

Green Operation Innovation of Enterprises under ESG Rating Pressure

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Abstract. Under the global low-carbon transition and China's dual-carbon strategy, ESG rating has evolved into a critical capital market mechanism that regulates corporate business behaviors, and supply chain scope 3 carbon emissions have become the core focus for enterprises to achieve deep decarbonization. This study uses a panel data mediation model with two-way fixed effects to examine the influence of ESG rating pressure on low-carbon supply chain performance and its transmission mechanism using a sample of Chinese A-share listed companies from 2010 to 2023. According to empirical findings, ESG rating pressure greatly enhances the performance of low-carbon supply chains by ensuring legitimacy, fostering stakeholder collaboration, and implementing environmental risk prevention strategies. The aforementioned path is partially mediated by green operation innovation, since ESG pressure compels businesses to boost green operation capabilities and make considerable environmental investments, thereby encouraging the low-carbon transformation of the entire supply chain. In addition to offering empirical support for business decarbonization and regulatory optimization, this work expands the research scope of ESG economic effects to supply chain management.

Keywords: ESG rating pressure, green operation innovation, low-carbon supply chain performance

1. Introduction

In recent years, amid global warming and frequent extreme weather events, promoting the green and low-carbon transition has become a global consensus. Under the guidance of China's carbon peaking and carbon neutrality strategy, physical enterprises, as the primary source of carbon emissions, face unprecedented emission reduction pressure. Therefore, building a low-carbon supply chain and promoting the greening of the supply chain is not only the core path for enterprises to achieve deep decarbonization, but also the key to obtaining their competitive advantage in the future under the strict ESG examination [1]. However, under external ESG rating pressure, do enterprises pursue substantive green transformation or merely engage in symbolic greenwashing?

There is a dearth of empirical research on the full transmission path between ESG rating pressure, green operation innovation, and low-carbon supply chain performance. Instead, the majority of

existing literature concentrates on the direct impact of ESG rating on corporate financial performance or examines the role of green operation innovation independently [2]. This study used the panel data mediation effect model to investigate the influence of ESG rating pressure on low-carbon supply chain performance and its transmission mechanism using Chinese A-share listed companies as samples. The findings demonstrate that low-carbon supply chain performance is greatly enhanced by ESG rating pressure, with green operation innovation playing a crucial mediating role. Theoretically, this paper constructs a novel framework consisting of external pressure, internal response, and supply chain performance. Practically, it provides clear implications for enterprises to respond to ESG rating pressure and for regulators to improve green-related policies.

Based on the above background, this paper focuses on how external capital market signals penetrate the boundaries of enterprises, thus affecting their internal operation and supply chain strategy, and specifically puts forward the following questions: Whether the pressure from ESG ratings can be successfully converted into a significant motivator for businesses to enhance the efficiency of their low-carbon supply chain. Will businesses increase internal green operation innovation to open up the transmission line of transformation to a low-carbon supply chain under the pressure of an ESG rating? While the majority of the work currently in publication concentrates on the direct effects of ESG on corporate financial performance, this paper expands the viewpoint to supply chains and operations management, revealing the hidden mechanism by which ESG pressure influences actual business operations. In addition, this paper combines institutional theory with resource-based view to build a theoretical framework of external pressure, internal response, and supply chain performance, which enriches the research on the pre drivers of sustainable supply chain management. In practice, the conclusions of this paper provide clear strategic guidance for real enterprises to cope with ESG rating pressure, and emphasize the pivotal role of substantive environmental protection investment in supply chain transformation.

2. Theoretical analysis and hypothesis raising

2.1. ESG rating pressure and low-carbon supply chain performance

Under the combined action of institutional pressure and capital market constraints, ESG rating pressure has a direct driving effect on low-carbon supply chain performance, which is realized through triple logic. First, the legitimacy guarantee mechanism. Institutional theory holds that enterprises must meet external institutional and social expectations to obtain organizational legitimacy. As a core metric for evaluating corporate environmental responsibility in the capital market, a low ESG rating leads to financing constraints, investor avoidance, and reputational losses, placing enterprises in a legitimacy crisis [3]. The ESG environmental dimension's fundamental assessment content consists of three carbon emissions within the supply chain. Promoting the development of a low-carbon supply chain and putting green procurement and green logistics into practice can immediately lower the carbon footprint of the entire life cycle, which is a crucial step for businesses to respond to external oversight and preserve their credibility [4]. Businesses are more motivated to gain legitimacy through low-carbon supplier chains when there is more focus on ESG ratings.

The mechanism of stakeholder synergy comes in second. Customers, suppliers, investors, and consumers continue to focus more on low-carbon growth, and ESG ratings have emerged for stakeholders to assess an organization's capacity for sustainable development [5]. Businesses will take the initiative to integrate green standards into supply chain management procedures and bolster upstream and downstream collaborative emission reduction in order to satisfy stakeholder expectations and stabilize cooperative relations. Businesses will expedite the green transformation of their supply

chains and enhance the performance of their low-carbon supply chains as a result of increased market expectations brought on by high ESG rating pressure [6].

Third, environmental risk prevention and control mechanisms. Supply chain environmental risks are conducive and sudden, and once there is an environmental violation, it will quickly lower the ESG rating and cause business losses [7]. ESG rating pressure urges enterprises to strengthen the identification and control of supply chain environmental risks and reduce exposure to supply chain risks through access to green suppliers, carbon footprint tracking, and environmental information disclosure. Businesses are further encouraged to raise the level of low-carbon supply chain management by the need for risk prevention and control [8]. In light of the aforementioned analysis, this paper suggests:

Hypothesis 1: ESG rating pressure has a significant positive impact on the performance of the low-carbon supply chain.

2.2. Intermediary role of green operation innovation

ESG rating pressure cannot directly act on supply chain terminals, and green operation innovation must be used as an intermediary carrier to achieve effective transmission from external pressure to supply chain performance. On the one hand, ESG rating pressure drives green operation innovation. Subject to external rating constraints, symbolic disclosure and public relations cannot improve ESG performance sustainably, so enterprises must conduct substantive environmental investment and technological transformation. Resource-based view points out that green operation innovation is scarce and difficult to imitate, and can form the core green competence of enterprises, which is a reliable path to deal with ESG pressure. The greater the pressure of ESG rating, the more inclined enterprises are to increase investment in environmental protection, upgrade cleaner production processes, and improve pollution control facilities, so as to improve the innovation level of green operation [9].

On the other hand, green operation innovation is promoting low-carbon supply chain performance. Internal green technology, management standards, providing technical support and implementation basis for green supplier management, collaborative production, and low-carbon logistics. The higher the level of green operation innovation, the more capable enterprises are to integrate upstream and downstream resources to promote carbon reduction in the whole chain, thus significantly improving the performance of the low-carbon supply chain. It can be seen that ESG rating pressure indirectly improves the performance of the low-carbon supply chain by promoting green operation innovation. Based on the above analysis, this paper proposes:

Hypothesis 2A: ESG rating pressure has a significant positive impact on green operation innovation.

Hypothesis 2B: Green operation innovation plays a significant intermediary role between ESG rating pressure and low-carbon supply chain performance.

3. Research methods and design

3.1. Sample selection

This study examines how ESG rating pressure affects low-carbon supply chain performance using China's A-share listed companies from 2010 to 2023 as an initial research sample. The China A-share listed firms from 2010 to 2023 serve as the basis for this paper's demonstration. This research performs industrial normalization when cleaning the original data set to remove statistical noise and guarantee the consistency of regression predictions. In order to avoid the measurement bias of

financial leverage features on variables like environmental investment, this paper manually removes such samples due to the fundamental differences between the asset liability structure of insurance firms and real enterprises.

For ST, *ST, or PT enterprises, because their business continuity is damaged and their strategic behavior may deviate from the rational path, this paper divests them from the observation pool. After excluding the samples with missing core explanatory variables and key controls, this study finally locked in an unbalanced panel containing 48083 company annual observations. To mitigate the impact of statistical outliers, all continuous variables are winsorized at the 1st and 99th percentiles.

3.2. Variable definition

Complete supply chain scope 3 carbon emission data are hard to come by for the dependent variable LSCP. This study employs the disclosure of green supply chain management data as a proxy variable for low-carbon supply chain performance in accordance with reputable literature. The company receives a score of 1 or 0 if it includes information about low-carbon supply chains, such as green procurement and green logistics, in its annual report or social responsibility report for that year.

For the independent variable ESG, this paper selects the CSI ESG Evaluation Index as the core independent variable, which differs from single environmental indicators. The rating constructs a continuous valuation system through nine credit ratings. It aims to accurately capture the external evaluation pressure perceived by enterprises under multiple institutional constraints. C=1, CC=2, ..., AAA=9 are the continuous variables from 1 to 9 that are assigned in this study. The higher the score, the better an organization's ESG rating performance is, and the higher the market expectations and possible downgrade pressure.

The precise measurement procedure is as follows: calculate the natural logarithm of the enterprise's total environmental protection investment for that year after adding 1. In response to ESG pressure, this indicator intuitively captures the true gold and silver that businesses have put into green production and operations. The percentage of independent directors serves as a gauge for corporate governance. The variable is centered in the cross-multiplier regression to prevent multicollinearity. For highly polluting industries, industry environmental sensitivity creates virtual variables. Mining, manufacturing, power, and thermal sectors are classified as highly polluting businesses with a value of 1, and other industries with a value of 0, according to the Securities Regulatory Commission's 2012 industry classification standard.

The enterprise size, asset liability ratio, and operating cash flow ratio are the control variables chosen for this study since they may have an impact on the low-carbon supply chain's performance. The year fixed effect and the individual fixed effect are also tightly controlled by the model.

3.3. Model building

The empirical portion of this work builds a panel data regression model using the two-way fixed effects of individual and time in order to evaluate the research hypothesis. Subscripts i and t in the model stand for firm i and year t , respectively. The random disturbance term is denoted by ε . Firm and Year stand for year fixed effects and firm fixed effects, respectively. The following Model (1) is built in order to assess the direct effect of ESG rating pressure on low-carbon supply chain performance. Assuming that H1 is true, a considerably positive coefficient α_1 indicates that the low-carbon supply chain's performance has been greatly enhanced by improvements in ESG rating performance.

$$LSCP_{i,t} = \alpha_0 + \alpha_1 ESG_{i,t} + \alpha_2 Size_{i,t} + \alpha_3 Lev_{i,t} + \alpha_4 CFO_{i,t} + \sum Firm + \sum Year + \varepsilon_{i,t} \quad (1)$$

Referring to the step-by-step regression method, based on Model (1), the following Models (2) and (3) are further constructed to test the intermediary effect of environmental protection investment Ln_EP [10]. β_1 in Model (2) is expected to be significantly positive, and γ_2 in Model (3) is expected to be significantly positive. If the value of γ_1 is less than α_1 or significantly decreased, there is a partial mediating effect.

$$Ln_EP_{i,t} = \beta_0 + \beta_1 ESG_{i,t} + \beta_2 Size_{i,t} + \beta_3 Lev_{i,t} + \alpha\beta_4 CFO_{i,t} + \sum Firm + \sum Year + \varepsilon_{i,t} \quad (2)$$

$$LSCP_{i,t} = \gamma_0 + \gamma_1 ESG_{i,t} + \gamma_2 Ln_EP_{i,t} + \gamma_3 Size_{i,t} + \gamma_4 Lev_{i,t} + \gamma_5 CFO_{i,t} + \sum Firm + \sum Year + \varepsilon_{i,t} \quad (3)$$

4. Empirical analysis and results

4.1. Descriptive statistics and correlation analysis

This study initially does descriptive statistics and correlation analysis of the primary variables prior to panel data regression. The findings demonstrate that there is considerable variation in the sustainable performance, with the mean of ESG, the primary explanatory variable, being 4.091 and the standard deviation being 0.965. Simultaneously, the range distribution of the explained variable LSCP and environmental protection investment is quite different, reflecting the notable variations among various businesses in the decarbonization process as well as the various stages that Chinese businesses have taken in the supply chain's green transformation.

The calculation result of the variable expansion factor is far lower than the critical value of 10. The Pearson correlation coefficient matrix shows that there is a preliminary positive coupling between variables in various dimensions, which eliminates a variety of collinearity technical hidden dangers for subsequent robust regression.

4.2. Benchmark regression results and mediating effects

This research investigates the benchmark effect of ESG pressure transmission to supply chain outcomes by building a two-way fixed effects model. Table 1's column 1 displays the regression findings. The contribution coefficient of ESG to supply chain carbon reduction behavior is 0.0200, which is highly significant at the 1% level, $t=7.82$, after removing the influence of firm size, leverage level, and cash flow quality. This outcome demonstrates that ESG rating pressure goes beyond simple symbolic adherence. Rather, it effectively encourages enterprise managers to spread the carbon emission reduction concept from internal production to the entire supply chain system as a high-frequency external regulatory signal. This study employs a step-by-step regression method for empirical analysis to investigate the mediating influence of Ln_EP between ESG rating pressure and low-carbon supply chain performance. The results are displayed in columns (2) and (3) of Table 1. Empirical results show that ESG pressure has significantly boosted green expenditure within enterprises, with a regression coefficient of 0.0905, confirming the forced mechanism of rating downgrade threat on green innovation. When the intermediate term Ln_EP and ESG are placed in the regression equation at the same time, Ln_EP still maintains strong explanatory power, with a coefficient of 0.0247, $p<0.01$. The benchmark coefficient is significantly diluted.

Table 1. Benchmark and intermediary regression results

Variable name	(1) LSCP (benchmark regression)	(2) Ln_EP (green operation innovation)	(3) LSCP (mediating effect)
ESG	0.0200*** (-7.82)	0.0905*** (-6.55)	0.0178*** (-7.07)
Ln_EP			0.0247*** (-20.91)
Size	0.0485*** (-10.39)	0.1170*** (-5.11)	0.0456*** (-10.05)
Lev	-0.0939*** (-5.36)	-0.6612*** (-7.90)	-0.0775*** (-4.56)
CFO	0.0725*** (-2.89)	0.0851 (-0.65)	0.0704*** (-2.86)
Constant	-1.1020*** (-11.32)	-2.7007*** (-5.62)	-1.0352*** (-10.93)
Firm	YES	YES	YES
Year	YES	YES	YES
N	48,083	48,083	48,083
Adj. R ²	0.2418	0.1729	0.2571
F value	278.31***	145.54***	340.23***

Note: The T value adjusted by company-level clustering is in brackets. ***, **, and * are significant at the statistical level of 1%, 5%, and 10%, respectively.

This typical partial mediation pattern shows that external pressure not only directly shapes corporate behavior but also enables the internal-to-external low-carbon transition of the supply chain by stimulating green investment in internal production processes. Hypotheses 2A and 2B are strongly supported. The aforementioned findings demonstrate that green operation innovation mediates the relationship between low-carbon supply chain performance and ESG rating pressure. This means that by encouraging internal environmental investment and operational innovation, the external ESG rating pressure not only directly encourages the supply chain to cut carbon, but it also enhances the supply chain's total low-carbon performance from the inside out.

4.3. Robustness test

This study also performs robustness tests, such as variable replacement and a one-period lag of the primary independent variable, to guarantee the validity of the aforementioned conclusions. The model incorporates the primary explanatory variable ESG rating, which lags behind one period due to the potential reverse causal link between supply chain carbon reduction and ESG rating. The findings demonstrate that the present low-carbon performance is still positively predicted by the ESG performance, falling short of the first period, demonstrating the stability of the main conclusion.

5. Conclusion

This study empirically examines the effect and internal transmission mechanism of ESG rating pressure on low-carbon supply chain performance using Chinese A-share listed businesses from 2010 to 2023 as research examples. The findings demonstrate that low-carbon supply chain performance is significantly improved by ESG rating pressure. Through three mechanisms, legitimacy guarantee, stakeholder collaboration, and environmental risk prevention and control, the capital market's ESG evaluation constraints can be effectively transformed into a significant driving force for businesses to promote green transformation of supply chains. The benchmark hypothesis has been completely confirmed. According to the mechanism test results, green operation innovation is a key intermediary in the impact path mentioned above. Through the upstream and downstream spillover of green technology and management expertise, ESG rating pressure can compel businesses to make significant investments in environmental protection, raise the bar for green operation innovation, and ultimately realize the low-carbon transformation of the entire chain. Regulators should optimize the rules for supply chain environmental information disclosure and guide green financial resources to support enterprises' green operation innovation.

This paper's primary theoretical contribution is to broaden the scope of ESG economic consequences research, overcoming the constraint that the current literature concentrates on the direct connection between ESG and company financial performance. The research perspective is extended to the dimension of operations management and supply chain, which opens up the black box of ESG external pressure penetrating enterprise boundaries and affecting the entity's business. At the same time, it integrates institutional theory and resource-based view, constructs an analytical framework of external pressure-internal response-supply chain performance, and enriches the research on the pre-determinants of sustainable supply chain management. The study's findings give actual businesses a clear strategic direction to deal with ESG rating pressure and advance the supply chain's low-carbon transformation. They also give regulators a point of reference for making decisions to enhance the green information disclosure system and maximize the low-carbon transformation's supporting policies. This study still has certain limitations. The use of dummy variables to measure low-carbon supply chain performance fails to accurately quantify the level of supply chain scope 3 carbon emissions. Future research can optimize the quantification of core variables, expand the dimension of heterogeneity analysis, and more accurately identify causal effects combined with quasi-natural experimental methods.

Authors contribution

All the authors contributed equally and their names were listed in alphabetical order.

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