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# RESEARCH ON THE RULES OF ESG PERFORMANCE AND VALUE CREATION BASED ON ROUGH SETS

Xue HU, Weidong ZHU*, Chao ZHANG, Tianjiao ZHANG, Chen ZHANG

*School of Management, HeFei University of Technology, Hefei, Anhui, China*

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**Abstract.** In the context of global sustainable development, the relationship between environmental, social responsibility, and governance (ESG) performance and multi-stakeholder value creation has been widely discussed. However, there is a complex causal relationship between ESG performance and value creation, many firm characteristics are involved, and there is no systematic study on them. In this study, we aim to explore the relationship between ESG performance and value creation, the joint role of firms' internal and external characteristics in this relationship, and how the three components of ESG performance act on value creation through their various configurations. To identify complex causal relationships among variables, this study introduces rough sets method to describe these configuration relationships by generating rules. We use China's 300 CSI-listed companies on the Shanghai and Shenzhen Stock Exchanges from 2015 to 2020 as research samples and find that firms with good ESG performance are more likely to have high-efficiency value creation; moreover, this relationship exists only among firms with specific characteristics. Additionally, different combinations of ESG components may have a differential impact on value creation, and we identify four configurations that generate high-efficiency value creation. This study contributes to guiding companies to strengthen their ESG practices and rationally allocate resources.

**Keywords:** ESG performance, value creation, rough sets, rule mining, firm characteristics, stakeholder theory.

**JEL Classification:** M41, C83, L20.

## Introduction

Given the global emphasis on social responsibility and sustainability, ESG performance has rapidly become a focal point of sustainable development. ESG performance is a crucial non-financial indicator of corporate environmental, social responsibility, and governance performance and drives companies to move from maximizing self-interest to maximizing social value. Accordingly, strong ESG performance is highly consistent with China's philosophy

*Corresponding author. E-mail: *zhuwd@hfut.edu.cn*

of high-quality development and commonwealth strategy. The Chinese government and regulatory agencies have launched a series of policies to strengthen the ESG information disclosure of listed companies and improve ESG performance. Faced with the dual pressures of external supervision and internal competition, enterprises regularly release ESG reports. However, in a market economy, compared with policy encouragement and institutional supervision, it is more critical to enable companies to derive efficient value creation from good ESG performance. Therefore, in addition to clarifying the relationship between ESG performance and value creation, it is particularly crucial to explore the role of firm characteristics in the relationship. The results of this study are helpful in guiding enterprises on how to choose the right ESG strategy according to their characteristics, rationally allocate corporate resources in ESG practices, and promote positive interaction between ESG performance and value creation.

Existing research has centered on the relationship between corporate ESG performance and value creation. Scholars have explored this relationship by establishing an econometric regression model to obtain a generalized conclusion that there is a positive (Rahman et al., 2023), negative (Atan et al., 2018), nonlinear (Wang et al., 2022) or no relationship between the two (Duque & Aguilera, 2021). The reason for the inconsistent findings on the relationship between ESG performance and value creation may lie in the inconsistency between stakeholders' perception of ESG performance, as they are the primary agents of value creation, and management, as they are the agents of stakeholders. Stakeholders perceive that firms with good ESG performance are more risk-resistant (Broadstock et al., 2021). Therefore, stakeholders are more inclined to invest resources in firms with better ESG performance. Management may use ESG in a self-interested manner to enhance its image and overinvest corporate resources in developing ESG to enhance its reputation. Some management's objective in enhancing ESG is to mask or divert public attention from other corporate misconduct (Zhang et al., 2022), which is detrimental to corporate value creation (Chintrakarn et al., 2020).

Firm characteristic heterogeneity affects the relationship between ESG performance and value creation (Khan, 2022). Scholars discuss firm heterogeneity by grouping firms according to specific characteristics. Existing studies generally agree that the relationship between ESG performance and value creation differs for firms with different characteristics. For example, larger firms tend to invest into the ESG activities due to economies of scale to better reflect stakeholders' demands (Bissoondoyal et al., 2023). Compared to non-state-owned enterprises, state-owned enterprises are under more pressure from the government and the public and can implement corporate ESG strategies more proactively (Hu et al., 2023). The heavy pollution industry is an essential object of environmental regulation by the government and the main target of public supervision, so the pressure of ESG information disclosure in the heavy pollution industry is more significant (Li et al., 2018).

Scholars have also analyzed the relationship between the three ESG components and value creation (Shaikh, 2022). Good environmental performance can help firms develop a competitive advantage for differentiation and a good corporate reputation among stakeholders (Duanmu et al., 2018). Firms that adopt an aggressive environmental strategy are more motivated to reduce pollution emissions and adopt new energy sources through technologi-

cal innovation (Shu et al., 2016). However, these investments in environmental protection are characterized by long payback cycles and uncertain returns (Ortiz & Bansal, 2016), creating heavy cost pressures for firms. The same state of research exists for social responsibility and governance performance, and no unified conclusions have been reached about their relationships with value creation (Buallay, 2019; Duque & Aguilera, 2021). In addition, scholars have ranked and compared the extent to which the three dimensions influence value creation (Velte, 2017; Cek & Eyupoglu, 2020).

We can find the following gaps in the existing studies. First, when exploring the relationship between ESG performance and value creation, the interaction between multi-characteristics needs to be explored. As a complex system, enterprise value creation involves many factors. The traditional econometric model explores the heterogeneous effects of firm characteristics by introducing interaction terms but cannot obtain multi-factor groupings simultaneously. Second, the model fails to capture the interactions among the three ESG components. How the E, S, and G work together to create enterprise value through their various configurations is crucial to enterprises' rational resource allocation in their ESG practice. The rough sets method can overcome these problems by recognizing the interdependence of all factors and then identifying multiple equivalents, obtaining inherent potential information from objective data without requiring any prior information (Pawlak, 1997). The rough sets method helps reduce unimportant variables and retain only the most essential firm characteristics to form corresponding decision rules and improve accuracy (Liu et al., 2015). Therefore, we can directly incorporate all firm characteristics that affect value creation into the information system without considering multicollinearity between the variables.

This paper selects data from 300 CSI-listed companies on the Shanghai and Shenzhen Stock Exchanges from 2015 to 2020. We use the rough sets method to examine the relationship between firm ESG performance and value creation and further analyze how subdimensional performance affects value creation. The innovations of this study are as follows. First, we apply rough sets-based rule mining technology to investigate the complex interactions between factors affecting firm value. Rule extraction technology can help us reach more detailed conclusions from enterprise data and show more clearly the distribution of conditional variables, which extends the single causality of traditional econometrics. Second, we establish a data analysis system including ESG performance, firm characteristics, and value creation, explore the relationship among E, S, and G and value creation and how these three components work together through their configurations, which provides new perspectives for ESG related research. Third, we expand the connotation of value creation and adopt a value added indicator that reflects the value distribution of stakeholders. Compared with the indicators of profit maximization and shareholder value maximization, value added reflects the contribution of stakeholders to the production and operation activities of the enterprise and the corresponding benefits, which is in line with the expectations of stakeholders for the enterprise.

The rest of the paper is structured as follows. Section 1 presents theoretical analysis and research framework. Section 2 presents the data, variables, and research methods used in this study. Section 3 presents the empirical results. Section 4 provides key findings and discussions, and the last section concludes the article, provides implications for managers, policymakers and investors, presents limitations, and offers possible avenues for future research.

## 1. Theoretical analysis and research framework

### 1.1. ESG performance and value creation

ESG performance reflects the practice of micro-enterprises in terms of sustainable development. Unlike financial information, which emphasizes only the "quantity" of enterprise performance, ESG performance reflects the "quality" of corporate development in three dimensions – the environment, social responsibility, and governance – and the unified development of economic and social values, which is a valuable supplement to traditional financial information. The ultimate goal of companies to improve their ESG performance is to create more value. The effect of ESG performance on corporate value creation is a relatively complex process. Enterprises can be viewed as linking the contracts among all resource owners. Stakeholder theory suggests that firms are platforms that enable different stakeholders to realize multiple value pursuits and that firms should create value for all stakeholders. Enhancing ESG performance can effect the value creation by influencing the behavior of the firm's key players and the high quality fulfillment of contracts with stakeholders (Atif & Ali, 2021). This study sorts out the theories supporting the relationship between ESG performance and value creation from the stakeholders' perspective.

First, ESG performance can help firms obtain resource support from stakeholders by enhancing corporate reputations (Freeman, 1984; Zhang et al., 2021). According to signaling theory, enterprises' improved ESG performance alleviates the information asymmetry with stakeholders. Good ESG performance sends a signal to the market that they have good financial performance and are aware of social responsibility, which is conducive to obtaining financial support from shareholders and creditors, alleviating financing constraints, reducing financial risks and capital costs, stabilizing the supply of funds (Kong, 2023), enhancing competitive advantages (DasGupta, 2022), and ultimately positively affecting the value creation efficiency (Tang et al., 2018; Kieu et al., 2022). Good ESG performance can also help firms improve their corporate reputations, create a positive corporate image for consumers, and increase sales revenues, enhancing corporate value (Zhang & Zhang, 2020).

Second, ESG performance can enhance communication between firms and stakeholders and help protect against potential risks (Dunbar et al., 2020). Legitimacy theory suggests that firms improving their ESG performance can gain social acceptance. Suppose employees perceive the firm as socially and legally legitimate. They are more likely to feel a sense of belonging and identification, which improves employee loyalty and promotes firms' stability and sustainable development (Jing et al., 2023). Good ESG performance helps firms gain support and recognition from the government, creating a favorable business environment and reducing the regulatory pressures that firms may face (Reber et al., 2022). When adverse events affect firms, the social capital formed by ESG inputs can also reduce the losses caused by adverse events (Chen & Zhang, 2023).

Third, ESG performance can alleviate principal-agent conflicts, strengthen stakeholders' supervision of managers, and improve governance efficiency (He et al., 2022). Good ESG performance helps reduce transaction costs, alleviate executives' opportunism and uncertainty, and enhance firm performance (Li et al., 2019). In addition, good ESG performance can provide institutional guarantees for value creation. Enterprises with good ESG performance

can pay more attention to stakeholders' interests when formulating development strategies and maximizing diversified value creation for stakeholders (Li et al., 2021).

### 1.2. Discussion of firm characteristic heterogeneity

Resource-based theory suggests that firms obtain lasting competitive advantage and create long-term value by continuously accumulating and fully utilizing their resources. It emphasizes the importance of resource management and organizational capabilities, which can help firms adapt to changing market environments by improving resource deployment efficiency (Lee et al., 2023). Based on the resource-based theory, we explore the impact of heterogeneity of factors such as financial situation, which can reflect the quality of financial resources, and governance characteristics, which can reflect the resource allocation efficiency, on the relationship between ESG performance and value creation.

The financial situation contributes to the value creation process by interacting with ESG performance. This paper divides the financial situation into earnings, growth, and risk (Qian & Zhang, 2011). The earning capacity determines its ESG performance level, and it demands a lot of human and material resources for an enterprise to improve its ESG performance. Therefore, if an enterprise has good earning capacity, it will have more energy to devote to ESG performance. Enterprise growth speed may strain enterprise resources (Higgins, 1977). ESG information disclosure releases signals to the government, investors, and the public, wins the trust and support of various stakeholders, and helps enterprises obtain resources. ESG performance also helps hedge potential risks (Shakil, 2021), alleviates financing constraints (Bai et al., 2022; Houston & Shan, 2022), achieves a virtuous cycle between it and the company's financial situation, and improves value creation efficiency.

Governance characteristics act on value creation by interacting with ESG performance. Corporate governance characteristics include internal governance and external governance (Tang et al., 2020). Internal governance characteristics include equity characteristics, board characteristics, and executive characteristics. In enterprises with a high concentration of ownership structure, major shareholders hold more shares and are motivated by self-interest (Wang et al., 2023). Board characteristics directly affect the effectiveness of board governance and operational efficiency. The larger the board, the more inefficient it is, which is detrimental to the effectiveness of the board's decision-making and the firm's ESG performance (Yermack, 1996). Compensation incentives directly link management compensation to corporate performance, which can reduce the possibility of moral hazard and adverse selection by managers. Higher levels of executive compensation may motivate management to better serve the enterprise and stakeholders by focusing on ESG responsibility fulfillment (Ho et al., 2022). External governance characteristics include industry competition and government intervention. In highly competitive industries, companies need to strategically replan their ESG behaviors to help them achieve a differentiated competitive strategy through improved ESG performance (Cicchiello et al., 2023). Government intervention can correct market failures, realize the optimal allocation of scarce resources, which in turn contributes to enhancing corporate value (Budiarso et al., 2019).

The macroeconomic conditions and regulatory environment that firms face can also affect the relationship between ESG performance and value creation. Regions with favorable macroeconomic conditions have greater market demand, growth opportunities, and enterprise financing channels. Local governments with high levels of economic development can provide more resources to support corporate ESG practices (Benkhodja et al., 2023). The regulatory environment also monitors the behavior of corporate management to prevent them from overinvesting in ESG practices and infringing on stakeholders' interests (Zhang et al., 2021).

### 1.3. Research framework

Based on the above theory and literature review, this study analyzes the interaction between ESG performance and firm characteristics to provide an analytical framework for exploring the path of ESG performance to enhance value creation. Figure 1 shows how ESG performance and firm characteristics work together in the value creation process through interaction. First, the enhancement of ESG performance will improve the financial and operational status by alleviating the financing constraints, improve the governance efficiency by alleviating principal-agent conflicts, and help the enterprise obtain more resources and strengthen the communication with stakeholders, improving the efficiency of corporate value creation. Second, various characteristics of enterprises also affect the relationship between ESG performance and value creation. A good financial situation and a governance environment will provide financial and decision-making support for corporate ESG practices. Third, firms' regulatory and macroeconomic environments will also impact the relationship between ESG performance and value creation.

Figure 1 lists all the variables in the research framework and uses the rough sets method to construct a configuration model of the factors influencing firm value creation. In addition to ESG performance and the three sub-dimensional performance, we categorize firm characteristics into financial situation, governance characteristics, and other factors. Among them,

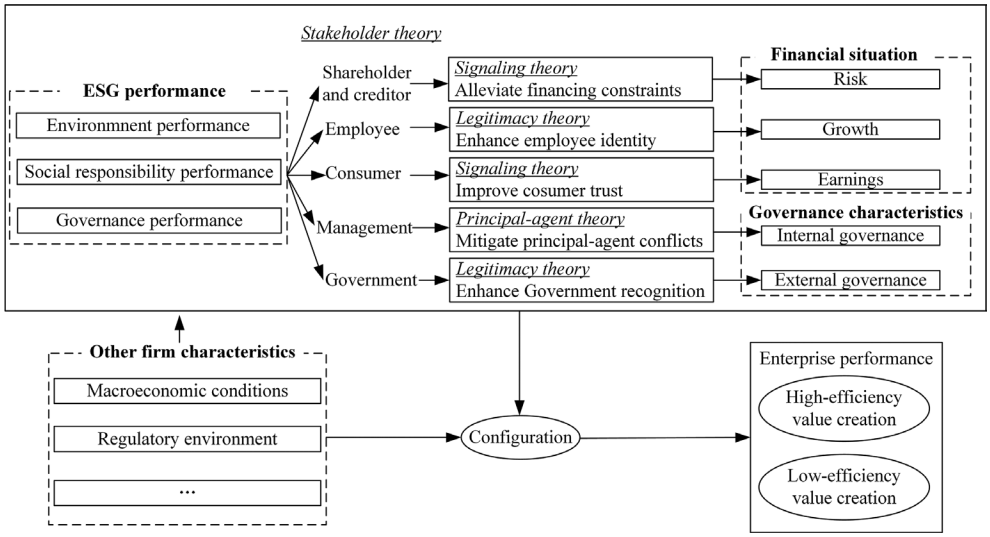


Figure 1. Research framework

financial situations include risk, earnings, and growth. Governance characteristics include internal governance characteristics and external governance characteristics. Internal governance characteristics are board, executive, and equity; external governance characteristics are industry competition and government intervention. ESG performance and firm characteristics affect the efficiency of corporate value creation through configuration. The rough sets method is introduced to mining the relevant patterns of corporate value creation and extract the rules related to ESG performance to discover the patterns existing between the two.

## 2. Methodology, variables, and data sources

### 2.1. Methodology: rough sets model (RS)

Pawlak Z proposed the concept of rough sets in 1982. Its basic idea is to generalize concepts and rules by classifying a case base, forming concepts by classifying the case base with conditional feature variables, and studying the target features through the generated concepts to obtain association rules. Rough sets simplify and identify the core feature variables, which simplifies the representation of rules. Rough set theory is based on databases and is especially used for management decision-making with more complex databases, such as the case where the values taken in the database are continuous or the database itself is incomplete. Rough set theory, as a tool for knowledge discovery and information fusion, can identify decision rules from complex databases and help solve the practical problems of actual decision-making. Next, we briefly introduce the details and application steps of the rough sets method.

*Establish an information system with the selected variables.* An information system is an abstract description of a database. Given an information system $S=(U,A,V,f)$, where $U$ is a nonempty set, $U=\{x_1,x_2,...,x_n\}$, each $x_i(i=1,...,n)$ in $U$ is one object. $A=C\cup D$, and $C\cap D=\varphi$. Information systems can also be written as $S=(U,C\cup D,V,f)$. The functions belonging to the set $C$ are condition attributes, $C=\{c_1,c_2,...,c_m\}$, and each $c_j(j=1,...,m)$ in $C$ is one condition attribute. The functions belonging to the set $D$ are decision attributes. Condition attributes and decision attributes are combined into decision tables. $V$ is the value range set of all attributes, $V_C=\{V_c|c\in C\}$ and $V_D=\{V_d|d\in D\}$ are the range sets of condition attributes and decision attributes, respectively, in the information system, and $f$ represents a mapping of $U\times A\to V$, which is called an information function: for $c\in C$ and $x\in U$, $f(x,c)=V_c$. Decision rules can be described in mathematical terms as follows:

$$IF\ f(x,c_1)=V_{c1}\ AND\ f(x,c_2)=V_{c2}\ AND\cdots AND\ f(x,c_m)=V_{cm},\ THEN\ x\in V_d. \quad (1)$$

*Discretization of attributes.* Since rough sets method cannot deal with missing data, to retain the original decision rules to the greatest extent, the mean / mode method is applied. The missing continuous sample condition attribute is filled with the average of other sample attribute values to obtain a complete decision table. The complete decision table is randomly divided into two sets: the training set and the testing set. The Boolean discretization algorithm discretizes the continuous attribute values, and the corresponding breakpoints are saved. Finally, the decision table composed of discrete data is obtained.

*Attribute reduction.* Attribute reduction is one of the core contents of rough sets research. Information systems contain many attributes of varying importance, but there are redundant attributes, which makes the rough model decision-making efficiency and accuracy poor. However, it can help decision-makers make correct and concise decisions. Attribute reduction can remove redundant attributes from an information system. The genetic algorithm performs attribute reduction on the training set in the experimental process. This adaptive stochastic search method takes the degree of adaptation as the objective function and gradually approximates the target by an incremental approach. It has the advantages of high robustness, low workload, and high accuracy.

*Obtain and filter rules.* Decision rules represent the causal relationships among condition attributes and decision attributes, which is the knowledge expression hidden in the knowledge system. After obtaining the rules, they are filtered based on accuracy and coverage. Then, the minimal attribute subsets are filtered according to two indicators, accuracy (Equation 2) and coverage (Equation 3), to produce if-then rules.

$$Accuracy(r) = \frac{\left|[x]_C \cap [x]_D\right|}{\left|[x]_C\right|}; \tag{2}$$

$$Coverage(r) = \frac{\left|[x]_C \cap [x]_D\right|}{\left|[x]_D\right|}, \tag{3}$$

where $[x]_C$ is the number of cases that match the condition part of rule $r$ and $[x]_D$ is the number of cases that match the decision part of rule $r$. $Accuracy(r)$ reflects the correctness of the decision rule $r$; the larger the value is, the higher the confidence in the rule. $Coverage(r)$ reflects the quality of the decision rule; the larger the value is, the higher the coverage of the support number of the rule in the corresponding decision class.

*Evaluation.* To evaluate the obtained rules, this paper discretizes the continuous condition attributes of the testing set with the breakpoints obtained. Then it classifies the discrete testing set with the filtered rules to obtain classification accuracy.

In summary, the practical application of the rough sets method can be carried out roughly according to the following four steps: Step 1, build an information system containing decision attributes and condition attributes, fill in the missing data, randomly divide the complete data set into the training set and testing set, discretize the continuous data values in the training set and save the breakpoints; Step 2, use a genetic algorithm to perform attribute approximation on the discretized training set; Step 3, obtain rules according to the result of approximation, and filter the rules according to coverage and accuracy to obtain the final rule base; and Step 4, use the breakpoints obtained in Step 2 to classify the continuous data in the testing set, obtain the classification accuracy, and evaluate the rule base obtained in Step 3.

## 2.2. Variables: decision attribute and condition attribute

### 2.2.1. Decision attribute

This study chooses the value-added ratio to measure enterprise value creation. Compared with traditional shareholder values and profit maximization, such as Tobin's Q (He et al., 2019) and economic value added (EVA) (Chi & Zou, 2015), the value-added indicator considers the contribution of participants both inside and outside the enterprise (Dai et al., 2022). Value added reflects the cocreated value of enterprise stakeholders and can also clearly reflect the distribution of such value among stakeholders.

The basic idea of maximizing value added is to put the long-term stable development of the enterprise in the first place and to ensure the sustainable development of the enterprise under the premise of satisfying the interests of all stakeholders. Specifically, it includes the coordinated relationship between the interests of shareholders; the immediate interests of the employees; the strengthening of ties with creditors and the safeguarding of the enterprise's financing channels; the concern for changes in government policies, the payment of taxes following the law as well as the enterprise's own retained earnings, and the safeguarding of the enterprise's investment capacity. The calculation of value added can be expressed as the summation of the value distribution of all stakeholders. The value-added ratio is measured by dividing the value added by the total assets.

$$\begin{aligned} \textit{Value added ratio} = (&\textit{employee income} + \textit{shareholder income} + \textit{creditor income} + \\ &\textit{governance income} + \textit{firm income}) / \textit{total asset}, \end{aligned} \tag{4}$$

where employee income = cash payments to and on behalf of employees + difference between the end and beginning of the payable period, shareholder income = shares in the current year × dividends per share, creditor income = interest expenses, government income = payments of all types of taxes + difference between end and beginning of taxable period + refunds of taxes, and firm income = net profit − dividend payout.

Through the above calculation process, we can calculate the value-added ratio of each sample, which is continuous data. When using the rough sets method, it is necessary to classify these data. Suppose the value of the value-added ratio of a sample is higher than the median value of the whole sample. In that case, the sampled company is clustered into the high-efficiency category, and we define the decision attribute as 1. Otherwise, the decision attribute is 0.

### 2.2.2. Condition attribute

*ESG performance.* We choose the SynTao Green Finance (STGF) rating score to measure the ESG performance of the sample companies. It launched the STGF ESG Rating Methodology in 2015 and obtained a comprehensive ESG score for each listed company by weighting the ESG materiality factors of different industries. The advantage of this rating methodology is that it integrates international ESG standards with the macro situation of China's environmental and social development, incorporates comprehensive ESG information as much as possible, and highly correlates with domestic and international rating systems.

*Firm characteristics.* According to the literature review, financial situation and governance characteristics are selected as condition attributes. The financial situation includes leverage, net operating margin, and revenue growth rate to reflect risk, earnings, and growth. Governance characteristics include internal governance and external governance. Internal governance characteristics include equity balance degree (EBD), remuneration of directors, and the number of directors to reflect equity, board, and executive characteristics. External governance characteristics include industry competition and government ESG-related subsidy. This paper also measures firm characteristics, including size, property rights, industry, age, region, macroeconomic, and regulatory.

Table 1. Attribute descriptions

| Attribute | Factor | Variable | Symbol | Description |
|---|---|---|---|---|
| Condition attribute | ESG performance | ESG performance | ESG-score | The data are all from SynTao Green Finance |
| | | Environment performance | E-score | |
| | | Social responsibility performance | S-score | |
| | | Corporate Governance performance | G-score | |
| | Financial situation | Leverage | Leverage | Total liabilities / total assets |
| | | Net operating margin | NOM | Net profit / revenue income |
| | | Revenue growth rate | RGR | (Revenue income for the current period–revenue income for the same period of the last year) / revenue income for the same period of the last year |
| | Internal governance | Equity balance degree | EBD | Sum of shareholding ratio from the second largest shareholder to the tenth largest shareholder / shareholding ratio of the first major shareholder |
| | | Remuneration of directors | Remun | Natural logarithm of average remuneration of top three directors |
| | | Number of directors | Direc | Natural logarithm of the number of directors |
| | External governance | Industry competition | HHI | Herfindahl index for the industry to which the enterprise belongs |
| | | Government ESG-related subsidy | Subsidy | ESG-related subsidies received by firms from government |
| | Firm size | Total assets | Size | Natural logarithm of total assets |
| | Property rights | Property rights | PR | 1 for state-owned enterprises, 0 for others |
| | Industry | Industry | Industry | 1 for the heavy pollution industry, 0 for others |
| | Firm age | Firm age | Age | Natural logarithm of years from the firm establishment |

*End of Table 1*

| Attribute | Factor | Variable | Symbol | Description |
|---|---|---|---|---|
| | Macro-economic | Gross domestic product | GDP | Natural logarithm of gross domestic product of the city to which the enterprise belongs |
| | Regulatory | Regulatory | Regu-latory | Number of environment-related terms appearing in the work report of the local government to which the enterprise belongs / number of words in the full report |
| Decision attribute | Value creation | Value-added ratio | VA | 1 for the high-efficiency category, 0 for the low-efficiency category |

Table 1 shows all variables and specific descriptions. ESG performance and enterprise characteristics are condition attributes, while value creation is a decision attribute. The condition attributes and decision attributes together form a complete decision table.

### 2.3. Sample selection and data sources

This paper selected China's 300 CSI-listed companies from 2015 to 2020 as research samples. The Shanghai and Shenzhen stock exchanges jointly released the index in 2005 to facilitate investors' tracking and portfolio investments. The industry distribution of the sample stocks is close to the industry distribution of the market, ensuring representativeness. China's ESG evaluation system started late, and corporate ESG performance has developed only rapidly in recent years, so this paper chooses data for the five years from 2015 to 2019. Considering the lag of ESG performance on value creation, value creation data are selected from 2016–2020. Data used were obtained from the SynTao Green Finance database, the CSMAR database, and the annual reports of listed companies and were screened according to the following steps: (1) exclude companies with no ESG scores given by SynTao Green Finance; (2) exclude the annual sample of companies that are ST companies in the current year, and finally obtain 1607 research samples. Table 2 presents the results of the descriptive statistics for the sample companies' main variables.

Table 2. Descriptive statistics

| Variable | N | Mean | SD | Min | Median | Max |
|---|---|---|---|---|---|---|
| ESG-score | 1607 | 48.05 | 5.40 | 30.88 | 47.25 | 67.63 |
| E-score | 1607 | 17.57 | 2.93 | 9.50 | 17.13 | 29.63 |
| S-score | 1607 | 17.36 | 2.10 | 8.25 | 17.25 | 25.37 |
| G-score | 1607 | 13.13 | 2.38 | 4.00 | 13.00 | 22.75 |
| Leverage | 1607 | 0.56 | 0.23 | 0.03 | 0.57 | 0.94 |
| NOM | 1607 | 0.18 | 0.21 | –0.38 | 0.12 | 1.21 |
| RGR | 1607 | 0.27 | 0.77 | –5.41 | 0.11 | 7.14 |
| EBD | 1607 | 1.05 | 0.83 | 0.04 | 0.81 | 5.62 |

*End of Table 2*

| Variable | N | Mean | SD | Min | Median | Max |
|---|---|---|---|---|---|---|
| Remun | 1607 | 14.89 | 1.09 | 0 | 14.78 | 17.58 |
| Direc | 1607 | 2.42 | 0.29 | 1.61 | 2.40 | 3.18 |
| HHI | 1607 | 0.23 | 0.23 | 0.03 | 0.14 | 1 |
| Subdidy | 1607 | 8.81 | 7.98 | 0.00 | 13.12 | 19.67 |
| Size | 1607 | 24.92 | 1.74 | 20.99 | 24.62 | 31.03 |
| PR | 1607 | 0.55 | 0.50 | 0 | 1 | 1 |
| Industry | 1607 | 0.26 | 0.44 | 0 | 0 | 1 |
| Age | 1607 | 2.90 | 0.35 | 1.10 | 2.94 | 3.69 |
| GDP | 1607 | 9.37 | 1.02 | 6.72 | 9.75 | 10.55 |
| Regulatory | 1607 | 0.004 | 0.001 | 0.001 | 0.004 | 0.01 |
| VA | 1607 | 0.16 | 0.09 | 0.00 | 0.16 | 0.76 |

As seen from the table, the mean ESG scores and the three individual scores are more significant than their medians, indicating that ESG presents right skewness. However, the standard deviations of the scores are significantly more minor than the mean values, indicating that the overall differences in ESG performance among the sample companies are not significant. Comparing the three individual scores, we find that the mean value of the governance score is 13.13, which is much smaller than the environmental score of 17.57 and the social responsibility score of 17.36, indicating that the overall corporate governance performance of the sample companies is the worst among the three. Comparing the standard deviation of the three individual scores, we find that the standard deviation of the environmental score is the largest, followed by that of the corporate governance score. The standard deviation of the social responsibility score is the smallest, indicating that the social responsibility performance is relatively consistent among the sample companies, and the environmental performance is significantly different.

## 3. Empirical results

We used the rough sets processing software Rosetta to extract ESG performance and value creation rules.

### 3.1. Discrete interval of continuous attributes

After establishing a complete decision table, the paper randomly divides each group of samples into the training set and testing set using the split function in Rosetta. Since the sample of this study is small for machine learning, a ratio of 7:3 is used to divide the sample. Then, the continuous condition attributes in the sample training set are discretized. Boolean discretization algorithm is the optimal discretization based on rough set theory. It will distinguish the resolution relations between all data with the minimum number of breakpoints, which is conducive to improving the efficiency of rule mining (Pawlak & Skowron, 2007). After Boolean reasoning discretization, we can obtain a set of interval boundaries. The results are shown in Table 3.

Table 3. Discretized results of continuous attributes

| Attribute | Low | High | Attribute | Low | High |
|---|---|---|---|---|---|
| ESG-score | [30.88, 48) | [48, 67.63] | Remun | [0, 14.68) | [14.68, 17.58] |
| E-score | [9.50, 17.13) | [17.13, 29.63] | Direc | [1.61, 2.40) | [2.40, 3.18] |
| S-score | [8.25, 17.13) | [17.13, 25.37] | HHI | [0.03, 0.13) | [0.13, 1] |
| G-score | [4, 12.75) | [12.75, 22.75] | Subdidy | [0, 13.41) | [13.41, 19.67] |
| Leverage | [0.03, 0.56) | [0.56, 0.94] | Size | [20.99, 27) | [27, 31.03] |
| NOM | [−0.38, 0.13] | [0.13, 1.21] | Age | [1.10, 2.94) | [2.94, 3.69] |
| RGR | [−5.41, 0.13) | [0.13, 7.14] | GDP | [6.72, 9.39) | [9.39, 10.55] |
| EBD | [0.04, 0.72) | [0.72, 5.62] | Regulatory | [0.001, 0.004) | [0.004, 0.01] |

In this study, Boolean discretization algorithm divided all continuous data in Table 1 into two categories. Taking ESG score as an example, if the sample company's ESG score is between 30.88 and 48, it is considered that the company's ESG performance is bad, and if the sample company's ESG score is between 48 and 67.63, it is considered that the company's ESG performance is good.

### 3.2. Reduct results

All reducts with a number of objects supporting the decision rule reached 100 were selected. We finally obtained 7058 reducts; only some results are shown in Table 4 due to space limitations.

Table 4. Reduct results

| No. | Reducts | Support |
|---|---|---|
| 1 | {ESG performance, Remuneration of directors, Net operating margin, Leverage, HHI} | 100 |
| 2 | {ESG performance, Equity balance degree, Net operating margin, Revenue growth rate, Leverage} | 100 |
| 3 | {Equity balance degree, Revenue growth rate, Property rights, HHI} | 100 |
| 4 | {Remuneration of directors, Revenue growth rate, Size, Subsidy} | 100 |
| 5 | {ESG performance, Number of director, Net operating margin, Age, Subsidy} | 100 |
| 6 | { Net operating margin, Leverage, Age, HHI, GDP} | 100 |
| 7 | {ESG performance, Number of director, Size, Regulatory} | 100 |
| 8 | {Net operating margin, Revenue growth rate, Leverage, Age, HHI} | 100 |
| 9 | {ESG performance, Property rights, Industry, Subsidy} | 100 |
| 10 | {Net operating margin, Leverage, Property rights, Age, Subsidy} | 100 |

Each row in the table represents a reduct result. For example, the first result represents 15 condition attributes, which can be reduced to 5 attributes: ESG performance, remuneration of directors, net operating margin, leverage, and HHI. Other attributes make no contribution to classification, and 100 pieces in the sample data support this reduct result. Next, rule mining is performed based on the reduct results obtained in this step.

### 3.3. Decision rules

Based on the reduct results, we can obtain enterprise value creation rules. Rosetta will show us all the rules, and analyzing them will make it more challenging to draw conclusions. Therefore, we will filter the rules by accuracy and coverage. The values of accuracy and coverage are derived from the classification accuracy of the testing set. Taking the training set into the rules we obtained from the training set, the rules are acceptable when the classification accuracies reaches 80% or more. Based on this criterion, we finally consider that the filtering conditions are set as accuracy greater than 0.8 and coverage greater than 0.2. Use the corresponding breakpoint set to discretize the testing set and the classification rules to classify the testing set. The performance estimates are shown in Table 5.

Table 5. Performance estimates of the proposed method

| | Predicted | | | |
|---|---|---|---|---|
| Actul | | Low | High | |
| | Low | 130 | 84 | 60.75% |
| | High | 10 | 258 | 96.27% |
| | | 92.86% | 75.44% | 80.50% |
| ROC | Class | High | | |
| | Area | 0.7539 | | |
| | Standard. Error | 0.0217 | | |
| | Thr. (0, 1) | 0.86 | | |
| | Thr. acc | 0.86 | | |

Table 5 demonstrates two tools for evaluating the performance of classification models, the confusion matrix and the ROC. Both evaluate and interpret the models from different perspectives; the confusion matrix provides a detailed analysis of the classification model across the classification results, while the ROC provides a comprehensive measure of the model's performance at different classification thresholds. The first five rows of the table show the confusion matrix results, and the last five rows show the results of the ROC.

The confusion matrix is a visualization tool, especially used for supervised learning, where each column represents the predicted category and each row represents the actul attribution category of the data. Each data element in the confusion matrix represents the model's sample classification result. Specifically, the value 130 in Table 5 represents that the model correctly predicted samples that would have been low-efficient value creation as low; 10 represents that the model incorrectly predicted samples that would have been high-efficient value creation as low; 84 represents that the model incorrectly predicted samples that would have been low-efficient value creation as high; and 258 represents that the model correctly predicted samples that would have been high-efficient value creation as high. We can calculate the accuracy and recall for each classification and the average accuracy of the model. For the classification of low-efficient value creation, the accuracy is 92.86%, and the recall is 60.75%. For the classification of high-efficient value creation, the accuracy was 75.44%, and the recall was 96.27%. The average accuracy is 80.50%, and the classification results are acceptable.

In the ROC results, "Class" refers to the category label in the dichotomy, which this study selects as the high-efficient value creation category. "Area" is the area under the ROC curve (AUC), which usually takes values between 0 and 1, with values closer to 1 indicating better model performance. "Standard. Error" is used to measure the reliability of the AUC, with lower standard errors indicating that the estimates are more stable and have higher reliability. "Thr. (0, 1)" is a range of values for the categorization threshold, providing a perspective on how the model's performance changes under different thresholds. "Thr. acc" indicates the degree of matching between the model's prediction results and the actual labels under different classification thresholds, i.e., the ratio of correctly predicted samples to the total number of samples. The results in Table 5 show that the ROC has an area under the curve of 0.7539, with a standard error of 0.0217. The classification result is acceptable. This also indicates that the rules obtained in this study have interpretive significance, and then the rules will be displayed.

Given that this study focuses on the relationship between corporate ESG performance and value creation efficiency, Table 6 shows 7 rules containing ESG performance. Rules 1–5 point to high-efficiency value creation, and 6–7 point to low-efficiency value creation.

Table 6. Rules of ESG performance and firm value creation

| No. | Rule | Accuracy | Coverage |
|---|---|---|---|
| 1 | ESG performance (good) AND Net operating margin (high) AND Subsidy(low) => High-efficiency value creation | 0.8861 | 0.2487 |
| 2 | ESG performance (good) AND Net operating margin (high) AND HHI(high) => High-efficiency value creation | 0.9091 | 0.2309 |
| 3 | ESG performance (good) AND Net operating margin (high) AND Leverage (low) AND Subsidy(low) => High-efficiency value creation | 0.9600 | 0.2131 |
| 4 | ESG performance (good) AND Net operating margin (high) AND HHI(high) AND Subsidy(low) => High-efficiency value creation | 0.9669 | 0.2078 |
| 5 | ESG performance (good) AND Net operating margin (high) AND Subsidy(low) AND Non-heavy polluting => High-efficiency value creation | 0.9280 | 0.2060 |
| 6 | ESG performance (bad) AND Leverage (high) AND Remuneration of directors (low) AND Size (small) => Low-efficiency value creation | 0.8869 | 0.2651 |
| 7 | ESG performance (bad) AND Leverage (high) AND Remuneration of directors (low) AND State-owned => Low-efficiency value creation | 0.9048 | 0.2028 |

The "rules" in machine learning usually refer to semantically transparent, objective rules or domain concepts that describe the data distribution and can be written as "if....., then....." (Furnkranz et al., 2012, p. 25). Thus, Rule 1 can be described as follows: if the firm has good ESG performance and high net operating margin and high subsidy, then the probability of high-efficiency value creation is 88.61%. The sample that meets this rule is 24.87% of the total sample. The remaining seven rules will not be explained.

Table 6 shows a clear relationship between ESG performance and value creation efficiency. Firms with good ESG performance have high-efficiency value creation, and firms with bad ESG performance have low-efficiency value creation. This conclusion is consistent with

most existing findings. Although firms need to invest more to improve ESG performance, the value enhancement effect is more than enough to compensate for the costs of investing in ESG practice activities. This conclusion provides a basis for companies to improve their ESG performance.

In addition to ESG performance and value creation efficiency, other firm characteristics are included in each rule. This reflects that not all firms with good ESG performance are more efficient in value creation. Only specific types of firms benefit from their value creation when they improve their ESG performance. The rules in Table 6 also clearly show us what characteristics are needed to improve value creation by improving ESG performance.

### 3.4. Results of dimensional performance configurations

In this section, we bring the environment, social responsibility, and governance scores into the data information system, replacing the total ESG score, and rerun rule mining. In Section 3.3, we have discussed the configuration of ESG performance with firm characteristics. In this section, we discuss only three components and ignore the role of other firm characteristics.

First, we discuss ranking the three components in terms of their importance in firm value creation. As seen in Table 7, after summing the hit frequencies in the high-efficiency rule base and the low-efficiency rule base, the hit frequency of governance performance is the highest, that of social responsibility performance is the second highest, and that of environmental performance is the lowest. Balachandran and Faff (2015) argue that corporate governance is central among the three components of ESG. This is consistent with the conclusion of this study. Among the three components of ESG, governance performance is the most important.

Table 7. Importance rankings of components

| Conditional variable | High-efficiency value creation | | | Low-efficiency value creation | | | Overall | |
|---|---|---|---|---|---|---|---|---|
| | Hit frequency | Sum | Rank | Hit frequency | Sum | Rank | Hit frequency | Rank |
| Good environment performance | 1.600 | 5.525 | 3 | 0.995 | 3.280 | 3 | 8.805 | 3 |
| Bad environment performance | 3.925 | | | 2.285 | | | | |
| Good social responsibility performance | 13.531 | 13.531 | 2 | 0.457 | 5.943 | 1 | 19.474 | 2 |
| Bad social responsibility performance | 0 | | | 5.486 | | | | |
| Good governance performance | 14.657 | 14.657 | 1 | 0 | 5.046 | 2 | 19.703 | 1 |
| Bad governance performance | 0 | | | 5.046 | | | | |

Next, we discuss the impact of the intersection of the three components on firm value creation. We obtain seven combinations, of which four combinations point to high-efficiency value creation and three to low-efficiency value creation. The results are shown in Table 8.

Table 8. Value creation efficiency configurations

| No. | Environment performance | Social responsibility performance | Governance performance | Overall coverage | Value creation |
|---|---|---|---|---|---|
| 1 | | ● | ● | 3.703 | High efficiency |
| 2 | ⊗ | ● | ● | 1.249 | |
| 3 | ⊗ | | ● | 1.176 | |
| 4 | ⊗ | ● | | 0.520 | |
| 5 | ⊗ | | ⊗ | 0.813 | Low efficiency |
| 6 | ⊗ | ⊗ | | 0.648 | |
| 7 | | ⊗ | ⊗ | 0.322 | |

*Note*: ● indicates that the firm's performance is good, and ⊗ indicates that the firm's performance is bad.

Among the high-efficiency value creation configurations, the configuration with the highest coverage is good social responsibility performance and good governance performance, with a total coverage of 3.703, much higher than other configurations. The second row combines bad environmental performance, good social responsibility performance, and good governance performance, with a total coverage of 1.249. The third row is a combination of bad environmental performance and good governance performance, with a total coverage of 1.176. The fourth row combines bad environmental performance, good social responsibility performance, with a total coverage of 0.520.

Among the low-efficiency value creation combinations, the configuration with the highest coverage is bad environmental performance and bad governance performance, with a total coverage of 0.813. The sixth row is a combination of bad environmental performance and bad social responsibility performance, with a total coverage of 0.648. The seventh row combines bad social responsibility and bad governance performance, with a total coverage of 0.322. This finding is consistent with the above total ESG score and value creation. When ESG performance is low for most firms, their value creation efficiency will also be lower.

## 4. Discussions

The findings of this study were as follows. First, we recognize a strong link between ESG performance and value creation, i.e., when ESG performance is good, value creation is more likely to be efficient. This finding is consistent with the research of most scholars (Broadstock et al., 2021; Kieu et al., 2022; Kong, 2023). Besides, enhancing value creation efficiency by firms' ESG performance cannot be separated from discussing other firm characteristics. The enhancement effect of ESG performance on value creation efficiency is evident for firms with high net operating margin, low leverage, less government subsidy, low industry competition,

and were non-heavy polluting. The reason is that such companies are in a better financial position and more resilient to risks, and they have more resources to devote to ESG practices. Such enterprises with better business conditions do not need financial support from the government. When enterprises' industry competition is more intense, the differentiation advantage brought by improved ESG performance takes time to transform into competitiveness quickly. Hence, enterprises in a relaxed competitive environment have a closer relationship between their ESG performance and value creation. Non-heavy polluting enterprises do not have policy mandates and are not mandated to make ESG disclosures. Their motivation to enhance ESG is mainly corporate strategy, and they do not use ESG as a reputational tool.

Second, the three dimensions of ESG play different roles in value creation. Among them, corporate governance performance plays the most significant role and is the foundation of ESG practical activities. Good governance performance can help enterprises implement sustainable development strategies and improve resource allocation efficiency (Shaikh, 2022). Next is the social responsibility performance, which includes product responsibility, supply chain responsibility management, management training, and other content, which are the most concerned topics for stakeholders (Wang et al., 2022). Enterprises with good social responsibility performance can better establish communication with stakeholders and thus obtain more production resources. The role of environmental performance is far less than the above two dimensions, and there is a negative correlation between environmental performance and value creation. Guo (2023) found that due to the lack of significant punishment measures and local protectionism, it is difficult for the Chinese central government's environmental policies to reach enterprises. The loose enforcement and supervision lead to a low environmental violation cost. Besides, investors lack environmental protection awareness, so enterprises lack the motivation to improve their environmental performance.

Third, the four configurations of ESG for high-efficiency value creation indicate that a company is not efficient in value creation if it scores high on all three components. Different from social responsibility performance and governance performance, value creation efficiency is higher when a company's environmental performance is poor. Table 7 also shows that firms with bad environmental performance are more efficient in creating value. This may be because there is more cost pressure on companies to improve their environmental performance, especially in the increasingly technologically advanced world. Relying on companies to reduce their energy consumption and pollution emissions is insufficient to enhance their competitive advantage in environmental performance. Companies are urgently required to pursue green innovation. It will undoubtedly continue to increase business operating costs, and the benefits of green innovation take time to translate into a competitive advantage in value creation. Investing its resources into social responsibility and corporate governance is an optimal solution for the enterprise. However, extreme neglect of environmental performance is not conducive to a sustainable development strategy. Therefore, the government must guide Chinese listed companies to actively participate in ESG activities and rationally allocate corporate resources through formulating policies.

## Conclusions

In recent years, as the construction of ecological civilization in China continues to advance, and the concept of sustainable development gradually gains popularity, ESG performance has also received much attention. The main objective of this study is to examine the relationship between ESG and value creation and how the three ESG components work together through their configurations to elucidate novel research perspectives on ESG. Accordingly, we establish a data analysis system including ESG performance, firm characteristics, and value creation and introduce a rough sets method to explore their relationships. The advantage of this research model is that it enables not only a clarification of the relationship between ESG performance and value creation but also an exploration of the role of various firm characteristics in this relationship. In contrast to previous approaches, rough sets-based rule mining technology can help us reach more detailed conclusions from enterprise data and show more clearly the distribution of the conditional variables, which extends the single causality of traditional econometrics. We uses China's 300 CSI-listed companies on the Shanghai and Shenzhen Stock Exchanges from 2015 to 2020 as a research sample. We found that (1) Firms with good ESG performance were likelier to have high-efficiency value creation. The relationship is stronger among firms with good financial situations, low industry competition, non-heavy pollution, and less government support. (2) The three components of ESG play different roles in the value creation process, and their importance is, in descending order, governance performance, environmental performance, and social responsibility performance. (3) Firms with bad environmental performance, good social responsibility performance, and good governance performance are more likely to obtain high-efficiency value creation.

Based on the above findings, we can obtain the following implications. First, enterprises should pay attention to the role of ESG performance in their value-creation process and fully implement ESG concepts in all aspects of production and operation. To gain an advantage in fierce market competition, companies still need to improve their ESG performance continuously. They should also develop a scientific ESG practice plan according to their conditions and not blindly follow the experience of other companies. Strengthen communication with stakeholders, and establish a good reputation and image with the help of ESG signal transmission. Second, the government should strengthen the supervision and guidance on the ESG performance of enterprises to provide a good institutional environment for ESG construction. China should fully play its institutional strengths to avoid "bias" in enterprises' ESG practice. Third, investors should incorporate ESG performance into the investment decision framework and take the initiative to strengthen communication with enterprises. In addition to paying attention to macro decisions and corporate financial information, investors should also pay extra attention to corporate environmental information, social responsibility information, and corporate governance information; strengthen their attention to corporate ESG performance; communicate with companies on the quality and scope of information disclosure on time; and guide the high-quality development of companies.

Applying the rough sets method to the relationship between ESG performance and value creation has helped us obtain detailed conclusions, but this study also has some limitations. First, our sample only covers China's 300 CSI-listed companies on the Shanghai and Shen-

zhen Stock Exchanges, a vital reference indicator in China's A-share market, but it needs to be more generalizable to other countries or regions. Future studies can expand the scope of data samples to compare data from different markets or cycles to validate rules and obtain broader conclusions. In addition, from the rules obtained in this study, it can be found that the results will contain more than one rule, and the attributes contained in different rules are different, which poses a challenge for us to extract the rule results and obtain economic implications. This article presents the obtained rules, but if there are too many rules, it will not be easy to demonstrate them in the article entirely. Therefore, it is crucial to summarize and organize all rules to obtain more targeted conclusions. In future research, existing rule mining methods can be improved to integrate rough sets method with other emerging technologies, making them more suitable for accounting and financial fields.

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## Author contributions

X. H. was responsible for data collection and analysis. W. Z. and T. Z. were responsible for supervision. X. H. conceived the study and were responsible for the design and development of the data analysis. C. Z. was responsible for review and editing. X. H. and W. Z. were responsible for data collection and analysis. X. H. and W. Z. were responsible for data interpretation. X. H. wrote the first draft of the article. C. Z. contributed a lot to revision.

## Disclosure statement

The authors declare no conflict of interest.

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