, we winsorize all continuous variables at the 1% and 99% levels and estimate Equation (1) again. The result in Column (3) is significant at the 1% level, again verifying the robustness of the findings of this paper.

Table 2: Robustness Test Results.

	(1)	(2)	(3)
EPU	0.4939***	0.5412***	0.7984***
	(0.0595)	(0.1660)	(0.1352)
EPU^2	-0.0019***	-0.0015*	-0.0026***
	(0.0002)	(0.0008)	(0.0006)
Controls	Y	Y	Y
Firm-fixed effect	Y	Y	Y
Industry-fixed effect	Y	Y	Y
Year-fixed effect	Y	Y	Y
Observations	9579	9594	9594
R^2	0.290	0.395	0.403

4.3 Heterogeneity Tests

If the marketization of a region is slow, it means that firms in this region are more dependent on government support and lack the tools and ability to hedge the risk of EPU. Higher degree of marketization means stronger the inter-regional linkages in terms of capital markets and trade activities, and the more vulnerable firms are to economic policy changes. Therefore, we further study the impact of EPU on firms' ESG performance under different degrees of marketization, and the results of the group regressions are shown in columns (1) and (2) of Table 3. We can see that for both the high and low marketization groups, there is a significant inverse-U nexus between EPU and ESG performance. The inflection point value for high marketization areas is greater than that of low marketization areas, which indicates that for firms in high marketization areas, active ESG activities is better able to cope with EPU.

Then, the data are grouped and regressed according to SOEs and non-SOEs to further investigate the differences in the impact of EPU on firms with different ownership. Columns (3) and (4)

of Table 3 report the results. We can find that the inverted U-shaped nexus exists in both types of firms. However, the inflection point of SOEs is slightly smaller than that of non-SOEs, indicating that the "insurance effect" of ESG activities is better for non-SOEs than for SOEs. This may be due to the different motives and patterns of resource allocation through CSR between SOEs and non-SOEs.

Finally, the impact of economic uncertainty on ESG performance may be influenced by firm size, given that different sizes of firms may experience different levels of attention and pressure from stakeholders regarding their ESG activities. Given that, we regress the sample in groups based on median firm size. Columns (5) and (6) of Table 3 show the results. It is easy to find that for large-scale firms, the nexus between EPU and ESG of firms shows a significant positive relationship rather than an inverted U-shaped relationship. However, for small-scale firms, higher levels of economic policy uncertainty exhibit an inhibitory effect on ESG, with an inflection point of 140.6926. The possible reason is that, relative to small-scale firms, large firms have sufficient resources to continue their ESG activities, even in an environment of high economic uncertainty.

Table 3: Heterogeneity test results.

	(1) High-mrk	(2) Low-mrk	(3) Soe	(4) Non-soe	(5) Big	(6) Small
EPU	0.8190***	5.1598**	0.7813***	0.7095***	0.5121**	1.0113***
	(0.1946)	(2.0146)	(0.2078)	(0.1931)	(0.2104)	(0.1718)
EPU^2	-0.0025***	-0.0226**	-0.0025***	-0.0022***	-0.0012	-0.0036***
	(0.0009)	(0.0091)	(0.0009)	(0.0008)	(0.0009)	(0.0008)
Break point	161.9973	114.3835	157.4578	161.3996	No	140.6926
Controls	Y	Y	Y	Y	Y	Y
Firm-fixed effect	Y	Y	Y	Y	Y	Y
Industry-fixed effect	Y	Y	Y	Y	Y	Y
Year-fixed effect	Y	Y	Y	Y	Y	Y
Observations	4908	4686	5063	4531	4957	4637
R^2	0.415	0.389	0.411	0.376	0.385	0.425

4.4 Machine Learning Model Analysis of Nonlinear Effects

In Section 3.2, we construct a Random Forest model with continuous dependent variables, uses regression

trees as the basic learners, and selects the splitting nodes with the minimum mean square error as the optimization criterion. Figure 1 depicts the degree of fit between the true value and the predicted value obtained from random forest regression. A comparison of the performance of the Random Forest

model and the classical two-way fixed effect econometric model reveals that the Random Forest model has a greater fitting advantage than the classical econometric model (0.437021>0.395).
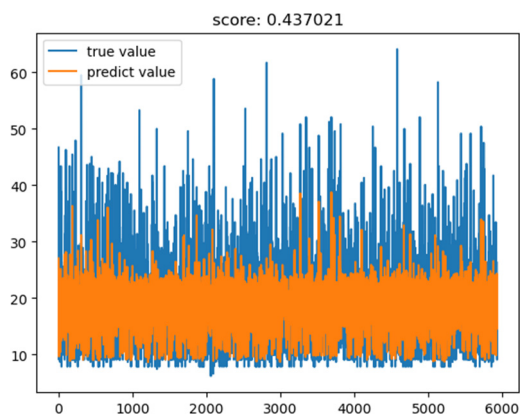

Figure 1: Regression Results Fit Degree Analysis.

We further compared the relative importance of EPU and traditional factors that affect the enterprise's ESG performance. The order of importance of all variable is shown in Figure 2. It can be easily found that EPU has the highest importance among the factors influencing ESG performance, and its importance score is much higher than other traditional factors influencing ESG performance, which confirms the core findings of this paper. The remaining variables with higher importance are firm age (*Age*) and asset liability ratio (*Lev*).
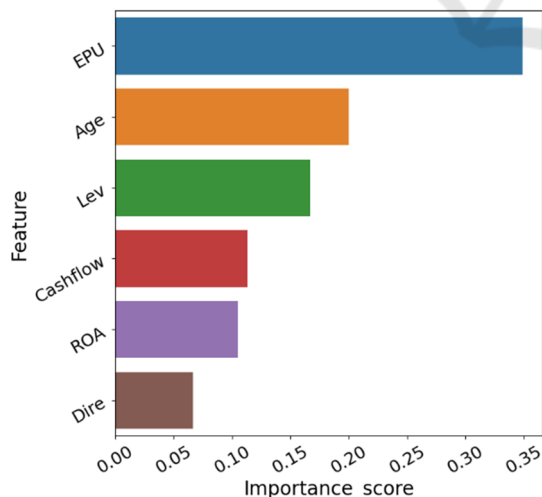

Figure 2: Feature Importance of Random Forest.

To more accurately depict the nonlinear relationship between EPU and enterprise ESG performance, we draw a partial dependence function

to determine the direction of EPU's impact on enterprise ESG performance. The results are shown in Figure 3. The internal scale of abscissa represents the 1/10, 2/10, ..., 9/10 quantile of EPU level. It can be seen that when the EPU level is low (before 1/10 quantile), the EPU and the enterprise ESG show a linear relationship. Then, with the increase of EPU degree, the model response value first decreases and then increases rapidly. After the EPU degree reaches 2/10 quantile, the model response value fluctuates sharply with the change of EPU degree, which strongly indicates the nonlinear relationship between EPU and enterprise ESG performance.
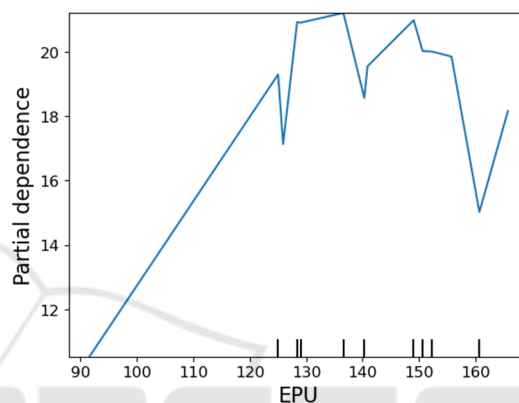

Figure 3: Partial Dependent Function Plot.

5 CONCLUSIONS

Whether companies will fulfil social responsibility as a strategy to cope with risks and whether this strategy changes with EPU are the main issue of concern in this paper. Based on ESG score data, China Economic Policy Uncertainty Index and data of all A-share listed enterprises in China from 2007 to 2020, this paper uses traditional econometric models and Machine Learning-Random Forest models to investigates the non-linear influence of EPU on corporate ESG performance, respectively. The empirical results indicated that there is a significant inverted U-shaped nexus between EPU and corporate ESG performance, which still holds after considering the endogeneity issue and conducting a set of robustness tests. Further analysis finds that the inflection point of the impact of EPU on ESG is larger for enterprises in more market-oriented regions and non-state enterprises, and for large-scale firms, EPU shows a positive relationship rather than an inverted U-shaped relationship with ESG performance. However, for small-scale enterprises, the inverted U-shaped relationship still holds. The results of the

machine learning model analysis show that the importance of EPU on the impact of corporate ESG is more prominent compared to traditional factors. There is a significant non-linear relationship between the two. Compared with the traditional econometric model, the machine learning model fits better.

Based on the above findings, this paper puts forward the following policy insights and suggestions. First, the government should consider the negative impact of policy uncertainty on ESG activities while implementing macroeconomic regulation to stabilize the economy, which requires the government to find an optimal balance between stabilizing the economy and keeping ESG performance at a high level. Secondly, enterprises should establish strategic mechanisms for long-term participation in social responsibility activities, so as to play a buffering role and insurance effect when facing the negative impact of EPU on financing. For example, firms can counter the negative impact of EPU on their financing channels by taking advantage of ESG performance as a non-financial performance signalling advantage: In addition, this paper further finds that the inflection point value is smaller among firms in low-marketing regions and state-owned enterprises, and the ESG activities of small-scale firms are more susceptible to the negative impact of high EPU compared with those of large-scale firms, which is a phenomenon that warrants government attention. When revising the original economic policies or issuing new economic policies, the government can consider giving certain policy preferences to such listed enterprises so that they can maintain a certain level of profitability and actively fulfil their social and environmental responsibilities at the same time.

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