

Mitigating the bullwhip effect: the role of ESG performance in Chinese enterprises

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Abstract

Supply chain resilience is vital to the long-term operation of enterprises. With the concept of sustainable development becoming deeply ingrained globally, enterprises are actively implementing environmental, social, and governance (ESG) practices. Based on panel data of China's A-share listed firms spanning 2010 to 2023 and ESG rating datasets sourced from Sino-Securities, this paper systematically investigates the associations, configurational mechanisms, and heterogeneous boundary conditions linking corporate ESG performance to a firm-level bullwhip-effect proxy. Baseline empirical results reveal that higher-quality ESG performance is associated with a significant reduction in the bullwhip-effect proxy. To move beyond the restrictive net-effect paradigm of traditional regression frameworks, this study adopts fuzzy-set qualitative comparative analysis (fsQCA) to unpack complex multi-factor configurational pathways. We select firm-level conditional antecedents and explore their joint combinatorial effects with ESG engagement in curbing the amplification of demand volatility along supply chains. It further identifies six equifinal configurational paths, including ESG compensation-oriented, operational agility-oriented, non-ESG internal governance-dominated, and state ownership-backed stability-driven configurations. These distinct combinations suggest that enterprises can pursue supply chain stability via differentiated governance portfolios, thereby highlighting multiple equifinal strategies to foster supply chain resilience under heterogeneous institutional and operational environments. Collectively, the empirical evidence suggests that ESG strengths can be converted into operational resilience dividends, delivering theoretical implications for sustainable supply chain management research within emerging market contexts.

Introduction

Amidst global industrial restructuring, supply chains are facing rising complexity and uncertainty. Frequent “black swan” events have exposed the fragility of traditional supply chain operation models. The World Bank highlights that widespread supply chain disruptions in 2020 generated sharp cost hikes for industrial firms, with a large share of small and medium-sized enterprises confronted with existential operational crises due to inadequate resilience capacity. These pressures have compelled companies to view risk management as a competitive advantage, as supply chain performance determines the ability to respond to market demand efficiently.

ESG is highly relevant to this risk management paradigm, as it integrates information disclosure, internal governance, stakeholder coordination, and long-term resource commitments. Existing studies associate superior ESG performance with market value (Zhou et al., 2022), financial outcomes (S. Chen et al., 2023), innovation (Yang et al.,

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2024), internal-control quality and firm performance (Boulhaga et al., 2023), and operational resilience (Jin et al., 2025). Within supply chain contexts, ESG-driven transparency and responsible governance can mitigate information asymmetry, foster stakeholder trust, and underpin more stable inter-firm coordination (Hofmann et al., 2014; Govindan et al., 2014; Wei et al., 2024).

The research gap we address is therefore more specific than the broad question of whether ESG is beneficial. Although existing evidence has documented the financial, innovation, and resilience benefits associated with ESG, far less is known about whether ESG is linked to lower operational volatility, as captured by firm-level supply-demand amplification. Governance, cost stickiness, and supplier relationships are not separate from this gap; they constitute the channels through which ESG may influence the information distortion, adjustment rigidity, and coordination failures that generate the bullwhip effect (Gurtu & Johny, 2021; Cek & Ercantan, 2023; Li et al., 2015; Hao et al., 2025).

China offers a substantively meaningful empirical setting, as Chinese A-share listed firms hold a pivotal position in global manufacturing networks and have advanced rapidly in ESG disclosure and governance amid evolving sustainability policies such as the dual-carbon strategic goals. Against this backdrop, this study conceptualizes the bullwhip effect as the core operational outcome of analysis. Given the availability of firm-level data, the bullwhip effect is operationalized as a concrete, observable indicator of supply chain risk, rather than as a comprehensive measure of multi-tier network dynamics. Signaling theory elucidates how ESG disclosure conveys credible signals regarding a firm's long-term strategic orientation and responsible operational practices, while stakeholder theory illuminates how stable collaborative relationships with suppliers, customers, investors, and regulators can curb opportunistic responses to demand uncertainty. Accordingly, this study addresses three core research questions: (1) whether ESG performance is associated with a lower firm-level bullwhip-effect proxy; (2) which configurations of ESG, governance, cost stickiness, supplier stability, ownership, and size are linked to mitigation; and (3) whether the association varies across ownership, industry-pollution status, and firm size.

Literature review

In supply chain operations, the bullwhip effect is a prevalent and critical issue that leads to widespread supply-demand mismatches. First proposed by Forrester (1961), this effect refers to the progressive distortion and amplification of demand information as it transmits upstream along the supply chain. Such information distortion further triggers multiple operational risks, including excess inventory and unstable production planning (Lee et al., 1997; Xiao & Chen, 2012). Flawed demand information flows upward without effective cross-firm information sharing, causing increasingly drastic order and inventory fluctuations throughout the supply chain. These fluctuations raise overall supply chain operational costs and disrupt normal order arrangement (Chen et al., 2000). Fundamentally, insufficient mutual trust between upstream and downstream supply chain participants is the core driver of persistent information distortion and the subsequent bullwhip effect.

Mitigating the bullwhip effect has long been a core research theme in supply chain management. Traditional mitigation strategies mainly focus on operational optimization, such as simplifying supply chain hierarchical structures, optimizing inventory management systems, and building cross-firm supply chain coordination mechanisms (Fransoo & Wouters, 2000; Jaipuria & Mahapatra, 2014). Recent studies have expanded the research boundary of bullwhip governance, verifying that firm-level initiatives including high-quality information disclosure (Z. Yang et al., 2020) and manufacturing servitization (Niu et al., 2025) can effectively curb supply chain demand fluctuations. While numerous studies exist in this field, few have explored corporate ESG performance. ESG shapes interfirm interactions and information conditions and directly tackles the trust gaps and information opacity underlying the bullwhip effect.

The rapid proliferation of ESG disclosure, accelerated by the UN Principles for Responsible Investment and, in China, the “dual-carbon” targets, has fundamentally altered the information landscape in which supply chains operate. By 2024, a majority of A-share listed firms had adopted standardized ESG reporting, with disclosure rates surpassing 90% in the financial sector. A substantial body of literature now confirms that strong ESG performance

improves firm-level outcomes such as market valuation (Zhou et al., 2022), profitability (S. Chen et al., 2023), innovation (Yang et al., 2024), and operational resilience (Jin et al., 2025). More pertinent to the bullwhip effect is the growing literature on ESG's supply chain spillovers. Favorable ESG profiles of downstream firms have been shown to spur green innovation in midstream partners and foster collaborative green upgrading across entire chains (Zhang et al., 2026). Crucially, recent studies reveal that ESG performance facilitates cross-firm sustainable cooperation and trust-based partnerships (Wei et al., 2024). While recent findings (e.g., L. Wu et al., 2024) imply that ESG could function as a governance mechanism that attenuates fluctuations, they stop short of analyzing how distinct firm-level mechanisms interact to produce this outcome. How these variables combine into specific operational configurations to break the amplification loop remains empirically unexplored.

Theoretically, high-quality ESG performance is expected to inhibit the bullwhip effect. From the perspective of signaling theory and asymmetric information theory, sound ESG performance sends credible signals of long-term strategic orientation and standardized responsible operation to supply chain partners. These effective signals reduce cross-firm information asymmetry and enhance mutual trust between suppliers and manufacturers (Connelly et al., 2011). Unlike conventional financial disclosure, ESG disclosure focuses on non-financial, long-term content closely linked to collaborative relationships (Sheng et al., 2026). It can directly mitigate information asymmetry regarding actual market demand, thereby curbing corporate behaviors such as over-ordering and artificial demand inflation at the source (Sheng et al., 2026). The valid signals conveyed via ESG disclosure reduce misinterpretation of downstream demand information and foster trust between supply and demand parties. This ensures the truthful and timely flow of demand information across the supply chain, which targets the fundamental causes of the bullwhip effect, rather than merely improving the overall information transparency of enterprises (Lin & Li, 2025; L. Wu et al., 2024). Stakeholder theory provides supplementary theoretical support. Firms with well-developed ESG governance systems prioritize establishing long-term, stable contractual relationships with key supply chain stakeholders such as suppliers and customers, thereby eschewing short-term, profit-driven opportunistic behavior (Parmar et al., 2010; Song et al., 2023; Sheng et al., 2026). Such stable cooperative relationships can effectively mitigate problems like order batching, material rationing, and shortage gaming—behaviors that the academic literature widely recognizes as direct contributors to the bullwhip effect. At the same time, a high level of ESG performance is typically accompanied by sound internal governance mechanisms, which reduce agency conflicts and curb opportunistic conduct such as management's deliberate exaggeration of demand and speculative order hoarding—behaviors that directly inflate upstream demand signals. In short, ESG does not enhance corporate risk prevention capabilities in a general and diffuse way; rather, it precisely targets the information distortions and irrational behaviors that give rise to demand amplification. The resource-based view and dynamic capabilities theory further elaborate the internal mechanism through which ESG performance mitigates the bullwhip effect in supply chains. From the perspective of the resource-based view, heterogeneous resources that are valuable, rare and inimitable constitute the source of firms' core competitive advantages. Dynamic capabilities theory highlights the value of firms' capacity to integrate and restructure internal and external resources to adapt to a dynamic market environment. Sound ESG practices of enterprises represent strategic resources and high-order dynamic capabilities embedded within organizational systems and difficult for peers to replicate, which specifically encompass cross-organizational information sharing mechanisms, sustainable supply chain collaboration processes and stakeholder response systems. Such practices help firms build long-term competitive advantages rooted in causal ambiguity and social complexity (Wang et al., 2026). Enterprises endowed with these core ESG capabilities can promptly capture real demand information from downstream partners and reduce the progressive amplification of distorted signals caused by demand forecasting errors. Meanwhile, the stable trust-based cooperation mechanisms across supply chains curb panic ordering driven by shortage gaming and speculative procurement triggered by price fluctuations. This stabilizes the flow of orders throughout the supply chain, thereby blocking the transmission path of supply chain volatility from the perspective of firms' internal capabilities and effectively alleviating the bullwhip effect (L. Wu et al., 2024).

This framing clarifies the role of the bullwhip effect (BWE) in the paper. The study does not claim to observe the full multi-tier bullwhip effect directly; rather, it examines a firm-level supply-demand volatility proxy that captures an observable manifestation of the same amplification mechanism. The specific contribution is to connect ESG governance with this operational risk proxy, identify equifinal configurations in which this proxy is mitigated, and test for

heterogeneity across ownership type, pollution-industry status, and firm size. Theoretically, this paper establishes a logical link between corporate ESG governance and bullwhip-effect mitigation, thereby bridging sustainable corporate governance and supply chain risk management. Methodologically, fsQCA is employed to explore complex configurational effects. Practically, the findings provide candidate pathways for small and medium-sized firms and state-owned firms to mitigate the bullwhip-effect proxy through coordinated ESG, governance, cost, and supplier-relationship practices.

Hypothesis development

ESG practices significantly contribute to reducing the bullwhip effect by enhancing forecasting accuracy and internal controls. This includes implementing advanced data analytics and transparency measures to provide better visibility (Abdel-Basset & Mohamed, 2020). By fostering accountability, ESG practices help stabilize demand dynamics and improve performance (Munir et al., 2020). Theoretically, ESG performance can contribute to bullwhip-effect mitigation through firm-level configurational conditions, including corporate governance, cost stickiness, supplier relationships, firm size and ownership.

First, regarding corporate governance, the bullwhip effect stems from irrational reactions and information distortion. While it affects operations, strong internal governance helps enterprises operate steadily by improving demand forecasting and reducing inflated safety inventory. When enterprises effectively manage risks, suppliers gain confidence, which facilitates rational production plans and improves forecasting accuracy. Enhanced internal control capabilities enable effective scientific inventory management, such as lean production, which reduces backlogs and mitigates the bullwhip effect. Corporate governance is crucial for integrating ESG considerations into supply chain strategies, leading to improved transparency and enhanced risk management. Effective structures ensure that ESG initiatives align with business objectives, improving decision-making and operational efficiency (Can Saglam et al., 2021). Governance practices establish clear accountability lines and metrics, which are critical for monitoring ESG outcomes (Mani et al., 2018).

ESG advantages offer new perspectives on governance and enhance internal controls. First, enterprises refine controls by incorporating environmental and social risks, ensuring the system's comprehensiveness (Boulhaga et al., 2023). As ESG emphasizes transparency, enterprises establish complete information systems to weaken supply chain asymmetry (Ouyang, 2007) and reduce demand information distortion (Moffitt et al., 2024). Second, according to signaling theory (Spence, 1973), enterprises transmit “high-quality” signals through their ESG performance to attract investors, forming an effective control mechanism. Robust ESG attracts long-term investors who monitor firms, reinforcing external scrutiny. Mandatory disclosures standardize information management, mitigating manipulation. ESG-associated governance structures enhance oversight and reduce fraud, while a sustainability-oriented culture decreases rule violations and mitigates moral hazard risks.

Second, cost stickiness—the asymmetric cost behavior whereby costs fall less when activity declines than they rise when activity increases—delays responses to demand and amplifies the bullwhip effect (Anderson et al., 2003). Reducing stickiness enhances upstream–downstream coordination and enables advanced inventory practices. The influence of ESG performance on cost stickiness involves two competing pathways. On one hand, ESG-related expenditures—including environmental facilities, employee welfare programs, and social responsibility initiatives—tend to exhibit high fixed-cost intensity and considerable adjustment rigidity. During demand downturns, considerations of strategic continuity, reputational preservation, and binding long-term contracts make it difficult for managers to scale down these outlays proportionally. From an accounting standpoint, green transformation and compliance adjustments directly add to current operating costs. Consequently, cost adjustments lag when demand falls, and this rigidity can propagate upstream, magnifying minor downstream fluctuations and reinforcing the bullwhip effect in the short run. On the other hand, and more fundamentally, from a long-term governance perspective, strong ESG performance strengthens internal governance, curbs managerial overinvestment and inefficient resource allocation, stabilizes supply chain relationships, and reins in discretionary cost redundancies. Compared to the short-term upward cost pressure exerted by rigid ESG expenditures, the governance effect in pruning non-

essential outlays and smoothing cost volatility proves more significant over time. Good governance constrains management's self-serving delays in cost adjustments (G. Yang et al., 2020). ESG practices optimize resource allocation and cost structure flexibility. Furthermore, partners with firm ESG commitments are more likely to accommodate order fluctuations, mitigating rigid inventory costs. ESG also encourages waste reduction and lean management, thereby stabilizing financial performance during periods of variability (Cek & Ercantan, 2023; Manhart et al., 2020). A flexible cost structure decreases production lags and enhances responsiveness to market demand (Govindan et al., 2014). In the long run, by weakening the asymmetric reaction of costs to activity changes, ESG practices reduce overall cost stickiness. This reduction curbs irrational cost-fluctuation biases, strengthens upstream–downstream coordination and market responsiveness, and consequently alleviates the bullwhip effect in which demand information distortion propagates through the supply chain, achieving synergy between long-term cost control and supply chain stability. Although ESG may temporarily intensify cost stickiness, the long-term governance effect dominates, yielding a net reduction in stickiness (Jiang & Yang, 2024). Hence, we hypothesize that ESG performance mitigates the supply chain bullwhip effect through decreased cost stickiness.

Third, supplier relationships based on mutual trust prevent shortage gaming and reduce distorted demand information (Gu et al., 2022). ESG commitments align sustainability goals, improving information sharing and reducing disruption (Fan & Stevenson, 2018; Li et al., 2015). Stable relationships allow enterprises to optimize internal control resources and jointly respond to market risks. For instance, partners can share costs during price fluctuations rather than shifting burdens unilaterally. Improved information sharing minimizes forecasting deviations caused by asymmetry. By establishing stable supplier relationships, enterprises reduce uncertainty and transaction costs. ESG serves as a link to strengthen partner cooperation, mitigating the bullwhip effect. Environmentally, joint green supply chains enable partners to align on protection goals. Robust ESG performance enhances resource efficiency, mitigates disruptions, and strengthens relationship stability. Firms with strong ESG commitments are favored partners due to their predictable demand and potential for collaboration. By promoting transparency and collaborative planning, ESG enhances coordination, reputation, and trust (S. Chen et al., 2023). This trust stabilizes market demand and reduces fluctuations caused by information asymmetry (L. Wu et al., 2024). According to signaling theory (Spence, 1973), good ESG performance conveys positive signals regarding sustainability and compliance, thereby enhancing suppliers' trust and strengthening cooperative relationships (Li et al., 2022).

Hypothesis 1: Enterprises' good ESG performance can mitigate the bullwhip effect and reduce supply chain risks.

Hypothesis 2: The mitigating effect of ESG on the bullwhip effect is not achieved through a single, uniform channel, but through multiple equifinal configurational pathways formed by ESG performance and combinations of internal control quality, cost stickiness, supplier stability, ownership, and firm size.

Hypothesis 3: The impact of ESG performance on the bullwhip effect is expected to vary systematically based on firms' ownership type, their status as a heavily polluting industry, and firm size.

Methodology

Data

ESG performance data were accessed through the WIND database using the Sino-Securities ESG rating. We collected unbalanced panel data on Chinese A-share listed companies from 2010 to 2023 and excluded financial industry enterprises, special treatment enterprises, and those with missing values. The final sample includes 4093 listed companies with 36,344 firm-year observations. Enterprise-level financial data were obtained from the CSMAR database. Stata and R software were used during the analyses.

Table 1 Descriptive statistics for 36,344 observations.

Variable	Mean	Standard deviation	Min	Max
<i>BWE</i>	1.295	1.277	0.002	20.476
<i>ESG</i>	4.183	1.046	1	8
<i>AUDIT</i>	0.063	0.242	0	1
<i>BM</i>	0.627	0.250	0.032	1.601
<i>INDBOARD</i>	0.377	0.056	0.143	0.800
<i>OCCUPY</i>	0.014	0.026	0	0.616
<i>ROE</i>	0.040	1.243	-186.557	64.056
<i>SIZE</i>	22.277	1.323	18.870	28.696
<i>AGE</i>	2.123	0.837	0	3.526
<i>LEV</i>	0.421	0.215	0.008	8.612

Source: Own research, 2025.

Variable construction

Explained variables

The bullwhip effect reflects information distortion across tiers. Some existing methods quantify upstream/downstream fluctuation deviations (Z. Yang et al., 2020). As correctly pointed out by supply chain scholars, true measurement of the bullwhip effect requires dyadic or multi-tier inter-organizational data. Due to the unavailability of tier-to-tier supply chain data for large-scale Chinese A-share samples, we followed Bray & Mendelson (2012), Cachon et al. (2007) and Shan et al. (2014) by utilizing a firm-level proxy. This proxy measures the deviation of a single enterprise's production fluctuation relative to demand, assuming that smooth internal production management stabilizes the overall chain. A value greater than 1 indicates the bullwhip effect. We acknowledge this proxy primarily captures firm-level supply-demand fluctuation vulnerability rather than cross-tier network amplification. Even in the absence of complete data on upstream and downstream matching relationships, the existence of amplification behavior at the focal firm can be identified by observing the discrepancy between its output volatility and the demand volatility it faces. If a firm's production-side volatility is significantly higher than its sales-side volatility, it indicates that the firm, as a supply chain node, transmits more drastic demand signals to its upstream partners. This serves as an observable manifestation of the bullwhip effect at the individual node level. First, we calculate production volume (Production) via Formula 1:

$$Production_{it} = COST_{it} + INV_{it} - INV_{it-1} \quad (1)$$

Subscripts *i* and *t* denote the enterprise and year. Operating income from CSMAR proxies demand (*Demand*), while *INV* and *COST* denote the quarterly cost of goods sold and the quarterly net inventory, respectively. Both *Production* and *Demand* represent the quarterly production volume and sales, respectively, after applying logarithmic and first-difference transformations to the original series $\{X_{it}\}$, i.e., transforming them into $\{\ln(X_{it}) - \ln(X_{it-1})\}$. The bullwhip effect (BWE) is calculated as the ratio of the quarterly standard deviation of production to that of demand (Eq. 2).

$$BWE_{it} = Std.(Production_{it}) / Std.(Demand_{it}) \quad (2)$$

Core explanatory and control variables

This study uses the Sino-Securities ESG rating as the core explanatory variable. Following the rating approach used in Ashbaugh-Skaife et al. (2006) and in recent ESG literature (e.g., Lin & Li, 2025; Jin et al., 2025), we convert the ESG evaluation ratings into a 9-point ordinal scale, assigning 9 to AAA and 1 to C. In the estimation sample reported in Table 1, the observed ESG values range from 1 to 8, indicating that no AAA observation appears in the current sample. To ensure robustness, we also use Sino-Securities ESG scores (1–100) and CNRDS database ratings in alternative specifications. Following prior studies (Niu et al., 2025), control variables include: LEV (asset-liability ratio), AGE (log of listing years), SIZE (log of total assets), ROE (return on equity), OCCUPY (major shareholder fund occupation), INDBOARD (independent director ratio), AUDIT (Big Four audit), and BM (book-to-market ratio).

The empirical model

To examine the relationship between corporate ESG performance and the bullwhip effect, this study uses a fixed-effects model. This approach accounts for unobserved time-invariant heterogeneity without assuming it is uncorrelated with explanatory variables. To test Hypothesis 1, the following model is constructed to examine the effect of ESG performance on the supply-demand bullwhip-effect proxy.

In addition to core variables, $Control_{it}$ represents the collection of control variables. Simultaneously, to account for significant differences between enterprises and time changes, the model controls for enterprise and year fixed effects, including a random error term e_{it} . I_t represents the year fixed effect, and m_i represents the individual fixed effect.

$$BWE_{it} = b_0 + b_1 ESG_{it} + b_2 Control_{it} + m_i + I_t + e_{it} \quad (3)$$

Table 1 presents the descriptive statistics. The mean ESG value was 4.183, indicating significant differences in performance among enterprises. The mean of BWE value was 1.295, with a standard deviation of 1.277 (maximum 20.476, minimum 0.002), indicating that the bullwhip effect is common among the enterprises.

Fuzzy Set Qualitative Comparative Analysis (fsQCA)

To address the complexity and equifinality inherent in supply chain management, we extend our methodology by employing fsQCA. While benchmark regressions identify average marginal effects, they may overlook the complex interdependencies between variables. Following Liu et al. (2023) and Jiang et al. (2024), who emphasize that sustainable performance is often the result of synergistic effects between environmental strategies and internal capabilities, we adopt a configurational perspective. This allows us to move beyond traditional linear mediation to identify the configurational combinations where ESG performance, internal control, cost stickiness, supplier stability, ownership, and firm size are associated with bullwhip-effect mitigation.

Following standard practices, we transformed continuous variables into fuzzy sets (0 to 1) using three direct calibration anchors: the 10th percentile (Full Non-membership), the 50th percentile (Crossover Point), and the 90th percentile (Full Membership). This calibration method is intended to prevent extreme outliers from distorting membership assignments while maintaining sufficient variation near the logical boundaries (Fiss, 2011). To ensure transparency, the descriptive statistics reported in Table 1 represent the raw pre-winsorized empirical distributions of our sample. In subsequent procedures, a standard 1% winsorization was applied to the variables prior to calibration and regression analysis to mitigate outlier distortion.

Specifically, the calibration anchors (the 10th, 50th, and 90th percentiles) are calculated directly from these winsorized distributions and are mathematically mapped to target fuzzy membership scores (μ) of 0.05, 0.50, and 0.95, respectively. To transform the raw winsorized values (x_i) into these fuzzy membership scores (μ_i), we employ

the standard direct calibration log-odds transformation. First, we compute the log-odds of membership as:

$$\log -\text{odds}_i = (x_i - x_{p50}) \times \frac{\ln(0.95/0.05)}{x_{p90} - x_{p50}}, \text{ for cases where } x_i > x_{p50} \quad (4)$$

and as:

$$\log -\text{odds}_i = (x_i - x_{p50}) \times \frac{\ln(0.05/0.95)}{x_{p10} - x_{p50}}, \text{ for cases where } x_i \leq x_{p50} \quad (5)$$

Second, these log-odds are converted to the final fuzzy membership scores using the standard logistic cumulative function:

$$\mu_i = \frac{\exp(\log -\text{odds}_i)}{1 + \exp(\log -\text{odds}_i)} \quad (6)$$

Following standard QCA protocols for binary dummy variables (Ragin, 2008), state ownership (SOE) was calibrated using qualitative direct assignment rather than percentile-based rules. Specifically, state-owned enterprises (SOE = 1) were assigned a fuzzy membership score of 0.75 ('mostly in the set'), and non-state-owned enterprises (SOE = 0) were assigned a fuzzy membership score of 0.25 ('mostly out of the set'). This qualitative assignment avoids the extreme mathematical constraints associated with absolute 1 and 0 fuzzy scores while keeping the calibration strategy independent of outcome-based tuning. To assess sensitivity to these threshold choices, we systematically vary these calibration anchors as part of our robustness checks in Section 5.7.

Regarding our data preparation sequence and missingness handling, we execute a rigorous, sequential pre-processing protocol to maintain strict empirical consistency across both our regression models and configurational analyses. We address missingness by applying listwise deletion at the firm-year level as the very first step in our pipeline. Any observation that lacks data for any single operational condition or the outcome variable is entirely excluded from the sample before any outlier adjustment or calibration occurs. This complete-case analysis guarantees a balanced, identical sample size across all analytical models. Following listwise deletion, we apply the 1% winsorization to the continuous variables, calculate the calibration anchors from the resulting winsorized empirical distributions, and execute the mathematical direct calibration to generate the fuzzy sets. This sequential order ensures that missing data do not bias the calculation of our percentile-based anchors, and that extreme outliers do not artificially warp the logical boundaries of our calibrated sets. Furthermore, we treat repeated firm-year observations as distinct, independent cases in our configurational analysis, a practice widely established in longitudinal and panel-data QCA (Beynon et al., 2020; García-Castro and Ariño, 2016).

Necessity and sufficiency logic

Prior to evaluating these configurations, a necessity analysis was conducted—as detailed in Appendix: Table A2—confirming that while no individual antecedent condition acts as a strictly necessary driver on its own (with all individual consistencies remaining below the standard 0.90 threshold), several dual-condition combinations achieve the required consistency levels to be considered necessary for mitigating the bullwhip effect. The adoption of fsQCA is further motivated by the principle of equifinality—the idea that multiple, non-competing pathways can lead to the same organizational outcome (Wang & Feng, 2026). By treating ESG performance and internal governance as interdependent conditions rather than independent predictors (Liu et al., 2023), our configurational approach evaluates how mechanisms (Internal Control, Cost Stickiness and Stability) act as synergistic components of a stability-enhancing configuration within specific firm contexts (size and ownership). To systematically validate the structural stability of these configurations against alternative design choices, we implement a rigorous sensitivity testing strategy outlined in Appendix: Fig. A1. This verification framework explicitly tests the baseline configuration (established at a 90/50/10 calibration, $n = 150$ frequency cut, and PRI = 0.50) by shifting to tighter calibration

Table 2 Benchmark regression results.

VARIABLES	(1) BWE	(2) BWE	(3) BWE	(4) BWE
<i>ESG</i>	−0.025** (0.006)	−0.028*** (0.007)	−0.021** (0.009)	−0.024*** (0.008)
<i>AUDIT</i>		0.063** (0.030)		0.225*** (0.062)
<i>BM</i>		0.048 (0.032)		−0.021 (0.052)
<i>INDBOARD</i>		−0.193 (0.120)		−0.318* (0.181)
<i>OCCUPY</i>		0.304 (0.269)		0.653** (0.320)
<i>ROE</i>		−0.018*** (0.005)		−0.018*** (0.005)
<i>SIZE</i>		−0.003 (0.008)		0.032* (0.018)
<i>AGE</i>		0.015* (0.009)		−0.107*** (0.027)
<i>LEV</i>		−0.200*** (0.038)		−0.011 (0.057)
Constant	1.399*** (0.028)	1.567*** (0.151)	1.381*** (0.037)	1.031*** (0.377)
Enterprise Fixed Effects	Uncontrolled	Uncontrolled	Controlled	Controlled
Year Fixed Effects	Uncontrolled	Uncontrolled	Controlled	Controlled
<i>Observations</i>	36,344	36,344	36,344	36,344
<i>R-squared</i>	0.000	0.002	0.268	0.269

Source: Own research, 2025.

Symbols ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively; the values in parentheses are cluster standard errors at the enterprise level.

boundaries (95/50/5), increasing case frequency cutoffs to higher thresholds ($n = 200$ and $n = 300$), and elevating Proportional Reduction in Inconsistency requirements ($PRI = 0.55$ and $PRI = 0.60$). Executing these variations allows us to verify that our emergent causal pathways remain empirically robust and are not artifacts of hyper-specific parameter tuning. Prior to evaluating these configurations, a necessity analysis was conducted—as detailed in Appendix: Table A2—confirming that no individual antecedent condition acts as a strictly necessary driver on its own, because all individual consistencies remain below the standard 0.90 threshold. In set-theoretic research, the absence of a single necessary condition does not preclude the existence of functional substitutes, where different mechanisms can substitute for one another to satisfy a necessary requirement (Schneider & Wagemann, 2012). To formally evaluate this possibility, Appendix Table A2 also reports dual-condition logical-OR (union) combinations. In QCA, testing the logical union of conditions provides a mathematical framework to evaluate functional equivalence; a high consistency score (exceeding 0.90) for a union implies that while neither condition is individually necessary, the presence of at least one of them is a requirement for the outcome. Because the consistency values of these logical unions also remain below 0.90, these union values are treated as explanatory and descriptive rather than as established necessary conditions, confirming that our explanatory model is characterized by complex sufficiency rather than strict necessary constraint.

The adoption of fsQCA is motivated by the principle of equifinality—the idea that multiple, non-competing pathways can lead to the same organizational outcome (Wang & Feng, 2026). By treating ESG performance and internal governance as interdependent conditions rather than independent predictors (Liu et al., 2023), our

Table 3 Endogeneity test.

<i>Variables</i>	(1) First Stage <i>ESG</i>	(2) Second Stage <i>BWE</i>	(3) First Stage <i>ESG</i>	(4) Second Stage <i>BWE</i>
<i>IV₁</i>	0.815*** (0.025)			
<i>IV₂</i>			0.098*** (0.017)	
<i>ESG</i>		−0.111** (0.043)		−0.447* (0.265)
<i>AUDIT</i>	0.056 (0.057)	0.231*** (0.084)	0.035 (0.045)	0.238*** (0.072)
<i>BM</i>	−0.121*** (0.044)	−0.032 (0.061)	−0.028 (0.039)	−0.052 (0.063)
<i>INDBOARD</i>	1.149*** (0.158)	−0.214 (0.210)	1.187*** (0.130)	0.037 (0.377)
<i>OCCUPY</i>	−1.513*** (0.288)	0.525 (0.415)	−1.019*** (0.240)	0.429 (0.465)
<i>ROE</i>	−0.001 (0.003)	−0.018** (0.008)	0.004 (0.004)	−0.022*** (0.006)
<i>SIZE</i>	0.281*** (0.019)	0.057** (0.025)	0.272*** (0.013)	0.151* (0.080)
<i>AGE</i>	−0.260*** (0.025)	−0.130*** (0.038)	−0.221*** (0.020)	−0.222*** (0.069)
<i>LEV</i>	−0.678*** (0.116)	−0.072 (0.067)	−0.886*** (0.050)	−0.277 (0.251)
<i>Observations</i>	36,344	36,344	31,549	31,549
<i>R²</i>	0.540	−0.002	0.528	−0.075
<i>Kleibergen-Paap rk LM statistic</i>	570.948 (0.000)		39.473 (0.000)	
<i>Kleibergen-Paap rk Wald F statistic</i>	1024.95		34.776	

Source: Own research, 2025.

configurational approach evaluates how mechanisms (Internal Control, Cost Stickiness and Stability) act as components of stability-enhancing configurations within specific firm contexts (size and ownership). To assess the structural sensitivity of these configurations against alternative design choices, we implement a sensitivity testing strategy outlined in Appendix: Fig. A1. This framework tests the baseline configuration (established at a 90/50/10 calibration, $n = 150$ frequency cut, and $PRI = 0.50$) by shifting to tighter calibration boundaries (95/50/5), increasing case frequency cutoffs to higher thresholds ($n = 200$ and $n = 300$), and elevating Proportional Reduction in Inconsistency requirements ($PRI = 0.55$ and $PRI = 0.60$). Executing these variations allows us to assess whether the emergent pathways are sensitive to parameter choices.

Results

Empirical analysis

First, we examine the impact of enterprise ESG performance on the supply-demand bullwhip effect. As Table 2 shows, the estimation result is significantly negative at the 1% level, verifying the inhibitory effect of ESG performance. Columns (1) and (2) show regression results without controlling for fixed effects; the coefficients are significantly negative with slight differences. Column (3) adds year and firm fixed effect, and the result remains

negative. Column (4) adds controls and fixed effects, yielding a marginal coefficient of -0.02 at the 1% level. The result is statistically significant, and more importantly, it presents clear economic implications for supply chain management. The regression coefficient of ESG is -0.024 , and the mean value of BWE stands at 1.295. A one-unit increase in the ESG score is associated with an approximately 1.85% reduction in BWE. Although this percentage change appears relatively small, the bullwhip effect is a highly stable operational indicator. According to descriptive statistics, the standard deviation of ESG is 1.046. When ESG scores vary across their full range (from 1 to 9), the estimated total reduction in BWE amounts to 12.97%. This magnitude of effect is comparable to major operational improvement interventions documented in prior literature. For instance, Niu et al. (2025) show that manufacturing servitization reduces it by 13.58%. Therefore, this marginal effect carries substantial real-world economic significance. This restraining effect presents long-term cumulative benefits, which validates ESG's value in easing supply chain frictions. The benchmark results indicate that good ESG performance significantly mitigates the bullwhip effect, confirming the positive impact on reducing supply chain risks and verifying Hypothesis 1.

Endogeneity issues

To avoid the interference of unobservable factors, we select the mean ESG performance in the same year and industry (IV_1) as an instrumental variable (Xu et al., 2014), using two-stage least squares to mitigate endogeneity. The basic rationale for this instrument relies on the positive correlation between the ESG performance of a single enterprise and the overall ESG performance of its industry.

In Table 3, Column (1), the first-stage estimated coefficient is significantly positive at the 1% level. The under-identification test (Kleibergen-Paap rk LM = 570.948, $p = 0.000$) and the weak-instrument test (Kleibergen-Paap rk Wald F = 1024.95) both exceed conventional thresholds. As shown in Column (2), the second-stage estimated coefficient is -0.111 , consistent with the benchmark regression and statistically significant at the 5% level.

However, recognizing the stringent requirements of the exclusion restriction, we acknowledge that industry-year mean ESG might still be susceptible to unobserved macro-level industry shocks (such as sudden regulatory changes or sector-wide disruptions) that could directly affect operational supply chain volatility. To address endogeneity and meet the strict exogeneity condition, we adopt the market value of pan-ESG funds (IV_2) as the primary instrumental variable, following Jin et al. (2025). Determined by macro capital market dynamics and institutional investor preferences, market value of pan-ESG funds are exogenous to idiosyncratic supply chain shocks at the local and industry levels. Moreover, because ESG-oriented funds screen investments exclusively on corporate ESG performance rather than supply chain attributes, their holdings do not directly affect the bullwhip effect—which stems from distorted demand information. Consequently, this instrument influences the dependent variable mainly through corporate ESG performance, satisfying the exclusion restriction.

Given the large original values (often in the hundreds of billions), we rescale IV_2 by dividing it by 10 billion to facilitate the display and interpretation of coefficients. This linear transformation does not affect the instrument's validity or any statistical inferences, and all reported estimates are based on the rescaled variable. As shown in Column (3), the first-stage coefficient for IV_2 is positively significant at the 1% level. The Kleibergen–Paap Wald F statistic of 34.776 confirms that the instrument is sufficiently strong. The main second-stage results in Column (4) yield an estimated coefficient of -0.447 , which is substantially larger in magnitude than both the OLS estimate (-0.024) and the IV_1 estimate (-0.111). This may be due to the difference between the local average treatment effect (LATE) and the average treatment effect (ATE), suggesting that ignoring endogeneity leads to an underestimation of the estimated effects. By demonstrating that the mitigating effect of ESG on the bullwhip effect holds even when utilizing a strictly exogenous, capital-market-driven instrumental variable, we confirm that our baseline conclusions are highly robust to endogeneity concerns.

Table 4 Robustness test.

	(1) Propensity Score Matching	(2) Replace Explanatory Variable 1	(3) Replace Explanatory Variable 2	(4) Change Time Window	(5) Exclude extreme values
<i>VARIABLES</i>	<i>BWE</i>	<i>BWE</i>	<i>BWE</i>	<i>BWE</i>	<i>BWE</i>
<i>ESG</i>	−0.027*** (0.010)			−0.031*** (0.012)	−0.023*** (0.009)
<i>ESG_new</i>		−0.004** (0.002)			
<i>ESG_score</i>			−0.003** (0.001)		
<i>AUDIT</i>	0.017 (0.042)	0.224*** (0.062)	0.221*** (0.085)	0.356*** (0.128)	0.226*** (0.085)
<i>BM</i>	0.086* (0.045)	−0.021 (0.052)	−0.023 (0.061)	0.020 (0.084)	−0.010 (0.059)
<i>INDBOARD</i>	−0.097 (0.169)	−0.319* (0.181)	−0.335 (0.208)	−0.389 (0.257)	−0.292 (0.223)
<i>OCCUPY</i>	0.713 (0.455)	0.588* (0.324)	0.608 (0.409)	0.836* (0.464)	1.156* (0.607)
<i>ROE</i>	0.004 (0.012)	−0.019*** (0.005)	−0.019** (0.008)	−0.029*** (0.007)	−0.090 (0.068)
<i>SIZE</i>	0.008 (0.011)	0.033* (0.018)	0.033 (0.022)	0.016 (0.029)	0.030 (0.022)
<i>AGE</i>	0.014 (0.013)	−0.101*** (0.027)	−0.097*** (0.035)	−0.129** (0.053)	−0.106*** (0.035)
<i>LEV</i>	−0.247*** (0.061)	−0.019 (0.058)	−0.008 (0.060)	0.006 (0.074)	−0.024 (0.090)
<i>Constant</i>	1.268*** (0.232)	1.165*** (0.390)	1.080** (0.473)	1.455** (0.615)	1.055** (0.470)
<i>Observations</i>	17598	36142	36142	22237	36344
<i>R-squared</i>	0.002	0.272	0.272	0.319	0.269

Source: Own research, 2025.

Propensity score matching test

To mitigate potential reverse causality—specifically, firms facing milder supply chain risks may possess abundant slack resources to prioritize ESG governance—we employ propensity score matching (PSM) to address this endogeneity concern and related confounding biases. Since our core explanatory variable (continuous ESG performance) cannot directly apply PSM, we first construct a binary treatment indicator based on the sample average ESG score. Firms with ESG performance at or above the sample mean are defined as the treatment group ($ESG_dum=1$, high ESG performance), while the remaining observations constitute the control group ($ESG_dum=0$). We include all firm-level control variables from our baseline regression as matching covariates and implement 1:1 nearest-neighbor matching with replacement.

The covariate balance test confirms that the matched sample satisfies the balance requirement. Figure A2 in the Appendix visualizes standardized percentage bias across all covariates before and after matching. After the matching procedure, the standardized bias of every covariate falls below the conventional 10% threshold, which verifies satisfactory covariate balance between the treatment and control groups. Figures A3 and A4 of Appendix illustrate the kernel density distributions of propensity scores pre- and post-matching. The nearly overlapping density curves of the treatment and control groups after matching verify compliance with the common support condition. Column (1) of

Table 5 Heterogeneity analysis.

	(1) BWE	(2) BWE	(3) BWE
<i>ESG</i>	−0.013 (0.010)	−0.036*** (0.010)	−0.024** (0.010)
<i>SOE</i>	0.141* (0.078)		
<i>ESG</i> × <i>SOE</i>	−0.032* (0.017)		
<i>dummy_size</i>		−0.115 (0.071)	
<i>ESG</i> × <i>dummy_size</i>		0.031** (0.015)	
<i>Pollution</i>			0.007 (0.094)
<i>ESG</i> × <i>Pollution</i>			0.001 (0.019)
<i>AUDIT</i>	0.223*** (0.062)	0.224*** (0.062)	0.224*** (0.062)
<i>BM</i>	−0.021 (0.052)	−0.017 (0.052)	−0.022 (0.052)
<i>INDBOARD</i>	−0.307* (0.181)	−0.324* (0.181)	−0.325* (0.181)
<i>OCCUPY</i>	0.649** (0.321)	0.653** (0.321)	0.656** (0.321)
<i>ROE</i>	−0.018*** (0.005)	−0.018*** (0.005)	−0.018*** (0.005)
<i>SIZE</i>	0.032* (0.018)	0.028 (0.020)	0.032* (0.018)
<i>AGE</i>	−0.106*** (0.027)	−0.108*** (0.027)	−0.106*** (0.027)
<i>LEV</i>	−0.013 (0.057)	−0.013 (0.057)	−0.010 (0.057)
<i>Constant</i>	0.977*** (0.379)	1.168*** (0.420)	1.029*** (0.378)
<i>Observations</i>	36343	36344	36340
<i>R-squared</i>	0.269	0.269	0.269

Source: Own research, 2025.

Table 4 reports regression results based on the matched sample. The coefficient on firm ESG performance remains significantly negative at the 1% statistical level, consistent with our baseline finding. This outcome validates the robustness of our core inference and lends empirical support to Hypothesis 1.

Robustness test

We conducted additional robustness checks by replacing explanatory variables and modifying the estimation sample. First, we replaced the Sino-Securities ESG rating data used in the benchmark regression with Sino-Securities ESG score data. Column (2) of Table 4 shows that the new regression result is consistent with the benchmark regression results. Second, to address potential ESG rating disputes, we used ESG rating data of listed companies from the China

Research Data Services Platform (CNRDS). As shown in Column (3) of Table 4, the estimated coefficient ESG_score is still negative and significant, indicating that the conclusion is robust. Finally, to exclude the interference of the COVID-19 pandemic on enterprise operations and supply chain management, we conducted a regression test by changing the time window and deleting samples from 2020 and later. As shown in Column (4) of Table 4, the estimated coefficient remains negatively significant, and the conclusion still holds. Last, to mitigate extreme values, we applied a 1% winsorization to control variables. Column (5) of Table 4 shows that the conclusion is still robust.

Heterogeneity analysis

To test boundary conditions of ESG's mitigating effect, we utilized formal interaction effect models rather than solely relying on sub-sample splitting. Due to ownership differences, enterprises have distinct governance structures and incentive mechanisms affecting operational efficiency. As shown in column (1) of Table 5, the formal interaction model ($BWE \sim ESG \times SOE$) yields an interaction coefficient of -0.032 ($p < 0.1$), providing cautiously framed evidence consistent with a stronger ESG-BWE association in state-owned enterprises. Driven by higher government expectations, state-owned enterprises may implement ESG principles and maintain close relationships with their supply chains. Their stable networks may promote information sharing and collaborative decision-making, reducing uncertainty. In contrast, non-state-owned enterprises may face stronger competition and resource constraints, which can limit the translation of ESG practices into bullwhip-effect mitigation.

Given differences in resource allocation, the impact may vary by firm size. The base effect in the size interaction model suggests that the mitigating association of ESG is concentrated in smaller enterprises in column (2) of Table 5 (ESG coefficient = -0.036 , $p < 0.01$). The positive and significant interaction term ($ESG \times dummy_size = 0.031$, $p < 0.05$) indicates that this association is offset for large enterprises, with the combined ESG effect becoming small. Small and medium listed companies are generally more flexible, able to respond quickly to market changes and maintain close collaboration, reducing information distortion. However, large firms often possess advanced risk management tools that may overshadow the marginal impact of ESG.

We initially hypothesized that pollution attributes might influence the impact of ESG performance in mitigating the bullwhip effect. Non-high-pollution enterprises prioritize ESG transparency, which may improve supply chain information sharing and demand forecasting. Conversely, high-pollution enterprises face regulatory pressures, compliance-based investments, and complex supply chains that could diminish the benefits of ESG. To test this, we introduced a formal interaction term ($BWE \sim ESG \times Pollution$) rather than solely relying on sub-sample splitting. As shown in column (3) of Table 5, the formal interaction test revealed no statistically significant divergence between high- and non-high-polluting industries (interaction coefficient = 0.001 , $p > 0.10$). This result does not support the hypothesized pollution-industry moderation in the reported model. Consequently, we rely on firm size and ownership structure as the primary contextual boundaries for the subsequent configurational mechanism analysis.

The configurational pathways to mitigation (mechanism analysis via fsQCA)

Antecedent conditions to BWE

First, this study selected internal control quality as the proxy variable for corporate governance level (Boulhaga et al., 2023). Data were obtained from the DIB Internal Control and Risk Management Database. Second, referring to previous research (Liu et al., 2025), the recurrence rate of the top five suppliers compared to the previous year was used to measure supplier relationship stability. This variable ranges from 0 to 1, with higher values indicating more sustainable and stable cooperative relationships. CSMAR data for the top five suppliers was verified against annual reports and tools like Qichacha. Third, we selected cost stickiness (*Sticky*) as the antecedent conditions for verification, quantified using the Weiss model (Weiss, 2010) as follows:

$$Sticky_{it} = \log(\Delta Cost / \Delta Sale)_{i\omega 1} - \log(\Delta Cost / \Delta Sale)_{i\omega 2} \quad (7)$$

$i\omega 1$ refers to the quarter in which revenue declines and which is closest to the year-end, among the four quarters of

Table 6 Configurational pathways for the mitigation of the bullwhip effect (Baseline Model).

Conditions	C1	C2	C3	C4	C5	C6
<i>Mechanisms</i>						
ESG Performance			⊗			●
Internal Control			●	⊗	●	⊗
Cost Stickiness					⊗	●
Supplier Stability	⊗					
<i>Firm Context</i>						
Enterprise Size (Large)				⊗		
Ownership (State-Owned)		●				
<i>Parameters</i>						
Consistency	0.621	0.728	0.737	0.725	0.749	0.784
PRI*	0.437	0.506	0.506	0.492	0.534	0.552
Raw Coverage*	0.402	0.553	0.355	0.390	0.448	0.314
Unique Coverage*	0.057	0.037	0.018	0.032	0.030	0.016

Raw Coverage measures the total explanatory power of each configuration. Unique Coverage represents the proportion of the outcome explained exclusively by a specific pathway, excluding cases that overlap with other configurations. PRI (Proportional Reduction in Inconsistency) indicates the degree to which a configuration is free from paradoxical simultaneous subset relations (i.e., avoiding combinations that lead to both the outcome and its negation simultaneously). Overall Solution Consistency: 0.629; Overall Solution Coverage: 0.836.

year t for firm i , and $i\omega 2$ refers to the quarter in which revenue increases and which is closest to the year-end, among the four quarters of year t for firm i . SALE and COST represent operating income and total cost (including operating, sales, and management expenses). Δ COST and Δ SALE represent the rates of change in total costs and revenues, respectively, for company i in a given quarter. All financial data is obtained from CSMAR. Calculated via Formula 7, when “Sticky” is negative, it indicates that the reduction in costs when sales revenue declines is less than the increase in costs when sales revenue rises, suggesting the presence of cost stickiness in the enterprise. The smaller this value, the higher the degree of cost stickiness in the enterprise.

Traditional mediation analysis yielded insignificant linear coefficients, indicating that these variables do not operate in a simple, sequential chain: ESG performance (Independent Variable) $\rightarrow$ Operational/Governance Mechanisms (Mediators) $\rightarrow$ Bullwhip Effect (Outcome). Instead we transition to fsQCA to evaluate how three internal and external operational mechanisms (Internal Control, Cost Stickiness, and Supplier Stability) combine with our primary condition of interest (ESG performance) to form complex, non-linear pathways. Prior to constructing the truth table, continuous variables were calibrated into fuzzy sets using the direct method. We established the 10th, 50th, and 90th percentiles as the robust thresholds for full non-membership, the crossover point, and full membership, respectively. To prevent cases from being dropped during analysis, a constant of 0.001 was added to values landing exactly on the 0.5 crossover point. Finally, the outcome variable was inverted to represent the successful mitigation of the Bullwhip Effect.

We first examined whether any single condition is a necessary prerequisite for BWE mitigation (Consistency $>$ 0.90). The results, presented in Appendix: Table A1, indicate that no single condition is strictly necessary on its own. The absence of state ownership ($\sim$ fs_SOE, consistency = 0.755), high supplier stability (fs_Stability, consistency = 0.729), and high ESG performance (fs_ESG, consistency = 0.676) have the highest consistency among the single conditions, but they remain below the necessity threshold. Appendix Table A1 also reports combined logical OR combinations (denoted by ‘+’). These combinations are informative descriptively, but the highest reported consistency is 0.899 for supplier stability plus non-state ownership (fs_Stability + $\sim$ fs_SOE, coverage = 0.586), which is still below the 0.90 threshold. Accordingly, we interpret the combined OR results as exploratory evidence of possible substitutability and functional equivalence rather than as established necessary conditions. The same caution applies to the ESG performance plus supplier stability union (fs_ESG + fs_Stability, consistency = 0.892, coverage =

0.576), the supplier stability plus SME-size union ($fs_Stability + \sim fs_Size$, consistency = 0.887, coverage = 0.579), and the ESG performance plus SME-size union ($fs_ESG + \sim fs_Size$, consistency = 0.860, coverage = 0.604).

Following necessity testing, we performed a sufficiency analysis to identify the combinations of conditions that lead to BWE mitigation. Given our exceptionally large sample size ($N = 36,344$), we set a strict frequency threshold ($n.cut$) of 150 cases (representing 0.41% of the sample) to filter out paradoxical simultaneous subset relations, the raw consistency threshold ($incl.cut$) was dynamically set at 0.830, and the Proportional Reduction in Inconsistency ($pri.cut$) was established at 0.5. This baseline PRI threshold of 0.5 was selected to capture theoretically meaningful configurations while filtering out highly inconsistent logical remainders. Following the guidelines of Ragin (2008), the consistency threshold for the sufficiency analysis was selected by evaluating the empirical distribution of consistency scores across the truth table rows in descending order to identify a distinct natural break. Our truth table exhibited a clear, natural drop-off in inclusion scores between 0.832 and 0.829. We therefore set our baseline consistency threshold at 0.830. This threshold successfully partitions the truth table, coding the 32 highly consistent configurations as positive outcomes ($OUT = 1$) while treating the remaining configurations as logical contrast cases ($OUT = 0$). This empirical threshold selection ensures sufficient logical contrast within the truth table, which is mathematically required to perform robust Boolean minimization.

Following standard fsQCA protocols (Ragin, 2008), Table 6 presents the intermediate solution configurations. Boolean minimization yielded six distinct pathways (Configurations C1 through C6) with moderate consistency values ranging from 0.621 to 0.784. Collectively, these six configurations achieve an overall baseline solution coverage of 0.836 and an overall baseline solution consistency of 0.629. The coverage metric is interpreted together with the moderate solution consistency rather than as standalone evidence that the pathways explain most successful mitigation cases. Solid circles (●) indicate the presence of a condition, while crossed circles (⊗) indicate the absence of a condition (negation); blank spaces indicate that the condition is not relevant to that specific configuration. Because the intermediate solution uses theory-guided counterfactuals, and because we do not distinguish core from peripheral conditions here, all conditions within a given configuration are presented with uniform circle size rather than differentiated symbols (Fiss, 2011).

Regarding the specific mechanisms, Table 6 provides exploratory configurational evidence of equifinality, suggesting that multiple, non-competing configurations may be associated with firm-level bullwhip-effect mitigation:

1. Configuration C1 (The Supplier Volatility Buffered Pathway, $\sim fs_Stability$) suggests that even in the absence of stable supplier relationships, firms can mitigate the bullwhip effect. This pathway has a consistency of 0.621 and raw coverage of 0.402.
2. Configuration C2 (The State-Backed Stability Pathway, fs_SOE) suggests that state ownership is associated with the outcome in this configuration. In this pathway, institutional backing and state-directed resource allocation may provide a buffer against demand volatility, yielding a consistency of 0.728 and raw coverage of 0.553.
3. Configuration C3 (The Non-ESG Internal Governance Pathway, $\sim fs_ESG * fs_IC$) shows that firms lacking high ESG performance ($\sim fs_ESG$) can successfully stabilize operations by leveraging strong internal control quality (fs_IC). This pathway yields a consistency of 0.737 and raw coverage of 0.355.
4. Configuration C4 (The SME Governance Pathway, $\sim fs_IC * \sim fs_Size$) demonstrates that smaller enterprises ($\sim fs_Size$, where 'Enterprise Size (Large)' is negated) can mitigate the bullwhip effect even in the absence of high internal control quality ($\sim fs_IC$), suggesting that their smaller organizational scale allows for rapid operational adjustments. This pathway has a consistency of 0.725 and raw coverage of 0.390.
5. Configuration C5 (The Agile Governance Pathway, $fs_IC * \sim fs_Stickiness$) highlights the importance of operational flexibility. When combined with strong internal controls (fs_IC), maintaining low cost stickiness ($\sim fs_Stickiness$) allows firms to dynamically adapt to demand shocks, achieving a consistency of 0.749 and raw coverage of 0.448.
6. Configuration C6 (The ESG Compensatory Pathway, $fs_ESG * \sim fs_IC * fs_Stickiness$) suggests that high ESG performance is associated with bullwhip-effect mitigation even in the absence of strong internal controls ($\sim fs_IC$) and in the presence of cost stickiness ($fs_Stickiness$). This pathway, which yields a consistency of

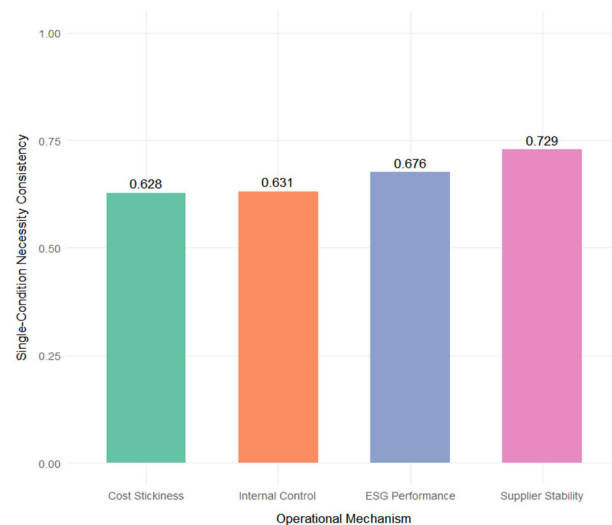


Fig. 1 Single-condition necessity consistency scores for mitigation conditions.

0.784 and raw coverage of 0.314, may indicate that external sustainability signaling and stakeholder trust can partly compensate for internal governance and operational deficits.

In our fsQCA, we treat these mechanisms as potential functional equivalents. As seen in the reported pathways, ESG performance does not operate in isolation. It may act as a substitute for weak internal controls in C6 and combine with internal governance and firm context in other configurations. This equifinality provides a more complex account of these mechanisms than a simple linear mediation path, but the interpretation remains subject to the consistency and threshold limitations noted above.

Figure 1 visualizes the single-condition necessity consistency scores of the four primary operational mechanisms. The consistency scores are 0.628 for Cost Stickiness, 0.631 for Internal Control, 0.676 for ESG performance, and 0.729 for Supplier Stability. The near-equal height of the bars in Fig. 1 suggests a state of equifinality. Because different mechanisms possess comparable set-theoretic strength, there is no single silver bullet for supply chain stability. Instead, these distinct mechanisms possess almost identical empirical weight. This serves as an empirical argument against linear models; it indicates that different enterprises can reach the same successful outcome through different strategic configurations. Figure 1 suggests that Internal Control, Supplier Stability, and Cost Stickiness are not just secondary effects of ESG, but rather robust operational pillars.

Robustness and sensitivity tests

To show that the configurational pathways identified in our primary analysis are structurally stable and not due to arbitrary threshold choices, we performed a series of systematic sensitivity and robustness checks (Oana & Schneider, 2021; Skaaning, 2011). Specifically, we altered three key parameters of our Fuzzy Set Qualitative Comparative Analysis (fsQCA): (i) the case frequency threshold ($n.cut$), (ii) the proportional reduction in inconsistency (PRI) threshold ($pri.cut$), and (iii) the calibration anchors. The detailed results of these sensitivity runs are presented in Appendix: Table A2 and Appendix: Figure A1 contains the detailed methodological flowchart of our robustness testing strategy.

First, we examined the stability of our configurations under stricter case frequency requirements. Since our dataset is exceptionally large ($N = 36,344$), we increased the frequency threshold from the baseline of $n.cut = 150$ to more conservative levels of $n.cut = 200$ and $n.cut = 300$. When $n.cut$ was increased to 200 (Strict Frequency a), the exact same six configurations obtained in the baseline model were preserved, with identical parameters (consistency = 0.629, coverage = 0.836). When the threshold was doubled to $n.cut = 300$ (Strict Frequency b), five of the six primary configurations remained stable, with a consistency of 0.635 and a coverage of 0.819. The dropped pathway

under this highly strict standard is Configuration C3 (~fs_ESG*fs_IC), which represents a smaller empirical strategic niche (non-ESG firms relying heavily on internal controls) that is naturally filtered out as frequency requirements tighten. These results suggest partial frequency-threshold stability, while the moderate consistency values and loss of one configuration limit claims about stability.

Second, we examined the effect of raising the PRI threshold to eliminate inconsistent or ambiguous configurations. Increasing the baseline PRI cut-off from 0.50 to stricter levels of 0.55 (Strict PRI a) and 0.60 (Strict PRI b) systematically reduced the number of active configurations due to the higher consistency filters. At a PRI cut-off of 0.55, the analysis yielded four robust configurations with a solution consistency of 0.723 and coverage of 0.537. This parameter change drops C1 (~fs_Stability) and C3, both of which exhibit lower baseline PRI scores, while retaining the core pathways C2, C4, C5, and C6. At a PRI cut-off of 0.60, standard logical minimization was not possible because all active configurations had $OUT = 1$, resulting in a logical remainder ceiling effect. In large-N designs ($N = 36,344$), the presence of inevitable unobserved heterogeneity makes a PRI threshold of 0.60 restrictive rather than informative. This indicates threshold sensitivity rather than full confirmation of pathway stability.

Third, a sensitivity analysis was conducted using more conservative calibration anchors at the 95th (Full Membership), 50th (Crossover), and 5th (Full Non-Membership) percentiles. With this alternative calibration ($n.cut = 150$, $pri.cut = 0.50$, $incl.cut = 0.885$), the analysis yielded five consistent configurations with an overall consistency of 0.634 and an overall coverage of 0.917. The inclusion cutoff of 0.885 for the alternative calibration, rather than the baseline 0.830, reflects the analyst-selected calibration and inclusion-threshold settings under this robustness specification.

This alternative calibration conceptually confirms that our pathways are stable under varying membership definitions. However, we retain the baseline 90/50/10 calibration as our primary model because it provides the necessary logical variation for robust Boolean minimization without running into logical remainder ceiling effects. This alternative calibration suggests partial overlap with the baseline results under varying membership definitions, retaining five out of our six baseline pathways while dropping the niche C3 configuration due to the more conservative percentile shifts. However, we retain the baseline 90/50/10 calibration as our primary model because it provides the necessary logical variation for Boolean minimization without running into logical remainder ceiling effects.

In summary, the sensitivity checks provide threshold-sensitive configurational evidence. This sensitivity distinguishes more stable pathways, such as C2 (State-Backed), C5 (Agile Governance), and C6 (ESG Compensatory), from more contextual configurations such as C1 and C3. Instead of presenting a single combined SME-SOE pathway, the findings reveal separate equifinal pathways for SMEs and SOEs, offering potential routes to supply chain resilience based on a firm's structural and institutional context.

Discussion

Summary of findings

According to the empirical results, benchmark regression analysis (with controls for fixed effects) shows a significantly negative coefficient for ESG performance, indicating that it is associated with lower values of the firm-level supply-demand bullwhip-effect proxy. This aligns with recent research supporting the positive role of strong enterprise ESG performance in operational stability. Studies indicate that increased transparency in ESG practices can reduce the variability between production and demand (L. Wu et al., 2024), enhancing supply chain resilience and mitigating risks (Yuan et al., 2025). These findings provide evidence consistent with Hypothesis 1.

These findings address the identified research gap by presenting ESG performance as a potential governance mechanism associated with more stable supply chain dynamics, extending the literature that has predominantly focused on financial and market-based outcomes. From a theoretical perspective, our work extends signaling theory into the domain of supply chain volatility management. The study suggests that ESG performance can act as a

credible signal of organizational quality, transparency, and long-term orientation, which in turn may align stakeholder expectations and reduce the information asymmetries that underpin demand amplification.

Unpacking the mechanisms

A central contribution of this study is elucidating how ESG performance and complementary operational mechanisms configuratively relate to the bullwhip-effect proxy. The fsQCA suggests that these factors may operate as a system of functional equivalents. The necessity analysis confirms no single condition is strictly necessary; high supplier stability, non-state ownership, strong ESG, and small enterprise size appear as contributory conditions in descriptive set-theoretic patterns. Because the combined necessity values remain below 0.90, we do not read them as showing that mitigation almost always requires one of the pillars. The sufficiency analysis identifies six equifinal configurations (C1–C6), collectively covering substantial outcome membership but with moderate consistency; the results therefore provide cautious support for Hypothesis 2.

Configuration C6 (the ESG Compensatory Pathway) suggests that ESG may compensate for organizational weaknesses when high ESG appears with absent strong internal controls and cost stickiness. Configurations C5 and C4 (Agile and SME Agility Pathways) suggest that strong internal controls with low cost stickiness, or small enterprise size even without strong internal controls, may enable operational flexibility, as lean structures and low stickiness allow rapid adaptation to demand shocks. Configuration C3 (the Non-ESG Internal Governance Pathway) suggests that robust internal controls without high ESG can stabilize operations, while Configuration C2 (the State-Backed Stability Pathway) suggests that state ownership buffers volatility through institutional backing.

The four mechanisms are not secondary ESG consequences but standalone configurational pillars in the reported model. The necessity consistency scores (Cost Stickiness: 0.628; Internal Control: 0.631; ESG: 0.676; Supplier Stability: 0.729) are similar in magnitude, supporting an exploratory equifinality interpretation. Thus, no single strategy ensures supply chain resilience. Firms may achieve stability through distinct configurations: weak-governance firms may leverage sustainability signaling; small enterprises may exploit inherent agility; state-owned firms may capitalize on institutional backing; and internally strong firms may maintain low cost stickiness or operate effectively without prominent ESG. Our findings also align with existing literature (Lavastre et al., 2014; Sun et al., 2025; Ding et al., 2024).

Heterogeneity analysis

Our heterogeneity analysis identifies boundary conditions for the ESG and bullwhip relationship. The reported models suggest that Hypothesis 3 is supported for ownership and size, but not for pollution-industry status. The mitigating association is stronger in SOEs due to institutional incentives and stable supply chain networks, whereas non-SOEs may face stronger short-term performance pressure and weaker translation of ESG into operational risk reduction. Firm size also matters: ESG significantly alleviates the bullwhip-effect proxy in SMEs thanks to higher flexibility and closer coordination, but its marginal impact is weakened in large firms with mature risk management systems. The pollution interaction is not statistically significant, so the reported evidence supports ownership and size heterogeneity rather than pollution-category heterogeneity.

Limitations and future research directions

While this study provides evidence on ESG's mitigating association with the bullwhip-effect proxy, several limitations warrant acknowledgment and open avenues for future inquiry. First, our bullwhip-effect measurement, based on firm-level production-demand deviation following Bray and Mendelson (2012) and Cachon et al. (2007), captures internal operational volatility rather than cross-tier amplification in multi-echelon supply chains. The unavailability of dyadic supplier-customer data for large-scale Chinese samples restricts our ability to directly measure inter-organizational demand distortion. Second, the ESG measure relies on Sino-Securities ratings, so the results may

partly reflect the rating provider's methodology and coverage choices. Future research may adopt dyadic or triadic data, such as supplier-customer linkage records, to directly calculate cross-echelon demand variance ratios for measuring the bullwhip effect. Combined with emerging supply chain mapping tools and blockchain-enabled traceability systems, scholars can construct authentic multi-tier indicators grounded in interfirm transaction data from a supply chain perspective, so as to more accurately capture the propagation of ESG signals throughout supply chain networks.

Second, the single-country focus on China, while offering advantages in terms of institutional coherence and data availability, limits cross-national generalizability. China's unique institutional environment—characterized by strong state involvement, distinctive ownership structures, and rapidly evolving ESG regulations—may influence the magnitude and mechanisms of ESG's operational effects. Comparative studies across developed and emerging markets, such as the United States, European Union, India, or Brazil, would illuminate how institutional context moderates the ESG-bullwhip relationship and whether the identified configurational pathways hold across regulatory regimes. Overall, ESG integration advances supply chain risk management, although further research is warranted across diverse industries and cultural contexts.

Third, although our fsQCA reports six equifinal pathways, the moderate overall solution consistency suggests that additional contextual factors—such as industry dynamism, technological intensity, or geographic supply chain dispersion—may further refine these configurations. Future qualitative research, including in-depth case studies of firms representing each configuration, could uncover the micro-processes through which ESG practices translate into operational stability and identify barriers to configuration realization.

Last, due to the database release timeline, our data are limited to 2023. We acknowledge this constraint and recommend that follow-up studies reassess the results using updated data. Another limitation is that the chosen instruments—namely, the industry-year average ESG and ESG fund holdings—are reasonable but not perfect. Future research is encouraged to identify more exogenous instruments or adopt alternative identification strategies.

Conclusion

This study utilizes data on Chinese A-share listed firms from 2010–2023 and reports that strong ESG performance is associated with a lower firm-level supply-demand bullwhip-effect proxy, with results supported by several robustness checks but still requiring careful interpretation of the BWE construction and identification assumptions. Integrating ESG practices into risk management may contribute to enhancing supply chain resilience. The fsQCA analysis indicates that there is no single necessary condition for mitigating the bullwhip-effect proxy; instead, six functionally equivalent pathways are reported through configurations of conditions such as internal governance, cost stickiness, supplier stability, firm context, and ESG performance. These mechanisms may contribute to operational stability, but we interpret the pathways as threshold-sensitive exploratory evidence. In conclusion, this study presents ESG performance as a potential governance mechanism for mitigating the firm-level bullwhip-effect proxy, advances configurational perspectives on supply chain resilience, and provides candidate pathways for managers and policy-makers in emerging markets.

Based on the research findings, this study provides the following key implications. First, at the corporate governance level, listed companies should move beyond a compliance-oriented mindset in ESG disclosure and deeply integrate ESG practices into supply chain risk management systems, leveraging ESG governance to mitigate the amplification effects induced by supply and demand fluctuations. They should also abandon singular governance models and, in accordance with their own resources and property rights characteristics, adopt a diversified portfolio of strategies—such as optimizing internal control quality, improving cost structures, and solidifying supply chain partnerships—to adapt to differentiated operational scenarios, stabilize production and operations, and reduce supply chain volatility risks. Second, at the policy and regulatory level, relevant authorities should enhance the ESG information disclosure regime for listed companies, unify disclosure standards, and reduce market information asymmetry. Differentiated support and incentive policies should be implemented to encourage enterprises to optimize supply chain stability through multidimensional governance combinations. Concurrently, an industry-chain

collaboration platform should be established to guide coordinated governance between upstream and downstream entities, thereby holistically strengthening the risk resilience of supply chains in emerging markets. Third, while emphasizing ESG performance, it is imperative to prevent greenwashing. Regulatory agencies should mandate that enterprises substantively embed ESG principles into internal control, cost management, and supplier relationships. By intensifying information disclosure, external oversight, and market discipline, companies can be compelled to unlock genuine ESG dividends, incentivized to mitigate risks, and propelled toward long-term stable development.

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Declarations

Competing interests The authors declare no competing interests.

Consent for publication All authors have provided full agreement to this submission and consent to be held accountable for all aspects of the work in ensuring that any questions related to the accuracy or integrity of any part of the work are suitably investigated and resolved. During the preparation of this work, the authors used Google's Gemini 3.0 large language model for coding, manuscript refinement, and readability improvement. After using these tools, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

Ethical approval This study uses anonymized, publicly available secondary data and does not involve direct interaction with human participants or identifiable personal information; therefore, ethical approval was not required.

Informed consent This research does not entail the collection of data from human participants.

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