Can Equity Checks and Balances Restrain the "Greenwashing"Behavior of Firms Along the Mining Industry Chain?—Causal Inference Integrating VAE and DML

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Abstract

[Objective] To investigate the inhibitory effect and mechanism of ownership balance on greenwashing behavior of enterprises in the mining industry chain, and to provide theoretical and empirical support for the green transition of the industry. [Methods] Using a sample of 201 listed companies in the mining industry chain from 2010 to 2022, this study constructs a VAE-DML hybrid causal inference framework and validates the conclusions through robustness tests, heterogeneity analyses, and other methods. [Results] Ownership balance exhibits a significant negative causal relationship with greenwashing behavior, with pronounced regional/industry/industry-chain heterogeneity and temporal dynamics. It operates through three channels: alleviating managerial performance pressure, enhancing the stability of the top management team, and strengthening media supervision. [Limitations] The sample does not include non-listed enterprises; the study period is limited; and not all potential mechanisms have been exhaustively explored. [Conclusion] Ownership balance is an effective instrument for curbing greenwashing in enterprises along the mining industry chain and provides an important reference for differentiated governance.

Full Text

Can Equity Balance Curb "Greenwashing" in Mining Industry Chain Enterprises?—A Causal Inference Framework Integrating VAE and DML

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Abstract:
Objective: This study investigates the inhibitory effect and underlying mechanisms of equity balance on greenwashing behavior among mining industry chain enterprises, providing theoretical and empirical support for the sector' s green transition. **Methods:** Using a sample of 201 listed companies in the mining industry chain from 2010 to 2022, we construct a hybrid VAE-DML causal inference framework, complemented by robustness tests and heterogeneity analyses to validate our findings. **Results:** Equity balance demonstrates a significant negative causal relationship with greenwashing behavior, exhibiting regional, industrial, and supply chain heterogeneity as well as temporal dynamics. The effect operates through three pathways: alleviating managerial performance pressure, enhancing executive team stability, and strengthening media supervision. **Limitations:** The sample excludes non-listed enterprises, the research period is limited, and not all potential mechanisms are exhaustively examined. **Conclusions:** Equity balance serves as an effective tool to curb greenwashing in mining industry chain enterprises, offering important references for differentiated governance strategies.

Keywords: Greenwashing; Mining Industry Chain; Double Machine Learning; Causal Inference; Variational Autoencoder (VAE)

1 Introduction

Against the backdrop of increasingly severe global climate change, environmental protection and green sustainable development have become societal consensus. China proposed its "dual carbon" goals in 2020 as a crucial strategic initiative to promote comprehensive green transformation of the economy and society. The Sixth Plenary Session of the 19th Central Committee further emphasized that protecting the ecological environment equates to protecting productive forces, while improving it equates to developing productive forces, highlighting the foundational role of ecological environment in high-quality development.

To implement this strategic call, China has prioritized establishing a comprehensive environmental information disclosure system to 压实主体责任 and strengthen social supervision. The 19th National Congress report first proposed improving mandatory information disclosure systems. In 2021, regulations such as the "Enterprise Environmental Information Disclosure Management Measures" were promulgated, clarifying enterprises'legal obligations for mandatory environmental information disclosure. The 20th National Congress further emphasized

improving the modern environmental governance system.

Consequently, Chinese enterprises face mounting pressure for environmental information disclosure. The mining industry chain, as a typical high environmental-risk sector, has become a focal point for environmental information disclosure and regulation due to significant environmental impacts across extraction, smelting, and processing stages [1][2]. However, the industry simultaneously confronts challenges including poor resource endowments, outdated technology and equipment, and imbalanced industrial structures [3][4][5], creating a contradiction between increasing environmental compliance pressure and limited actual sustainable investment capacity that fosters greenwashing motivations. Real-world cases underscore the severity: In 2021, Xintiandi Iron Mine in Xunwu County, Ganzhou, illegally extracted over 50,000 tons of ore without wastewater collection facilities, causing severe ecological damage through open-air dumping of waste rock and sludge. The same year, Daye Nonferrous Metals Company' s smelter had ineffective waste gas treatment facilities and severely corroded equipment in its acid treatment workshop, resulting in excessive pollutant emissions. In 2022, Yangguang Sand and Gravel Factory' s restoration measures were inadequate, resorting to installing green dust nets and hanging plastic leaves as false rectification instead of substantive ecological restoration. Such behaviors not only conceal actual pollution conditions and cause persistent ecological damage, but also distort environmental information transmission along the industrial chain, seriously misleading policy formulation and ultimately delaying the entire chain' s green transformation [7]. Therefore, curbing greenwashing in mining industry chain enterprises has become an urgent problem.

Existing research systematically examines the drivers of corporate greenwashing from internal governance and external constraints. Regarding internal governance, scholars focus on executive characteristics and ownership structure. Executive characteristics show significant context dependency. For instance, executives'environmental cognition and international background can foster long-term environmental responsibility and inhibit greenwashing under ideal conditions [8][9][10]. However, when facing strong external pressure, environmental cognition may become alienated, shifting from substantive environmental protection to symbolic image maintenance, thereby inducing greenwashing [11]. Additionally, large internal pay gaps intensify executives' short-term profit motives and social comparison psychology, exacerbating greenwashing tendencies [12]. Ownership structure research reveals complex governance effects. Short-sightedness of non-green institutional investors [13], capital and policy conveniences from state shareholders [14], and agency conflicts exacerbated by controlling shareholders' share pledging [15] may all facilitate greenwashing. To address this dilemma, studies find that green institutional investors can promote long-term environmental value and curb greenwashing through synergistic governance effects [13], while executive equity incentives reduce agency costs from decision-making sources by building internal interest communities [16].

External constraints function through information supervision and government regulation, complementing internal governance. Media attention constrains behavior by increasing reputational risks of violations [17][18], while government regulation guides corporate behavior through punitive deterrence [19][20]. Bank regulatory penalties, as powerful government supervision tools, can curb greenwashing through credit constraints, information transmission, and internal control strengthening, with effects varying by corporate heterogeneity and penalty type [21]. Notably, some environmental regulations may increase compliance costs and produce unintended effects without supporting incentives, such as environmental taxes potentially inducing greenwashing to evade regulatory pressure [22].

Existing research generally agrees that the effectiveness of internal governance and external constraints depends on supervisors themselves being effectively supervised. Whether executives pursue short-term interests through greenwashing or external supervision fails due to information asymmetry, both represent typical supervision failures. Specifically, if internal supervisory bodies like supervisory boards lack constraints, they will neglect their duties and tolerate executive opportunism. If external supervisors like regulators and third-party rating agencies operate without oversight, information asymmetry worsens, rendering external supervision superficial. Both scenarios stem from supervisors not being effectively supervised themselves. Therefore, it is necessary to build practical checks and balances from the source of corporate power structures. Equity balance, as a fundamental governance architecture, can effectively constrain controlling shareholders' opportunistic behavior through mutual supervision among multiple large shareholders [23][24], with its governance effects validated across traditional corporate governance dimensions [25][26][27]. This mechanism can strengthen internal supervisors' willingness and effectiveness while reducing information manipulation space and alleviating external supervision' s information asymmetry dilemma. However, current research on equity balance and greenwashing remains insufficient, likely due to theoretical and methodological limitations. Theoretically, as a structural variable, equity balance' s impact on greenwashing often operates indirectly through complex mediating mechanisms. Methodologically, diverse measurement approaches and significant institutional and industry influences weaken the generalizability of existing conclusions.

While prior studies have accumulated findings on equity balance governance effects and greenwashing drivers, few systematically examine their causal mechanisms in the mining industry chain context characterized by high environmental externalities and strong resource dependence. Given that greenwashing in this chain may cause irreversible environmental damage with significant amplification effects, identifying effective governance tools is particularly important. This study uses 201 mining industry chain listed companies from 2010-2022 to empirically examine equity balance' s impact on greenwashing and its mechanisms. Our marginal contributions are threefold: (1) We analyze equity balance and greenwashing in the mining industry chain context featuring high pollution, high resource dependence, and prominent green transformation contradictions, filling

research gaps in segmented industrial chain governance and providing industry-level evidence for precisely curbing greenwashing. (2) We construct a VAE-DML hybrid causal inference framework that combines latent space counterfactual generation with double machine learning orthogonalization, effectively mitigating sample selection bias and providing robust methodological support for accurately estimating causal effects. (3) We integrate behavioral decision theories like prospect theory and self-determination theory with corporate governance theory to deepen understanding of decision-makers' psychological motivations, revealing that equity balance curbs greenwashing by alleviating managerial performance pressure, enhancing executive team stability, and strengthening media supervision, offering new theoretical perspectives on greenwashing drivers and governance.

2 Theoretical Analysis and Research Hypotheses

In mining industry chain enterprises characterized by strong environmental sensitivity and capital intensity, highly concentrated equity enables controlling shareholders to unilaterally dominate corporate decisions. Since mining and smelting activities cause environmental damage, enterprises face stricter environmental disclosure requirements and costly long-term environmental compliance investments. In this context, when controlling shareholders weigh short-term interests against long-term environmental investments, greenwashing motivations arise—using selective disclosure or misleading propaganda to create an environmental image while avoiding substantive investment. Particularly when controlling shareholders separate control rights from cash flow rights through pyramid structures or cross-holdings [24], they create risk-shifting space and expanded power, causing internal supervisory bodies like boards to become ineffective due to large shareholder control. This weakened internal constraint provides space for controlling shareholders' greenwashing opportunism based on personal will and risk preferences. From a behavioral decision perspective, prospect theory suggests decision-makers exhibit loss aversion under uncertainty, valuing loss avoidance far more than pursuing equivalent gains. For mining enterprises, using greenwashing to evade costs may face potential penalties—an uncertain future risk. Moreover, equity concentration forms closed social networks that hinder critical information flow, causing controlling shareholders to underestimate the probability and severity of greenwashing detection and exacerbating decision myopia, making them more likely to view greenwashing as a low-cost strategy to avoid certain expenditures.

In contrast, equity balance as an alternative ownership structure creates a power-checking pattern by introducing multiple large shareholders with comparable stakes. This structure disperses decision-making power, preventing any single shareholder from acting arbitrarily and compressing greenwashing implementation space from the source. This mechanism proves particularly effective in mining enterprises. Due to large investment scales and strong asset specificity, mining industry chain enterprises face high shareholder exit barriers with inter-

ests deeply tied to long-term corporate value. Consequently, shareholders remain highly vigilant against greenwashing that may trigger policy penalties and reputational damage, possessing strong motives to supervise strategic decisions and prevent controlling shareholders' opportunism from harming their interests. Additionally, environmental risks in mining enterprises exhibit systemic characteristics—environmental accidents can trigger chain reactions including production license revocation. This risk profile enables shareholders from different backgrounds to form consensus on environmental compliance, inhibiting greenwashing. Under this ownership structure, when one shareholder proposes greenwashing-suspect decisions, other large shareholders can independently assess through their own information channels and use voting power to check or jointly oppose, raising decision costs and execution risks for such myopic behavior. Therefore, equity balance forms an effective internal supervision and game mechanism that curbs greenwashing by increasing its decision costs and risks, forcing decision-makers to balance interests and make more farsighted decisions. Thus, we propose:

H0: Equity balance has a significant negative causal effect on greenwashing behavior in upstream and downstream mining industry chain enterprises.

Profitability is a key metric for capital markets to evaluate corporate performance. Investors typically use analysts' earnings forecasts as investment judgment basis. For mining enterprises, performance volatility is significantly affected by commodity prices, environmental policy adjustments, and resource reserve changes. For instance, copper and lithium prices frequently fluctuate under multiple supply-demand factors, affecting upstream mining revenues while constituting cost pressures for midstream smelters. Environmental policy differences directly impact compliance costs, while resource reserve changes create supply uncertainty, exacerbating performance volatility. Since these external factors are uncontrollable, performance below expectations often occurs, triggering shareholder dissatisfaction and exposing management to salary cuts or dismissal risks [28]. To evade such risks, management may adopt greenwashing to reduce compliance costs and embellish short-term performance. This behavioral tendency stems not only from economic considerations but also from external pressure' s impact on intrinsic motivation. Self-determination theory posits that individuals have an intrinsic need for autonomy. When autonomy is supported, they are more likely to make decisions aligned with long-term interests. When management chronically faces performance pressure from controlling shareholders, this external control severely inhibits their autonomy, limiting behavioral goals to short-term performance metrics and increasing tendencies toward greenwashing opportunism to embellish performance, weakening intrinsic motivation for long-term organizational value.

Equity balance governance structures alleviate this dilemma by introducing diversified shareholder interests. In capital-intensive industries like mining with long investment recovery periods and prominent environmental/social risks, heterogeneous shareholder demands are intensified by industry characteristics. Fi-

nancial investors may focus on short-term cash flow returns, while strategic or state shareholders emphasize long-term resource reserve control and development. When addressing environmental risks, shareholders from different backgrounds exhibit significant disagreements on preventive investment scale—those with high asset specificity and sunk costs tend to front-load investments to avoid risks, while those with strong asset liquidity resist such investments to protect short-term returns. Consequently, management must coordinate multiple demands, gaining greater discretion and transforming from passive implementers to managers with certain decision-making autonomy. In this process, management performance pressure is alleviated, and behavioral motivations shift from external pressure-driven to intrinsic value identification, fundamentally weakening greenwashing tendencies to embellish performance. Moreover, heterogeneous shareholder interests create internal checking mechanisms that buffer and correct myopic goals, steering corporate decisions toward strategic balance and long-term value. Therefore, equity balance curbs greenwashing by enhancing management autonomy and intrinsic motivation while correcting myopic goals through checking mechanisms, guiding management decisions toward long-term value creation through dual motivation and goal pathways.

Executive team stability is crucial for long-term healthy development, particularly in technically and managerially specialized mining industries. Stable executive teams facilitate effective accumulation and inheritance of professional experience while building lasting, trust-based relationships with mining communities, laying foundations for coherent long-term environmental strategy formulation and execution. However, when executive positions lack security and face replacement threats, psychological threat rigidity effects emerge, narrowing cognition and causing reliance on existing solutions while avoiding long-term investment and innovation, focusing decision goals on short-term self-protection. Moreover, job insecurity significantly strengthens extrinsic motivation, manifested as excessive external approval-seeking that exacerbates myopic decision-making. Prospect theory similarly suggests that executives with low job security are more sensitive to potential losses. Consequently, substantive environmental transformation with large investments and long cycles is perceived as high-risk, while low-cost greenwashing that creates good environmental appearances becomes a strategy aligning with short-term risk avoidance needs.

Conversely, stable executive teams help members build deep emotional connections with enterprises under organizational identity theory, binding personal success with long-term corporate development. This motivates executives to cherish long-term reputation and sustainable development, actively avoiding greenwashing that may damage corporate credibility. Existing research also shows that executive team stability reduces agency costs, making management more attentive to corporate sustainability than short-term interests [29], and more inclined to disclose authentic, comprehensive environmental information to build sustainable competitive advantages [30]. Equity balance further curbs greenwashing by ensuring executive team stability. On one hand, this structure prevents single shareholders from arbitrarily appointing or removing executives,

providing stable tenure environments. On the other hand, it reduces executive turnover risks caused by decision conflicts through multi-shareholder consultation mechanisms, protects their legitimate rights through standardized governance structures, lowers voluntary turnover rates, and maintains team stability. Meanwhile, stable tenure environments strengthen interest alignment between executives and long-term corporate development, enhancing their motivation to maintain corporate reputation and making them more attentive to long-term environmental compliance and information authenticity, fundamentally inhibiting greenwashing.

In mining enterprises with highly concentrated equity, controlling shareholders can systematically weaken media supervision effectiveness through their decision-making dominance. Due to the high professionalism and operational closure of mining and smelting activities, published environmental data are often difficult for outsiders to independently verify. Therefore, controlling shareholders can filter and embellish unfavorable environmental data at the information source, placing media supervision at a disadvantage from the outset. Moreover, when negative environmental information faces exposure risks, controlling shareholders can mobilize corporate funds to exert public relations pressure on media through advertising cooperation influence or affiliate pressure, increasing investigation resistance. Under such pressure, media often downplay or abandon relevant reports, weakening their supervisory role. With ineffective internal checks, such behaviors often avoid internal accountability, further strengthening controlling shareholders' motivations to manipulate environmental information. Ultimately, multiple factors suppress media supervision' s information channels and reporting space, severely weakening external governance and creating conditions for controlling shareholders to manipulate environmental information and implement greenwashing.

Conversely, equity balance strengthens external governance mechanisms like media supervision by introducing diversified shareholder interests. Heterogeneous interests among multiple large shareholders create competitive information environments. When greenwashing damages certain shareholders' interests, they have strong motivations to release information to media to check other parties, breaking internal information monopolies [31] and transforming enterprise-media relations from unilateral suppression to multi-party games. Under this model, enterprises cannot block information, while media gain stable information sources, substantially improving supervision precision and deterrence and increasing greenwashing detection probability and punishment certainty. Existing research confirms that media supervision can force enterprises to abandon greenwashing and improve environmental performance by exposing violations and triggering regulatory intervention, causing reputational losses [32][33]. For mining enterprises with prominent environmental and social impacts, media exposure' s social amplification effect is particularly strong, creating powerful psychological deterrence. Consequently, to maintain resource acquisition and social legitimacy, enterprises internalize environmental pressure into decision criteria, transforming environmental compliance from cost expenditure to strategic

investment, driving abandonment of greenwashing and shift toward substantive environmental governance. Based on this, we propose:

H1: Equity balance curbs greenwashing behavior in upstream and downstream mining industry chain enterprises by reducing management performance pressure, enhancing executive team stability, and increasing media supervision intensity.

3.1 Research Methods

(1) Variational Autoencoder (VAE)

The fundamental obstacle in causal inference is the unobservability of counterfactuals. For any given sample, only the actual outcome under one treatment can be observed, while the potential outcome under alternative treatments remains forever unobserved, creating the core data missing problem in causal discovery. Traditional causal methods primarily rely on observational data and statistical adjustments to simulate counterfactuals, but their validity heavily depends on unverifiable assumptions (e.g., no unmeasured confounding) and correct model specification. Variational Autoencoder (VAE) is a neural network generative model that integrates autoencoder architecture with variational inference, learning data latent representations and generating new samples through unsupervised learning. Its core objective is learning a probability distribution of latent variables to generate new samples similar to input data [34]. VAE' s unique probabilistic generation capability enables high-quality, diverse counterfactual sample generation, overcoming observational data limitations. The specific implementation process is shown in Figure 1 [Figure 1: see original paper].

Figure 1 illustrates the complete VAE-based counterfactual data generation process: First, original data undergo preprocessing to construct a VAE model comprising an encoder, latent space, and decoder, with loss functions composed of mean squared error and KL divergence with coefficient β. During iterative training, the encoder outputs latent variable mean μ and variance σ^2 based on input data. After reparameterization sampling in latent space to obtain latent variables, these are input to the decoder to generate initial counterfactual drafts. The model trains through loss functions and backpropagation to update network parameters until generated counterfactual data passes quality verification via SMD, MAE, MSE and other metrics. The validated counterfactual data are then combined with original data and input into the Double Machine Learning (DML) model [35] to complete causal effect estimation.

(2) Double Machine Learning Model

Subsequently, the key to causal discovery is unbiasedly and robustly estimating causal effects from these extended datasets containing both factual and counterfactual data. While VAE generates counterfactual data through latent space interventions, residual confounding effects may remain incompletely stripped [36]. Moreover, simply calculating global average treatment effects cannot pre-

cisely depict heterogeneous causal effects varying with individual characteristics. DML can further strip residual confounding potentially missed by VAE by analyzing relationships between residuals of treatment and outcome variables, and support estimation of conditional average treatment effects [35]. Therefore, this study adopts DML for causal discovery, as shown in equations (1) and (2):

In equation (1), Y is the outcome variable representing corporate greenwashing behavior; D is the treatment variable representing equity balance degree; X is a multi-dimensional control variable including macro factors, industry factors, and internal corporate characteristics; $g(\cdot)$ and $m(\cdot)$ have unknown specific forms but can be estimated through machine learning methods; U and V represent error terms for outcome and treatment variables respectively, both with conditional means of 0. The treatment effect is $\theta = E[g(D = d, X) - g(D = d_0, X)]$, where d and d_0 represent different value combinations of the treatment variable.

In equations (1) and (2), $g(X)$ and $m(X)$ require estimation using machine learning algorithms. In this study' s first stage, gradient boosting decision trees estimate $g(D, X)$ and $m(X)$ to obtain $\hat{g}(D, X)$ and $\hat{m}(X)$, then calculate residuals $\hat{Y}$ and $\hat{D}$. The second stage uses linear regression with ordinary least squares (OLS) to estimate the effect of residual $\hat{D}$ on residual $\hat{Y}$, thereby calculating the causal effect estimate $\hat{\theta}$.

3.2 Variable Selection

(1) Outcome Variable

This study uses the degree of corporate environmental information embellishment as the greenwashing measure. Environmental information embellishment refers to the discrepancy between disclosed environmental information text volume and substantive environmental information disclosure volume, measuring the extent to which enterprises use textual information to package substantive environmental disclosures.

To comprehensively measure environmental information text volume, we follow Zhang et al. [37] by collecting 56 Chinese environmental policy documents including the "Environmental Protection Law of the People' s Republic of China," extracting terms related to green low-carbon, ecological environment, and pollution control. Combined with environmental keywords from existing literature, after deduplication and manual review, we obtained 1,749 environmental keywords to establish a keyword library. Using web crawlers, we retrieved corporate social responsibility reports and environmental reports from CNInfo, converted them to text format using the pdfplumber module, added the environmental keyword library to custom dictionaries, and performed precise word segmentation using the jieba module. After removing Chinese stop words, we calculated total report word frequency and environmental keyword frequency, using the ratio between them to measure text disclosure volume.

The substantive disclosure indicator system is constructed from reliability and

specificity dimensions of environmental information. As shown in Table 1 , each indicator is scored to obtain substantive disclosure scores ranging from [0,36]. We then measure environmental embellishment through the deviation between text disclosure volume and substantive disclosure volume, as shown in equation (3).

Table 1 Corporate Substantive Disclosure Indicator System
(Table content preserved with structure showing indicators and scoring criteria)

Equation (3) standardizes both text and substantive disclosure volumes before calculating their difference:

$$GW_{i,t} = \frac{mw_{i,t} - \text{mean}(mw_t)}{\text{sd}(mw_{i,t})} - \frac{mr_{i,t} - \text{mean}(mr_t)}{\text{sd}(mr_{i,t})} = mws_{i,t} - mrs_{i,t}$$

where $\text{mean}(mw_t)$ and $\text{mean}(mr_t)$ are annual means of text and substantive disclosure volumes, $\text{sd}(mw_{i,t})$ and $\text{sd}(mr_{i,t})$ are their annual standard deviations, and $mws_{i,t}$ and $mrs_{i,t}$ are standardized text and substantive disclosure volumes.

(2) Treatment Variable
Equity balance refers to an ownership pattern where multiple large shareholders mutually check each other to prevent single-shareholder control abuse. Its intensity is typically measured by other large shareholders' checking ability against the largest shareholder, with values ranging from [0,1). Values closer to 1 indicate stronger checking ability. This study uses the ratio of the sum of the second to tenth largest shareholders' ownership to the largest shareholder' s ownership. For enhanced reliability, subsequent robustness tests use alternative measures: the ratio of the second to fifth largest shareholders' sum to the largest shareholder, and the second shareholder' s checking ability against the largest shareholder [24].

(3) Control Variables
We select 12 control variables: firm size, firm age, asset-liability ratio, return on total assets, ownership concentration, independent director ratio, property rights nature, CEO duality, executive incentives, firm growth, industry competition, and regional environmental pollution degree. Details are shown in Table 2 .

Table 2 Control Variable Definitions
(Table content preserved with variable definitions and data sources)

3.3 Data Sources and Descriptive Statistics

This study collected 1,743 observations from 201 upstream and downstream mining industry chain enterprises during 2010-2022. Given limited original data volume and potential feature distribution bias that could weaken causal relationship identification reliability and limit DML' s ability to control high-dimensional confounders, we used VAE combined with resampling methods to

generate 1,743 counterfactual data points. Verified through SMD, MSE, and MAE metrics, the generated data showed no significant distribution differences from original data, effectively avoiding distribution shift. The combined original and counterfactual data were then input into the DML model to estimate causal effects. Descriptive statistics of the combined data are shown below:

Table 3 Descriptive Statistics
(Table structure preserved showing sample size, mean, median, standard deviation, min, and max for key variables)

4.1 Causal Inference Results

To ensure causal inference accuracy and robustness, we employ cross-fitted double machine learning models with a 1:4 sample split ratio, estimating based on both original datasets and combined datasets integrating VAE-generated counterfactual data to systematically identify equity balance' s causal effect on greenwashing.

(1) Causal Effect Estimation Based on Original Dataset
Initial causal inference using the original dataset yields results shown in Table 4 . Analysis reveals negative coefficient estimates for equity balance, indicating preliminary signs of a negative relationship with greenwashing.

Table 4 Causal Inference Results Using Original Data
(Table structure preserved showing coefficient estimates and standard errors)

However, robust standard errors in Table 4 are relatively large, yielding low estimation precision with no coefficients passing statistical significance tests. This suggests that relying solely on original samples may fail to clearly and stably identify causal effects due to limited sample size and selection bias.

(2) Causal Effect Verification Using Combined Dataset
To overcome original dataset limitations, we re-estimate using the combined original and counterfactual dataset, with results shown in Table 5 . Compared with Table 4, results change substantially.

Table 5 Causal Inference Results Using Combined Data
(Table structure preserved showing significant negative coefficients)

Comparison reveals: First, the doubled sample size improves estimation efficiency and reduces sampling error. Second, equity balance coefficients in Table 5 are highly significant at the 1% level with substantially smaller robust standard errors than Table 4, indicating material improvement in estimation precision. Causal inference must consider different scenarios and possibilities —counterfactual data constructs virtual control scenarios highly similar to real samples, effectively filling "non-intervention" data gaps in observational data and enhancing statistical inference stability and causal effect identification credibility. These results clearly identify a robust negative causal effect of equity balance on greenwashing, supporting hypothesis H0. In summary, phased causal

inference results demonstrate that introducing counterfactual data to construct combined datasets significantly improves causal identification precision and reliability, validating the core conclusion that equity balance inhibits greenwashing in mining enterprises.

4.2 Robustness Tests

(1) Winsorization and Model Algorithm Replacement
We verify conclusion robustness through data processing and model specification tests. First, to eliminate extreme value impacts from geographical and economic differences, we apply 1% two-sided winsorization to all variables and re-estimate. Second, to ensure results are unaffected by model specification and sample split ratios, we replace DML algorithms with LASSO, XGBOOST, and Random Forest, and use 1:2 and 1:7 split ratios instead of 1:4. Results are shown in Table 6 .

Table 6 Robustness Test Results
(Table structure preserved showing consistent negative effects across algorithms and split ratios)

After 1% winsorization, the causal effect coefficient is -0.3412, highly significant at 1%, indicating core conclusions are unaffected by extreme values. Algorithm replacement tests show significant negative causal effects across LASSO, XGBOOST, and Random Forest. Different sample split ratios yield consistent results. These findings demonstrate that the core conclusion— "equity balance curbs mining enterprise greenwashing"—is highly reliable and unaffected by data processing methods, algorithm selection, or sample split ratio changes, supporting hypothesis H0.

(2) Alternative Treatment Variables
To ensure reliability, we conduct robustness tests using two alternative indicators to exclude measurement method interference.

Table 7 Robustness Results with Alternative Treatment Variables
(Table structure preserved showing significant negative coefficients across alternative measures)

Results show that using both alternative indicators, causal effect coefficients remain significantly negative at 1% across different control variable and fixed effect combinations. This confirms that equity balance' s inhibitory effect on greenwashing is robust to variable measurement approaches, further validating conclusion reliability and hypothesis H0 robustness.

(3) Comparison with Traditional Causal Inference Methods
To exclude framework bias, we further employ four traditional causal inference methods—Propensity Score Matching (PSM), Inverse Probability Weighting (IPW), Causal Forest, and Bayesian causal inference—for robustness testing. Re-estimation using combined data yields results shown in Table 8 .

Table 8 Traditional Causal Inference Method Results
(Table structure preserved showing significant negative effects across all methods)

All four traditional methods support equity balance' s inhibitory effect on greenwashing, with causal effect coefficients of -0.2934, -0.3385, -0.1168, and -0.0880 respectively, all passing significance tests. These results completely align with the DML main model, indicating the negative causal relationship is robust across methods, supporting hypothesis H0. Variations in effect values across methods align with their characteristics—PSM and IPW control observable confounders, yielding values close to DML, reflecting DML' s precision advantages in handling high-dimensional nonlinear confounding; Causal Forest, sensitive to variable interactions due to its focus on heterogeneous effects, shows relatively smaller values; Bayesian methods, based on posterior probability inference, produce more conservative results. Despite reasonable numerical differences, all methods consistently show significant negative causal relationships, further confirming conclusion robustness and reliability from a methodological perspective.

4.3 Heterogeneity Analysis

(1) Regional Heterogeneity Analysis
Since regions differ significantly in industrial structure and environmental regulation intensity, we examine regional heterogeneity by testing three regions—central, eastern, and western—to reveal differentiated mechanisms.

Table 9 Regional Heterogeneity Analysis
(Table structure preserved showing coefficients for each region)

Eastern region shows the weakest effect (-0.1166) but still supports H0, primarily due to higher marketization, complete environmental regulation systems, and effective external governance mechanisms like media supervision that compress violation space. Eastern enterprises also have more mature governance structures where board supervision and independent director systems partially substitute equity balance functions, limiting marginal governance contributions. Central region shows moderate effect (-0.3079), supporting H0. As an industrial transfer area, central region' s environmental regulation intensity lies between east and west with some policy flexibility. Equity balance effectively compensates for minor external regulatory gaps through multi-shareholder collaborative supervision, forming stable governance effects. Western region shows the strongest effect (-0.5422), supporting H0. As mineral resource-rich areas with insufficient regulatory coverage in some regions, enterprises have stronger greenwashing motives. State capital shareholders' high attention to environmental compliance makes equity balance the most important internal governance mechanism, demonstrating the strongest constraint effect.

(2) Industry Heterogeneity Analysis
Different industries' operational attributes, regulatory environments, and risk characteristics may affect equity balance' s inhibitory effect. We select ten industries based on "National Economic Industry Classification and Codes" (GB/T

4754-2017) for heterogeneity analysis to control for industry-specific interference. Results are shown in Tables 10 and 11 .

Table 10 Industry Heterogeneity Analysis (Mining)
(Table structure preserved showing coefficients for mining industries B06-B11)

Equity balance shows significant industry heterogeneity. B06 (coal) and B07 (oil & gas) show significant negative causal effects, supporting H0. B06' s significance stems from high pollution and strict regulation with persistent environmental pressure and prominent greenwashing motives. Large-scale enterprises with diversified ownership provide shareholders with adequate supervision motivation to avoid penalties and maintain long-term reputation. Equity balance effectively prevents single shareholders from sacrificing environmental investment for short-term gains. B07' s stronger effect relates to its national strategic status and governance rigidity—strict environmental requirements and high social attention make greenwashing extremely costly. Dominated by large state-owned enterprises with standardized ownership structures, shareholders have direct and efficient environmental compliance supervision channels, enabling equity balance to precisely strengthen decision supervision. In contrast, B08 (ferrous metal mining), B09 (non-ferrous metal mining), and B11 (mining support activities) show no significant effects due to laxer regulation, more concentrated ownership, smaller enterprise scale, and weaker greenwashing motives.

Table 11 Industry Heterogeneity Analysis (Manufacturing)
(Table structure preserved showing coefficients for manufacturing industries C25-C33)

In manufacturing, equity balance shows significant differences. C25 (fuel processing), C32 (non-ferrous metal smelting), and C33 (metal products) show significant negative causal effects at 1%, supporting H0. C25 shows the strongest effect due to its core position in fossil energy processing with extreme environmental sensitivity, strict regulation, and high greenwashing costs. Standardized ownership structures enable smooth shareholder supervision channels, creating rigid constraints. C32 faces huge environmental pressure as a high-pollution, high-energy consumption core link, with diversified ownership motivating shareholders to actively supervise to avoid risks and protect reputation. C33 has relatively lower pollution intensity but its surface treatment processes involve hidden pollution, and scaled enterprises with relatively diversified ownership enable non-controlling shareholders to supervise through governance channels. However, C30 (non-metallic mineral products) and C31 (ferrous metal smelting) show no significant inhibition. C30' s internal differentiation between strictly regulated cement plants and loosely regulated ceramic plants prevents unified supervision standards and motivation. Predominantly small-medium private enterprises with concentrated ownership lack supervision channels. C31' s high state-owned proportion faces disputes between massive environmental investment and short-term performance, weakening equity balance's supervisory effect through internal interest coordination needs.

(3) Mining Industry Chain Link Heterogeneity Analysis
To examine whether equity balance' s effect varies by chain position, we divide the sample into upstream, midstream, and downstream based on production division. Upstream includes B06, B07, B08, B09, and B11, conducting exploration and extraction as raw material providers. Midstream covers C25, C30, C31, and C32, processing and smelting minerals into industrial raw materials or semi-finished products. Downstream is represented by C33, as it best reflects downstream value transmission and processing attributes through direct processing of midstream products, representing key value-added steps. Terminal industries like construction have become integrated material consumption scenarios where mineral products are no longer core processing objects, so we confine downstream to C33.

Table 12 Mining Industry Chain Link Heterogeneity Analysis
(Table structure preserved showing upstream, midstream, and downstream effects)

Results show structural differences in equity balance' s inhibitory effect along the chain: strongest and highly significant upstream effect, weaker midstream effect, and strong but statistically insignificant downstream trend.

Upstream effect is -0.3989, significant at 1%, the strongest, supporting H0. This stems from direct resource extraction involvement with strict environmental regulation, high social attention, and large violation risks. Minority shareholders have strong motivation to constrain controlling shareholders' greenwashing for short-term extraction profits. Midstream effect is -0.1488, significant at 5%, supporting H0, possibly because profitability relies more on scale and technology, environmental investment is often viewed as cost, and some costs can be transferred through the chain, reducing overall shareholder environmental compliance demands. Controlling shareholders' dominance in scaled production also limits checking mechanism space. Downstream effect is -0.4018, not statistically significant but with large absolute value and inhibition trend comparable to upstream, partially supporting H0. Downstream enterprises face consumer markets where environmental reputation closely ties to brand value, giving shareholders supervision motivation. Non-significance may stem from limited sample size reducing statistical power, though coefficient direction already reflects inhibition tendency.

4.4 Temporal Effects Analysis

Since corporate greenwashing is influenced not only by cross-sectional characteristics like industry attributes but also by time-varying external conditions such as macro environment, we further control for time fixed effects to remove systematic shocks and ensure unbiased equity balance estimates. Results are shown in Table 13 .

Table 13 Temporal Effects Analysis
(Table structure preserved showing lagged effects)

Results indicate equity balance' s inhibitory effect on greenwashing decreases over time but remains significantly cumulative. The contemporaneous effect is -0.2514, significant at 1%, showing immediate governance effects, likely because equity balance forms effective internal supervision synergy—once greenwashing tendencies emerge, shareholders can quickly intervene and pressure, promptly curbing opportunism. Although the effect weakens over time, it remains statistically significant, reflecting persistent deterrence that influences management' s long-term behavioral expectations. The cumulative effect is -0.0660, significant at 1%, indicating equity balance not only constrains greenwashing in the short term but also improves corporate governance atmosphere and stabilizes/strengthens green information disclosure norms over longer periods.

4.5 Mechanism Analysis

Following Liu and Mao [38] and practices in authoritative economics and management journals since 2022, we empirically analyze causal effects of the treatment variable on three mediating variables: management performance pressure, executive team stability, and media supervision.

Since management performance receives multifaceted internal and external attention, gaps between actual and expected performance create management performance pressure (Pressure) [39], calculated as:

$$\text{Pressure} = \frac{\text{Analyst Forecast Net Profit} - \text{Actual Net Profit}}{\text{Ending Total Assets}}$$

where analyst forecast net profit uses the average of all analysts'annual net profit forecasts for the company. To mitigate endogeneity from reverse causality, the Pressure variable is lagged by one period—only when performance expectation gaps occurred in the previous year is management considered to face performance pressure in the current year. Higher Pressure values indicate greater management performance pressure.

Executive team stability (TSTA) follows Luo et al. [30] with the formula:

$$\text{TSTA}_{t,t+1} = \frac{M_t - (S_t/S_{t+1})}{M_t + M_{t+1}} + \frac{M_{t+1} - (S_{t+1}/S_t)}{M_t + M_{t+1}}$$

where M_t and M_{t+1} represent total executive numbers in years t and $t+1$, while S_t/S_{t+1} and S_{t+1}/S_t represent executives who left between t and $t+1$ and newly joined executives in $t+1$ respectively. TSTA ranges from (0,1], with values approaching 1 indicating higher stability.

Media supervision intensity follows Li et al. [40], measured using the J-F coefficient based on media report data from the China Research Data Services Platform (CNRDS) financial database:

$$\text{J-F Coefficient} = \begin{cases} \frac{e^2-ec}{ec-c^2} & \text{if } e > c \\ \frac{c^2-ec}{ec-e^2} & \text{if } e < c \end{cases}$$

where e is positive reports, c is negative reports, and t is total reports. The coefficient ranges from -1 to 1, reflecting media supervision intensity. Values approaching 1 indicate weaker supervision, while values approaching -1 indicate stronger supervision.

Results analyzing the three channels are shown in Table 14 .

Table 14 Mechanism Analysis Results
(Table structure preserved showing coefficients for each mechanism)

From the management performance pressure dimension, equity balance' s causal effect is -0.0066, significant at 1%, indicating that increased equity balance significantly alleviates executive performance pressure. Under equity balance, diversified shareholder interests create more balanced corporate assessment systems that consider long-term development, effectively reducing pressure to sacrifice environmental investment for performance targets and weakening greenwashing motivations to cover performance deficiencies, supporting H1.

From executive team stability dimension, equity balance's causal effect is 0.0057, significant at 5%, showing that higher equity balance promotes team stability. Equity balance constrains controlling shareholders' arbitrary executive appointments through multi-shareholder collective decision-making, ensuring stable tenure. Stable executive teams prioritize long-term value and career reputation, giving them greater motivation to implement genuine environmental investment rather than greenwashing, supporting H1.

From media supervision dimension, equity balance' s causal effect is 0.0117, significant at 5%, indicating that equity balance enhancement effectively strengthens media supervision. The mechanism operates as: under equity balance, minority shareholders have motivation to promote information transparency to protect their interests, reducing internal information asymmetry; concurrently, relatively standardized governance attracts media attention. Combined information transparency and media attention significantly increase greenwashing exposure risk, creating effective deterrence and inhibiting greenwashing motivation, supporting H1.

5 Conclusions and Policy Recommendations

Using double machine learning models on combined data, this study deeply investigates equity balance' s causal effect on corporate greenwashing, conducting robustness tests, heterogeneity analysis, temporal effects analysis, and mechanism analysis. Core conclusions are:

(1) **Causal Effect:** Equity balance has a significant negative causal relationship with greenwashing behavior. This conclusion remains robust after

extreme value treatment, algorithm replacement, sample ratio adjustment, and validation against traditional causal inference methods, effectively excluding potential bias interference.

(2) **Systematic Heterogeneity:** The inhibitory effect shows regional, industrial, and supply chain differences. Regionally, it presents a west-strong-east-weak gradient, with western regions showing the strongest governance substitution effect due to relatively weak regulatory environments. Industrially, high environmental sensitivity sectors show clear inhibition, while effects are limited in sectors with 粗放 governance structures. Along the supply chain, upstream extraction shows the strongest effect, midstream processing weakens due to cost transfer characteristics, and downstream manufacturing shows inhibition trends but insufficient statistical significance.

(3) **Temporal Dynamics:** The inhibitory effect shows time lag—contemporaneous effects are strongest, reflecting immediate shareholder supervision constraints; lagged effects decrease over time but remain significant, indicating persistent governance mechanism effects.

(4) **Mechanism Verification:** Equity balance curbs greenwashing through three pathways: alleviating management performance pressure, enhancing executive team stability, and strengthening media supervision. These pathways respectively weaken short-term motives, safeguard long-term orientation, and enhance external constraints, forming a complete internal governance-external supervision transmission mechanism.

Based on these conclusions, we propose:

(1) **Optimize Internal Governance:** Guide enterprises to build full-cycle supervision systems integrating equity balance and environmental governance. Promote establishing environmental supervision committees under boards, incorporate environmental performance into executive assessments, and create rapid response mechanisms for shareholder proposals to strengthen immediate supervision effectiveness. Given the diminishing equity balance effect over time, establish lagged tracking mechanisms for environmental responsibility fulfillment, requiring regular compliance progress disclosure to shareholders and linking compliance performance with compensation and dividend incentives to sustain governance pressure. Encourage enterprises to write substantive environmental targets into articles of association and embed environmental responsibility into governance structures through shareholder-appointed board participation, achieving organic integration of short-term constraints and long-term norms to comprehensively enhance environmental governance standardization and sustainability.

(2) **Implement Differentiated Governance Strategies:** Regionally, eastern regions should combine equity balance with market mechanisms like analyst attention and strengthen minority shareholders' environmen-

tal litigation rights; central regions can leverage industrial agglomeration advantages to build shareholder environmental co-governance platforms and establish special transition funds to address regulatory gaps; western regions need increased green transition subsidies and joint professional institutional investors to enhance local shareholder supervision capacity. Industrially, high environmental sensitivity sectors should strengthen shareholders' environmental supervision rights and improve emission disclosure mechanisms; sectors with concentrated ownership or 粗放 governance should be guided to introduce strategic investors and broaden minority shareholder governance channels; state-dominated sectors should link environmental investment with performance assessments to 压实 state shareholder supervision responsibility. Along the supply chain, upstream should strengthen minority shareholders' environmental supervision rights, midstream should establish environmental cost internalization mechanisms to prevent responsibility shifting, and downstream can enhance governance effectiveness through green procurement and other market means while establishing cross-link environmental responsibility traceability systems to build multi-level, differentiated collaborative governance systems.

(3) **Build Multi-Stakeholder Supervision Networks:** Government departments should establish information sharing and joint enforcement mechanisms between environmental and securities regulators, incorporating enterprise equity balance effectiveness into environmental credit evaluation systems. Activate market and social supervision by supporting third-party assessments of equity balance and greenwashing risks, encouraging media focus on high-risk enterprises with supervision reward mechanisms, and guiding public participation in environmental information questioning and feedback. Through comprehensive linkage among government, market, and society, create favorable supervision environments for equity balance to curb corporate greenwashing.

References

[1] Ren H, Liu M, Wang Z, et al. Research on China' s manganese ore resources and industrial chain security issues[J]. *Chinese Engineering Science*, 2022, 24(3): 20-28.
[2] Zuo Z, Cheng J, Guo H, et al. Evolution and evaluation of structural resilience in lithium industry chain trade networks[J]. *China Population, Resources and Environment*, 2024, 34(02): 155-166.
[3] Ren Z, Jiang M, Behrens P, et al. Declining demand and circular transition possibilities of sand, gravel and crushed stone in China[J]. *Nature Communications*, 2025, 16(1): 9294.
[4] Wei Y M, Liu L C, Kang J N, et al. Navigating energy transition solutions for climate targets with minerals constraint[J]. *Nature Climate Change*, 2025, 15(8): 833-841.

[5] Gan Y, Peng S, Mao J, et al. Research on high-quality development strategy of China' s critical mineral and material industry supply chain[J]. *Chinese Engineering Science*, 2022, 24(3): 1-9.
[6] Gao W. Will new CEOs' career concerns intensify corporate "greenwashing" ?[J]. *Science & Technology Progress and Policy*, 2025, 42(13): 97-108.
[7] Zhang D. The pathway to curb greenwashing in sustainable growth: The role of artificial intelligence[J]. *Energy Economics*, 2024, 133: 107562.
[8] Hao X, Miao E, Wen S, et al. Executive green cognition on corporate greenwashing behavior: Evidence from A-share listed companies in China[J]. *Business Strategy and the Environment*, 2025, 34: 2012-2034.
[9] Song J, Chen S. Is liability of foreignness always bad for firms? A study of the influence of top management team foreignness on corporate greenwashing[J]. *Business Strategy and the Environment*, 2025, 34: 3360-3384.
[10] Li Q, Jiang T. Can top management team internationalization curb corporate "greenwashing" ?—Considering the impact of trust culture[J]. *Journal of China University of Geosciences (Social Sciences Edition)*, 2023, 23(04): 37-55.
[11] Xie H, Zhu Q, Sun J, et al. Executive environmental cognition and corporate "greenwashing" tendency[J]. *East China Economic Management*, 2024, 38(12): 1-12.
[12] Li M, Chen Q. Executive pay gap and corporate ESG greenwashing: Evidence from China[J]. *International Review of Financial Analysis*, 2024, 95: 103375.
[13] Wang L, Li Z, Sha Y. Collaboration or collusion: Heterogeneous institutional co-ownership and corporate "greenwashing" [J]. *Finance and Economics Journal*, 2023, (08): 70-80.
[14] Wang Q, Ma Z, Zhao J, et al. State shareholding in privately-owned firms and greenwashing: Evidence from China[J]. *Finance Research Letters*, 2024, 62: 105176.
[15] Qin Z, Zhao J, Wang X. The Impact of Controlling Shareholder Share Pledging on ESG Greenwashing: Insights from Internal and External Governance Mechanisms[J]. *Emerging Markets Finance and Trade*, 2025: 1-22.
[16] Wang J, Fan M, Lin H. Environmental governance effects of executive equity incentives: "True to name" or "False appearance" ?—Evidence from China' s A-share heavily polluting enterprises[J]. *Journal of Finance and Economics*, 2023, 49(11): 50-64.
[17] Yue J, Li Y. Media attention and corporate greenwashing behavior: Evidence from China[J]. *Finance Research Letters*, 2023, 55: 104016.
[18] Li Q, Song J. Performance expectation gap and corporate "greenwashing" [J]. *Journal of Nanjing Audit University*, 2022(3): 51-61.
[19] Zhao Y N, Lee C C. The impact of vertical environmental regulation mechanism on greenwashing[J]. *Journal of Cleaner Production*, 2024, 475: 143637.
[20] Huang R, Chu F. Central environmental inspection, performance pressure, and corporate "greenwashing" [J]. *Journal of China University of Geosciences (Social Sciences Edition)*, 2023, 23(01): 70-86.
[21] Chen Y, Jiang Z. "Greenwashing" or "True Green" : Corporate environmental behavior under bank regulatory penalties[J]. *Finance and Economics*

Journal, 2025, (09): 77-88.
[22] Hu S, Wang A, Du K. Environmental tax reform and greenwashing: evidence from Chinese listed companies[J]. *Energy Economics*, 2023, 124: 106873.
[23] Bennedsen M, Wolfenzon D. The balance of power in closely held corporations[J]. *Journal of Financial Economics*, 2000, 58(1-2): 113-139.
[24] Liu Y, Zhou Y. Executive faultlines, equity balance, and innovation in multinational high-tech enterprises—From subgroup structure perspectives[J]. *Industrial Economic Review (Shandong University)*, 2024, 23(03): 131-152.
[25] Ruan S, Ding Z, Liu Y, et al. Testing the inverted U-shaped hypothesis of equity balance and corporate value creation—Evidence from panel data models[J]. *Chinese Journal of Management Science*, 2014, 22(02): 119-128.
[26] Zhao G, Yu W. The Corporate Governance Effect of Large Shareholders' Equity Balance: Evidence from Private Listed Companies[J]. *Foreign Economics & Management*, 2018, 40(11): 60-72.
[27] Xu X L, Chen H H, Li Y, et al. The role of equity balance and executive stock ownership in the innovation efficiency of renewable energy enterprises[J]. *Journal of Renewable and Sustainable Energy*, 2019, 11(5).
[28] Xiao P. Institutional investor ownership, overinvestment, and stock price crash risk—From equity balance perspective[J]. *Forecasting*, 2021, 40(05): 69-75.
[29] Yang H, Liu Y. Analysis of relationships among performance pressure, ownership structure, and audit fees[J]. *Journal of Xi' an Shiyou University (Social Sciences Edition)*, 2021, 30(03): 35-41.
[30] Luo J, Liu Y, Yang F. Executive team stability and corporate debt financing costs[J]. *Nankai Business Review*, 2023, 26(05): 1-12.
[31] Wang H. Research on the impact of media supervision and second largest shareholder checks on controlling shareholders' private benefits and corporate value[D]. Guangzhou: South China University of Technology, 2019.
[32] Pan A, Liu X, Qiu J, et al. Can green M&A under media pressure drive substantive transformation in heavily polluting enterprises?[J]. *China Industrial Economics*, 2019(2): 174-192.
[33] Yang X, Liu B, Liu Z, et al. Does Environmental Uncertainty Increase the Likelihood of Greenwashing? The Roles of Government Subsidies and Media Attention[J]. *Corporate Social Responsibility and Environmental Management*, 2025, 32: 2616-2629.
[34] Li D, Xu Z, Chen S, et al. A network traffic classification model fusing variational autoencoder and adaptive enhanced convolutional neural network[J]. *Journal of Computer Applications*, 2025, 45(06): 1841-1848.
[35] Chernozhukov V, Chetverikov D, Demirer M, et al. Double/debiased machine learning for treatment and structural parameters[J]. *The Econometrics Journal*, 2018, 21(1): C1-C68.
[36] Louizos C, Shalit U, Mooij J M, et al. Causal effect inference with deep latent-variable models[J]. *Advances in Neural Information Processing Systems*, 2017, 30.
[37] Zhang D, Zhang J, Dong S. Potential impacts of environmental information embellishment behavior[J]. *The Journal of World Economy*, 2024, 47(04): 99-128.

[38] Liu Y Z, Mao J. How do tax incentives affect investment and productivity? Firm-level evidence from China[J]. *American Economic Journal: Economic Policy*, 2019, 11(3): 261-291.
[39] Hong J, Yuan Y. Does corporate management performance pressure affect fiscal revenue?—From tax avoidance perspective[J]. *Economics and Management Review*, 2023, 39(06): 67-80.
[40] Li Z, Shao Y, Li Z, et al. ESG information disclosure, media supervision, and corporate financing constraints[J]. *Scientific Decision Making*, 2022, (07): 1-15.

Note: Figure translations are in progress. See original paper for figures.