From Configuration to Evolution: Corporate Social Responsibility Practices and Supply Chain Effects on Environmental Innovation

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***Abstract*—**This paper employs the stakeholder theory and practice-based view to examine how Corporate Social Responsibility (CSR) practices combine to drive environmental innovation in manufacturing firms under different supply chain network contexts. Leveraging data from Refinitiv and FactSet, this study uses fuzzy-set qualitative comparative analysis (fsQCA) to identify three equifinal CSR configurations associated with high environmental innovation. Firms positioned with high centrality and few structural holes in their supply chains display distinctive CSR patterns. Extending this analysis, an N-K fitness landscape model simulates the dynamic evolutionary paths of CSR implementation, revealing that the order in which CSR practices are adopted critically affects environmental innovation outcomes. Shareholder-oriented practices lay the foundation. They are followed by environmental and workforce-oriented practices in sequence. Customer-oriented practices build on these prior implementations, whereas supplier-oriented practices exert influence only after the preceding practices are established. By combining configurational analysis with an evolutionary perspective, this study clarifies both the joint effects of CSR practices and the role of implementation sequence in shaping environmental innovation outcomes.

Keywords*—Corporate social responsibility, Supply chain network, Environmental innovation, Stakeholder theory, Practice-based view, Evolution dynamics.*

I. INTRODUCTION

As sustainable development has gained increasing attention, corporate social responsibility (CSR) has become an important means for firms to enhance their environmental performance [1]. In today's business environment, CSR practices extend beyond traditional social and environmental responsibilities to include multiple dimensions such as employee welfare, customer relations, and supply chain management [2]. These practices interact with one another and jointly shape firms' environmental innovation capabilities. At the same time, a firm's position within the supply chain network (SCN) can substantially influence its access to and allocation of resources, thereby affecting the effective implementation of CSR practices and environmental innovation outcomes [3]. Firms may invest heavily in CSR, yet their environmental innovation outcomes vary considerably depending on how different CSR practices are combined [4]. This suggests that isolated practices are insufficient to fully capture the overall effects of CSR on environmental innovation [4].

CSR practices influence firms' environmental innovation not only through *what* is implemented, but also through *how* these practices are implemented and *in what sequence* [5]. Because different CSR practices are characterized by resource dependencies and mutual constraints, certain practices can generate positive effects only after others have been established. An inappropriate implementation sequence may therefore weaken or even offset their potential contributions to environmental innovation. Consequently, understanding the evolutionary order of CSR practice implementation and its implications for environmental innovation is critical for explaining heterogeneity in firms' environmental innovation performance.

Grounded in stakeholder theory and the practice-based view [6, 7], this study conceptualizes CSR as a system of interrelated practices rather than a set of isolated actions implemented independently. Specifically, we focus on five categories of CSR practices oriented toward different stakeholder groups. Shareholder-oriented practices reflect a firm's effectiveness in ensuring the equal treatment of shareholders and in implementing anti-takeover mechanisms designed to protect shareholder rights, thereby strengthening the foundation of corporate governance including environmental innovation [8]. Workforce-oriented practices emphasize the protection of employee rights and the design of incentive mechanisms, which enhance employee satisfaction and organizational commitment and, in turn, shape the development of internal capabilities [9]. Customer-oriented practices focus on providing high-quality and reliable products and services, facilitating the realization of innovation outcomes in the marketplace [10]. Environmental-oriented practices capture firms' institutionalized efforts to reduce carbon emissions, improving environmental management, and promoting green and sustainable development, serving as a direct carrier of environmental innovation [11, 12]. Finally, supplier-oriented practices operate through supply chain collaboration and the diffusion of responsibility, fostering inter-organizational learning and knowledge diffusion and thereby influencing environmental innovation performance across broader network contexts [13].

Based on the observation sample from manufacturing firms, this study combines CSR practice and environmental innovation data from Refinitiv Workspace with supply chain relationship data from the FactSet dataset to examine the configurational relationships between CSR practices and environmental innovation. We first employ fuzzy-set qualitative comparative analysis (fsQCA) to identify multiple equivalent configurations associated with high environmental innovation. The results reveal three equivalent configurations and show that firms occupying positions of high centrality and few structural holes in SCNs tend to exhibit distinct CSR practice combinations. We further apply an N-K fitness landscape model by abstracting CSR practices as a set of elements and simulating the evolutionary paths through which high environmental innovation emerges. This study not only captures performance differences across CSR practices states under a given interaction structure, but also reveals the optimal evolutionary sequence and associated path dependence leading to high environmental innovation. The simulation results indicate that the effects of CSR practices extend beyond configuration choice (what is implemented) to the dynamic order of implementation (how practices are introduced). In particular, shareholder-oriented practices play a foundational and leading role in the early stages of evolution, whereas supplier-oriented practices release the environmental innovation potential only after preceding conditions have been established.

The main contributions are as follows:

First, this study extends the practice-based view and stakeholder theory to the context of CSR. By conceptualizing CSR as a system of interdependent practices rather than isolated actions, it deepens our understanding of how multi-dimensional CSR activities jointly drive environmental outcomes.

Second, we examine CSR practices through a configurational lens, integrating firms' positions in the supply chain network. This analysis shows that environmental innovation depends on both how CSR practices are combined and where firms are positioned in the supply chain network.

Third, we capture the evolutionary paths and dynamic sequences of CSR practices leading to high environmental innovation through an NK model. The findings reveal that the order of implementing CSR practices affects their effectiveness, offering insights into path-dependent innovation processes.

The remainder of this paper is organized as follows. Section II reviews the relevant literature and presents the theoretical foundations. Section III describes the sample, observations, and data used in the analysis. Section IV reports the results of the configurational analysis of CSR practices and environmental innovation. Section V examines the dynamic evolution of CSR practices using an NK fitness landscape approach. Finally, Section VI concludes the study and discusses its implications.

II. Literature Review

A. *Corporate Social Responsibility*

Corporate social responsibility (CSR) is typically defined as a firm's voluntary integration of social and environmental concerns into its business operations and interactions with external stakeholders, alongside the pursuit of economic objectives [14]. In contemporary corporate settings, CSR is no longer limited to symbolic commitments or normative statements; rather, it has evolved into concrete practices embedded within daily operations and management systems [15], such as employee management, product responsibility, environmental governance, and supply chain management. This practice-oriented perspective frames CSR as observable, and comparable combinations of corporate behaviors [15].

In the existing research, CSR is often operationalized into stakeholder-oriented dimensions [16]. The theoretical foundation for this approach primarily derives from stakeholder theory, which posits that firms are not accountable solely to shareholders but are embedded within a network of diverse stakeholders, with their survival and development dependent on effectively addressing the expectations of key stakeholders [17]. Following the research of Park and Ghauri [8], this study categorizes CSR practices into five dimensions: shareholders, employees, customers, suppliers, and the natural environment. Specifically, *shareholder-oriented practices* reflect a firm's effectiveness in governance, fair treatment of investors, and risk management [18]. *Employee-oriented practices* capture the governance of human capital, workplace conditions, and capability development [19]. *Customer-oriented practices* focus on product quality, safety, and fulfillment of responsibilities [20]. *Environmental-oriented practices* represent the firm's ability to manage emissions and environmental impact in its production and operations [21], and *supplier-oriented practices* reflect the firm's governance approach to promoting environmental and social responsibility throughout its supply chain. These dimensions together form a comprehensive set of CSR practices under the constraints of multiple stakeholders together [22].

B. *Relationships between CSR and Environmental Innovation*

Environmental innovation represents a critical strategic response by firms to environmental constraints and emerging market opportunities. It is typically manifested through the adoption of new technologies, processes, or eco-oriented product designs that reduce the environmental footprint of products and services across their entire life cycle, thereby reshaping cost structures and value creation mechanisms. Compared with conventional technological innovation, environmental innovation is characterized by high investment intensity, long payback periods, and pronounced externalities, making it difficult to be driven solely by short-term market signals or isolated technological capabilities. Instead, it relies on firms' ability to mobilize resources, share risks, and coordinate actions within a network of multiple stakeholder relationships.

First, *shareholder-oriented practices* enhance corporate governance quality, information transparency, and investor trust, thereby alleviating the financing constraints and short-term performance pressures associated with environmental innovation and providing stable capital support for green R&D investments characterized by high uncertainty [18]. Second, *employee-oriented practices* improve working conditions and strengthen training and capability development, fostering a human capital base that facilitates the identification of environmental issues and the development of green technologies, thus enhancing the organizational capacity for environmental innovation [19]. Further, *customer-oriented practices* reinforce commitments to product responsibility, quality, and safety, which heighten firms' sensitivity to green demand signals and incentivize the use of environmental innovation as a key instrument of competitive differentiation [23]. *Environmental-oriented practices* themselves, through institutionalized emission control, resource efficiency management, and the establishment of environmental targets, directly drive continuous improvements in production processes and technological trajectories [24]. Meanwhile, *supplier-oriented* *practices* introduce social and environmental standards at the supply chain level, promoting inter-organizational collaborative learning and knowledge diffusion, thereby reducing the coordination costs and implementation risks of environmental innovation for individual firms [25].

C. *Theoretical perspective and framework*

This study integrates stakeholder theory with the practice-based view to explain how CSR practices shape firms' environmental innovation performance. Stakeholder theory emphasizes that environmental innovation is not driven solely by technological capabilities or market incentives, but is embedded in firms' ongoing interactions with key stakeholders, including shareholders, employees, customers, suppliers, and the natural environment. Under this perspective, the practice-based view conceptualizes CSR not as abstract commitments or values, but as observable organizational practices in day-to-day operations. From this perspective, stakeholder-oriented practices influence environmental innovation by structuring firms' access to resources, uncertainty tolerance, information-processing routines, and coordination mechanisms across organizational boundaries. Environmental innovation thus emerges as a combined outcome of firms' enacted responsibility practices under multiple stakeholder constraints and supports, rather than as an isolated technological or investment decision.

We also incorporate SCN structure as a set of contingencies to capture how a firm's external relational environment conditions the mechanisms described above. Specifically, we focus on two of the most widely used indicators in supply chain network research: network degree centrality and structural hole constraint. Network centrality reflects a firm's structural position and access to resources within the supply chain network [26]. Firms with higher centrality are more likely to obtain diverse technological information, environmental standards, and opportunities for collaboration, thereby amplifying the positive effects of CSR practices on environmental innovation. In contrast, structural holes capture a firm's brokerage advantage arising from non-redundant ties [27]. A higher level of structural hole occupancy enables firms to integrate heterogeneous rules, knowledge, and institutional requirements across different supply chain actors, which facilitates the translation of CSR practices into environmental innovation outcomes. The theoretical framework of this study is shown in Fig. 1.

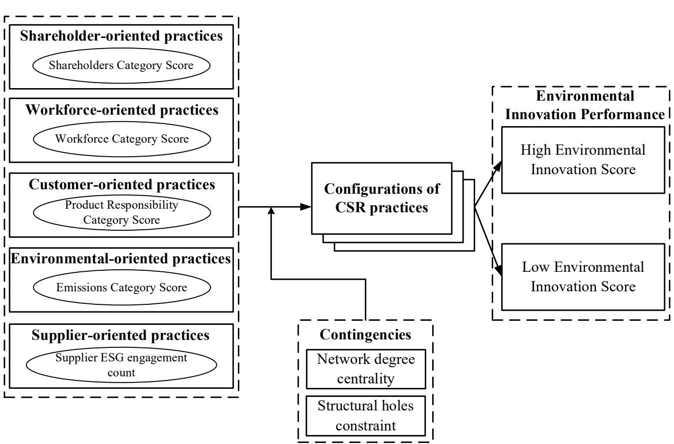

Fig. 1. The theoretical framework

III. Sample, Data and Measurement

A. *Sample and Data*

The sample and data used in this study are primarily drawn from *Refinitiv Eikon* and *FactSet*, two internationally recognized commercial databases, which are employed to measure firms' CSR practices and SCN characteristics, respectively.

Data on CSR practices and the outcome variable are obtained from Refinitiv Workspace. Refinitiv is part of the London Stock Exchange Group (LSEG) and originated from the former Thomson Reuters Financial & Risk business [28]. Refinitiv's indicators are constructed based on publicly disclosed and verifiable information. These data have been widely adopted in academic research and international investment analysis [28]. In this study, we use Refinitiv indicators to operationalize firm-level CSR practices and environmental innovation. Data on supply chain contingencies are sourced from the FactSet Revere Relationships database [29]. FactSet is a well-established global provider of financial and corporate relationship data [29]. Its Revere database captures supplier–customer relationships among firms and has been extensively used in SCN and industrial organization research [30]. Based on FactSet, we identify firms' supply chain relationships and construct firm-level SCN characteristics.

Regarding sample selection, we first identify publicly listed manufacturing firms from Refinitiv Workspace according to the internationally recognized Standard Industrial Classification (SIC) system, resulting in an initial sample of 2,227 manufacturing firms. Given the substantial missing values for fiscal year 2025, we restrict the analysis to fiscal year 2024 and exclude firms with missing information on the outcome variable (environmental innovation) or key antecedent variables. The remaining firms are then matched with the FactSet Revere supply chain database to determine whether observable supply chain network relationships exist in 2024. Only firms with valid supply chain relationship records are retained. After this screening process, 729 manufacturing firms with complete data on environmental innovation, CSR practices, and supply chain relationships in 2024 are obtained. From this matched sample, we further employ random sampling to select 400 manufacturing firms as the final analytical sample. The distribution of manufacturing sub-industries covered by the sample is reported in TABLE I. Building on this, we further construct the firm-level supply chain network using the selected manufacturing firms as core nodes. For each core firm, both first-tier and second-tier suppliers and customers were identified to capture the broader network structure. The resulting supply chain network comprises 4,718 nodes and 6,875 edges, totaling 10,914 supplier–customer relationships, providing a foundation for calculating network characteristics.

TABLE I. Summary of Sample Observations

No.	SIC Major group name (code)	Freq. (N)	PCT (%)
1	Food and kindred products (20)	14	3.5
2	Tobacco products (21)	3	0.75
3	Textile mill products (22)	3	0.75
4	Lumber and wood products (24)	3	0.75
5	Furniture and fixtures (25)	4	1
6	Paper and allied products (26)	3	0.75
7	Printing, publishing, and allied industries (27)	7	1.75
8	Chemical and allied products (28)	92	23
9	Petroleum refining and related industries (29)	6	1.5
10	Rubber and miscellaneous plastics products (30)	6	1.5
11	Stone, clay, glass, and concrete products (32)	5	1.25

12	Primary metal industries (33)	10	2.5
13	Fabricated metal products (34)	4	1
14	Industrial and commercial machinery and computer equipment (35)	53	13.25
15	Electric and other electrical equipment (36)	64	16
16	Transportation equipment (37)	39	9.75
17	Measuring, analyzing and controlling instruments (38)	81	20.25
18	Miscellaneous manufacturing industries (39)	3	0.75
	Total	**400**	**100**

B. Outcome, Conditions and Contingencies

1) Outcome

The outcome of this study is ***Environmental Innovation Performance*** (***EIP***), measured by the *Environmental Innovation Score* obtained from Refinitiv Workspace. The Environmental Innovation Score reflects a firm's capacity to create new market opportunities through the development and adoption of novel environmental technologies, production processes, and eco-designed products while simultaneously reducing the environmental costs and burdens for its stakeholders. The score ranges from 0 to 100, with higher values indicating a stronger capability to translate environmental responsibility into technology and market innovation outcomes.

2) Conditions

Shareholder-oriented Practices (***ShoP***). With respect to shareholders, we capture firms' practice orientation toward shareholder interests using the *Shareholders Category Score* from Refinitiv Workspace. This score reflects a company's effectiveness in ensuring the equal treatment of shareholders and in implementing anti-takeover mechanisms designed to protect shareholder rights. Conceptually, this condition represents the extent to which a firm adopts governance arrangements that align managerial decision-making with shareholder interests and mitigate potential agency conflicts. The score ranges from 0 to 100, with higher values indicating a stronger shareholder-oriented governance posture.

Workforce-oriented Practices (***WoP***). To capture the effectiveness of a firm's employee-related practices, we employ the *Workforce Category Score* from Refinitiv Workspace. This score evaluates a company's effectiveness in promoting job satisfaction, ensuring a healthy and safe working environment, fostering diversity and equal opportunities, and providing development opportunities for its workforce. The score ranges from 0 to 100, with higher values indicating greater effectiveness in managing employee-related concerns.

Customer-oriented Practices (***CoP***). To consider the effectiveness of a firm's customer-related practices, we employ the *Product Responsibility Category Score* from Refinitiv Workspace. This score reflects a company's capacity to produce high-quality goods and services while integrating customers' health and safety considerations, product integrity, and data privacy protection. The scale spans from 0 to 100, with higher scores reflecting more effective implementation of product responsibility practices aimed at concerning customers' interests.

Environment-oriented Practices (***EoP***). To assess the effectiveness of environment-related practices, we rely on the *Emissions Category Score* from Refinitiv Workspace which evaluates a company's effectiveness in managing and reducing emissions arising from its production and operational processes. Scores range from 0 to 100 and capture variation across firms in the effectiveness of environment-related practices.

Supplier-oriented Practices (***SuoP***). To assess the effectiveness of supplier-oriented practices, we construct a measure based on six binary indicators reported in Refinitiv Workspace, each capturing whether the firm has implemented a concrete practice for governing environmental and ESG issues within its supply chain: (1) supplier environmental commitment, (2) environmental due diligence for new suppliers, (3) supplier environmental policy communication, (4) supplier environmental policy training, (5) environmental risk evaluation for existing suppliers, and (6) supplier ESG training. Each issue is coded as 1 if the practice is implemented and 0 otherwise.

3) Contingencies

Network Degree Centrality (***NDC***) is included as a contingency variable to capture the position of a firm within its supply chain network in terms of its direct connections. Supply chain linkages are obtained from the FactSet Supply Chain Relationships database, which identifies firm-level supplier–customer connections. According to Eq. (1), the formulation of NDC for firm *i* is defined as,

$$NDC(i) = \frac{\deg(i)}{N-1}, \tag{1}$$

where deg(*i*) represents the degree of firm *i*, that is, the total number of its direct SC connections, including both first-tier suppliers and first-tier customers, and *N* represents the total number of nodes in the constructed SCN. Firms with higher NDC are more centrally positioned in the network, which may enhance their ability to access information, monitor supply chain activities, and coordinate environmental and innovation-related practices [26].

Structural Hole Constraint (***SHC***) captures the extent to which a firm's immediate supply chain partners are redundant or interconnected, thereby constraining the firm's ability to broker information and resources across otherwise disconnected actors in the supply chain network [27]. Following Burt's (1992) structural holes framework, SHC is computed based on the firm-level SCN constructed from the FactSet Supply Chain Relationships database, which documents supplier–customer linkages identified from public disclosures and verified sources. For a firm *i*, the computation of SHC is shown as follows:

$$SHC(i) = \sum_{j\in N\ i}\left(p_{ij} + \sum_{j\in N\ i} p_{iq}p_{qj}\right)^2, \tag{2}$$

where $N(i)$ denotes the set of core firm *i*'s direct SC partners, including first-tier suppliers and customers. p_{ij} reflects the share of dependency that *i* allocates to partner *j*. SHC ranges between 0 and 1 that lower values indicate that the firm occupies a brokerage position with many structural holes, while higher values reflect redundancy among partners and fewer brokerage opportunities.

The measures and descriptive statistics of conditions are summarized in TABLE II. as follows:

TABLE II. MEASURES AND DESCRIPTIVE STATISTICS OF CONDITIONS

Conditions	Measure	Mean	S.D.	Max	Min	Medium
ShoP	Shareholders Score	50.435	27.738	99.958	0.548	50.186
WoP	Workforce Score	49.184	30.005	99.887	0.182	47.259
CoP	Product Responsibility Score	52.219	28.936	99.133	0	57.301
EoP	Emissions Score	44.208	32.489	99.576	0	42.266
SuoP	Supplier practice count	1.908	1.962	6	0	1
NDC	Degree centrality	0.001	0.001	0.015	0	0
SHC	Structural hole	0.241	0.322	1	0.004	0.091

IV. Configuration of CSR Practices

A. Calibration of the Outcome and Coditions

Building on stakeholder theory and the PBV, CSR does not operate through isolated practices, but rather influences firms' environmental innovation through combinations of multiple responsibility practices. Variations in how these practices are combined can lead to substantial heterogeneity in environmental innovation outcomes. Therefore, it is necessary to adopt a configurational perspective that examines different CSR practices as interconnected sets of conditions. Fuzzy-set qualitative comparative analysis (fsQCA) is well suited to this purpose, as it is grounded in set-theoretic logic and allows for a systematic analysis of how multiple conditions jointly shape specific outcomes [31]. Compared with linear analytical approaches, fsQCA is better able to capture the potential nonlinear effects arising from the interplay between responsibility practices and structural conditions.

The fsQCA analysis of environmental innovation begins with the calibration of both conditions and the outcome variables. The raw data for both conditions and outcomes are transformed into continuous membership scores ranging from 0 to 1. The calibration criteria for high environmental innovation are as follows: firms at or above the 95th percentile are considered fully in the set of high environmental innovation; firms at the 50th percentile are assigned the crossover point; and firms at or below the 5th percentile are regarded as fully out of the set [32]. To examine how combinations of CSR practices lead to low environmental innovation, membership in the set of low environmental innovation is calibrated by negating the corresponding high environmental innovation sets (i.e., fully in at or below the 5th percentile, crossover at the 50th percentile, and fully out at or above the 95th percentile). Similarly, when transforming the condition (CSR practices) into fuzzy-set membership scores between 0 and 1, the 95th, 50th, and 5th percentiles are used as the thresholds for full membership, the crossover point, and full non-membership, respectively [32].

Subsequently, we analyze the necessity and sufficiency of configurations of CSR practices and their relationships with environmental innovation. A CSR practice configuration is considered sufficient for high environmental innovation when it consistently leads to a high level of environmental innovation. Sufficiency is assessed using consistency, with a commonly accepted threshold of 0.80 [31]. In addition, coverage is used to indicate the extent to which a given antecedent configuration explains the outcome set, thereby assessing the empirical relevance of the solution. We also examine CSR practice configurations associated with low environmental innovation. Data processing and analyses are conducted using fsQCA 3.0 software.

B. Necessity and Sufficiency Analysis of CSR practices

According to the common practice in fsQCA, a necessity analysis of CSR practices is conducted prior to the configurational analysis. The consistency threshold is set at 0.90. As shown in TABLE III. none of the conditions (ranging from 0.266 to 0.887) meets this threshold, indicating that no single CSR practice constitutes a necessary condition for either high or low environmental innovation.

TABLE III. Results of Necessary Coditions

Conditions	High EI		Low EI	
	Consistency	Coverage	Consistency	Coverage
ShoP	0.639	0.647	0.526	0.632
WoP	0.736	0.709	0.430	0.549
CoP	0.727	0.674	0.426	0.575
EoP	0.887	0.717	0.266	0.457
SuoP	0.748	0.756	0.388	0.467
NDC	0.624	0.669	0.539	0.608
SHC	0.403	0.615	0.736	0.632

TABLE IV. reports the fsQCA sufficiency results of CSR practices for high and low environmental innovation. Configurations 1–3 correspond to high environmental innovation, whereas Configurations 4–6 pertain to low environmental innovation. For high environmental innovation, the overall solution exhibits a consistency of 0.821 and a coverage of 0.589, while the consistency of individual sufficient configurations ranges from 0.835 to 0.860, all exceeding the 0.80 threshold. At both the solution and configuration levels, the consistency and coverage values indicate a strong association between CSR practice configurations and environmental innovation. Sufficiency configurations for low environmental innovation can be interpreted in a similar manner based on consistency and coverage. The results show that SuoP (the most important), WoP, CoP, and ShoP frequently appear as core conditions, whereas EoP (the least important) does not emerge as a core condition in any configuration.

TABLE IV. Summary of Sample Observations

	High EI				Low EI		
	1	2a	2b	3	4	5	6
CSRP							
ShoP		●	●				•
WoP	●			●	⨂	⊗	⨂
CoP		●	●	●	⨂	⊗	⨂
EoP	•	•	•	•	⨂	⨂	
SuoP	●	●	●	●	⨂		⨂
Contingency							
NDC	●	•	⊗	⊗			
SHC	⨂	⊗	•	•	⨂		⨂
Raw coverage	0.461	0.323	0.209	0.249	0.289	0.265	0.278
Unique coverage	0.139	0.012	0.009	0.037	0.019	0.076	0.023
Consistency	0.837	0.839	0.860	0.835	0.868	0.864	0.872
Overall solution coverage		***0.589***				***0.388***	
Overall solution consistency		***0.821***				***0.824***	

From the high EI configurations, Configuration 1 represents the "Workforce-Supplier embedded" archetype. When firms occupy positions characterized by high degree centrality and low structural hole constraints, their supply chain ties tend to be dense, interaction-intensive, and relational stable. Under such conditions, employee-oriented responsibility practices strengthen employee participation, perceptions of fairness, and organizational trust, thereby providing an internal organizational foundation for the consistent enactment of environmental requirements in day-to-day operations. At the same time, supplier-oriented responsibility practices are more likely to be translated into collectively observed operational norms within highly embedded supply chains, rather than remaining symbolic commitments or one-sided compliance pressures. Low structural hole constraints further imply strong interconnections among key suppliers, enabling environmental standards and improvement initiatives proposed by the focal firm to diffuse more readily across the network and to crystallize into shared expectations.

Configuration 2 represents a "Shareholder–Customer Governance-Driven Innovation" path. Shareholder-oriented responsibility practices foster a long-term value orientation, enhance governance stability, and mitigate short-term performance pressures, thereby enabling firms to sustain strategic patience in environmental innovation activities characterized by high uncertainty and long payoff horizons. At the same time, customer-oriented responsibility practices embed environmental innovation directly into the logic of market competition, transforming green technologies and environmentally friendly products from mere compliance tools into key instruments for responding to customer expectations and achieving differentiation. Building on this foundation, supplier-oriented responsibility practices extend governance and market logics to the supply chain level. By promoting shared standards and coordinated implementation, these practices reduce coordination costs and execution frictions associated with cross-organizational environmental innovation. In contrast to Configuration 1, this configuration does not rely on a firm's central position within the supply chain network. Instead, it is grounded in a stable relational environment supported by low structural hole constraints. This pattern suggests that when internal governance mechanisms are highly aligned with external market demands, environmental innovation can emerge as a strategic governance outcome, without the need for intermediary advantages or dominance derived from network structural positions.

In Configuration 3, employee-oriented, customer-oriented, and supplier-oriented practices jointly constitute the core conditions. Firms in this configuration are typically positioned with low supply chain network centrality and high structural hole constraints, which limits their ability to access diverse knowledge and collaborative resources through extensive external connections. Employee-oriented practices strengthen labor protection and perceptions of organizational fairness, thereby reducing internal barriers that hinder employees from identifying and reporting environmental problems. As a result, employees are more likely to proactively disclose resource waste, emission risks, and process inefficiencies in production. This mechanism enables environmental issues to be identified in a timely manner even when firms occupy peripheral network positions, thus laying the foundation for continuous environmental improvement and innovation. Customer-oriented practices embed environmental requirements directly into the attributes of products and services delivered to the market, rather than confining them to compliance-driven internal objectives. Specifically, firms offer products with higher energy efficiency and reliability, allowing environmental improvements to be translated into product features that customers can directly compare in their purchasing decisions. Under conditions of constrained network structures, supplier-oriented practices play a critical substitutive coordination role. Low network centrality and high structural hole constraints restrict firms' ability to connect with multiple suppliers and obtain broad information simultaneously. However, by establishing responsibility-based and long-term relationships with key suppliers, firms can still develop stable and high-trust collaboration mechanisms in material selection, process improvement, and the implementation of environmental compliance.

V. Dynamics of Condition Evolution

To analyze the sequence of CSR practices in improving environmental innovation, we abstracted the five types of CSR practices above into five entities and applied the NK model to conduct configurational evolution analysis through the construction of a fitness landscape. The NK model formalizes the multiple elements of a complex system and their interdependencies into an interaction matrix [33], allowing the simulation of the system's evolutionary path from low to high fitness states. This approach enables the identification of the optimal implementation sequence of CSR practices, providing decision-making guidance for firms aiming to enhance environmental innovation.

A. Interdependencies among CSR Practices (K)

Step 1. Expert evaluation of pairwise interdependencies. Consider a set of N = 5 CSR practices. Let $i, j \in \{1,2,\ldots,5\}$ denote the i-th and the j-th practice, respectively. Assume there are M experts who evaluate whether practice j exerts an influence on practice i. For each expert $m \in \{1,2,\ldots, M\}$, a binary indicator is defined as:

$$\alpha_{ij}^{(m)} = \begin{cases} 1, & \text{practice } j \text{ influence practice } i, \\ 0, & \text{otherwise.} \end{cases} , \tag{3}$$

This procedure yields M expert-evaluated interaction matrices:

$$A^{(m)} = \left[\alpha_{ij}^{(m)}\right]_{5\times5},\ m = 1,\ldots,M, \tag{4}$$

Step 2. Aggregation of experts judgments. In this step, interaction judgments are aggregated across experts. For each ordered pair (i, j), the average influence score is computed as:

$$S = \left[s_{ij}\right]_{5\times5},\ \text{where } s_{ij} = \sum_{m=1}^{M} \alpha_{ij}^{(m)}. \tag{5}$$

Each element $s_{ij} \in \{1,2,\ldots, M\}$ represents the total number of experts who indicate that CSR practice j influences practice i.

Step 3. Construction of the binary interaction matrix. To distinguish influential from non-influential interdependencies, we compute the average level of expert agreement across all possible ordered pairs of CSR practices. The overall mean of the aggregated interaction matrix is given by:

$$\bar{s} = \frac{1}{N\times N}\sum_{i=1}^{5}\sum_{j=1}^{5} s_{ij}. \tag{6}$$

After that, the binary interaction matrix is obtained by comparing each aggregated interaction score to the overall mean threshold:

$$\mathrm{IM}_{ij} = \begin{cases} 1, & \text{if } s_{ij} > \bar{s}, \\ 0, & \text{otherwise.} \end{cases} . \tag{7}$$

$\mathrm{IM}_{ij} = 1$ indicates that the influence of practice j on practice i is stronger than the average interdependency identified across all practice pairs, whereas $\mathrm{IM}_{ij} = 0$ indicates a weaker-than-average or negligible influence.

Step 4. Derivation of the interdependencies. The number of interdependencies affecting practice i is captured by parameter K_i. Accordingly, for each practice $i = 1, 2, \ldots, 5$,

$$K_i = \sum_{i=1}^{5} \mathrm{IM}_{ij}. \tag{8}$$

The vector K=K_i/5 summarizes the complexity of practices and contributes to the construction of the NK fitness landscape.

In this study, evaluations are provided by four experts with complementary expertise in corporate management, supply chain management, human resource management, and green operations management. All expert judgments are collected independently and aggregated as the procedure described above. Following the procedure above, we obtain the final binary interaction matrix IM_{ij}:

$$IM_{ij} = \begin{bmatrix} - & 1 & 1 & 1 & 1 \\ 1 & - & 1 & 0 & 0 \\ 1 & 1 & - & 1 & 1 \\ 1 & 1 & 0 & - & 0 \\ 0 & 0 & 1 & 1 & - \end{bmatrix}. \tag{9}$$

According to IM_{ij}, the overall level of interdependence in the system can be obtained as $K = 2.8$.

B. *Construction of the NK Fitness Landscape*

Building on IM_{ij}, we construct the NK fitness landscape to model the dynamic evolution paths of CSR practices. The model specifies $N = 5$, corresponding to CSR practices from five stakeholders: ShoP (a_1), WoP (a_2), CoP (a_3), EoP (a_4), and SuoP (a_5). Assume $s \in \{0,1\}^5$ denotes the states of CSR practices, where $s_i = 0$ indicates that the i-th practice is implemented at a relatively low level, and $s_i = 1$ otherwise. According to the NK model, the contribution of practice i under state s is denoted by $f_i(s)$, which is drawn from a uniform distribution over [0,1],

$$f_i(s) \sim U(0,1), \quad i = 1, \ldots, 5. \tag{10}$$

The overall fitness F is defined as,

$$F = \frac{1}{N}\sum_{i=1}^{N} f_i(s), \quad \text{where } N = 5 \tag{11}$$

Based on these specifications, the NK fitness landscape is generated and simulated in MATLAB 2021b. A total of 150,000 random landscape evolution simulations are conducted to ensure the stability and reliability of the results, and the most frequently observed evolutionary path among the simulations is identified as the dominant path. The climbing process of CSR practices evolution can be shown as Fig. 2. The x-axis represents the states of a_1, a_2, and a_3, while the y-axis represents the states of a_4, and a_5. The z-axis indicates the fitness value corresponding to each configuration. Different fitness values form peaks of varying heights in the landscape.

According to Fig. 2, ShoP (a_1) contributes the most to the overall fitness landscape. Therefore, the first stage of evolution prioritizes ShoP (a_1), corresponding to the fitness landscape transition from the initial state {00000} (point a) to {10000} (point b). Then, EoP (a_4) exhibits the largest local fitness contribution under the current state, prompting the implementation of EoP (a_4) in the second stage. This is reflected in the fitness landscape by the transition from {10000} (point b) to {10010} (point c). Subsequently, WoP (a_2), CoP (a_3), and SuoP (a_5) are sequentially implemented, ultimately reaching the highest fitness state {11111} (point f). Thus, according to the NK fitness landscape model, the simulation results show that the evolutionary sequence of CSR practices is: $a_1 \rightarrow a_4 \rightarrow a_2 \rightarrow a_3 \rightarrow a_5$.

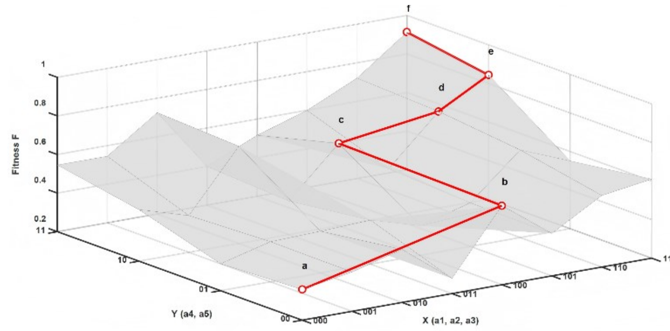

Fig. 2. Fitness landscape and climbing process

To provide a clear illustration of the evolutionary path, a two-dimensional fitness landscape is presented in Fig. 3. In each box, the first row indicates the state of CSR practices, while the second row shows the corresponding fitness value. Specifically, ShoP (a_1) is implemented first. It provides the financial and resource support that forms the foundation for enhancing environmental innovation. Next, EoP (a_4) is carried out. This ensures the enforcement of corporate environmental policies and green innovation measures, and it provides the institutional and resource support needed for subsequent WoP (a_2) and CoP (a_3). Third, once ShoP (a_1) and EoP (a_4) are in place, enhancing WoP (a_2) motivates employees to engage in environmental innovation by safeguarding their rights and interests. Subsequently, CoP (a_3) builds on the prior implementation of EoP (a_4) and WoP (a_2) to deliver reliable products and services that meet customer demands. Finally, after the preceding practices are established, SuoP (a_5) is implemented by leveraging supply chain collaboration to further improve environmental innovation and overall performance across the supply chain.

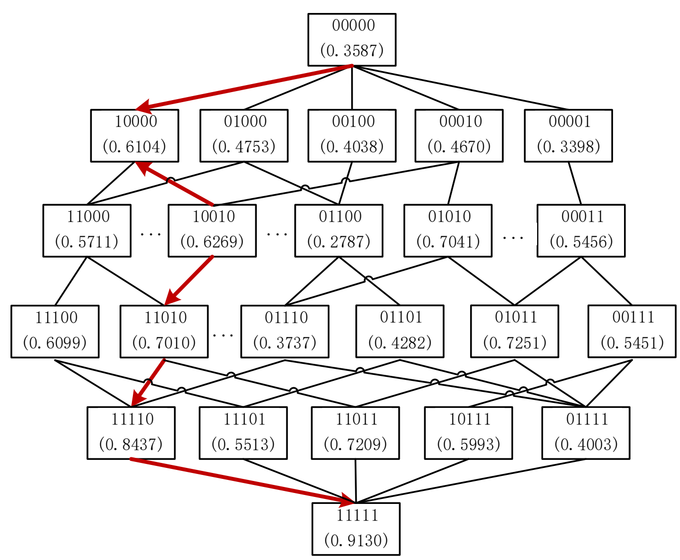

Fig. 3. Two-dimensional fitness landscape map

VI. Conclusion

In this study, we investigate how CSR practices drive environmental innovation through different configurations and evolutionary pathways. We conceptualize five different stakeholder oriented practices as an integrated bundle through the practice-based view and stakeholder theory. We identify three equifinal configurations associated with high environmental innovation and find that firms positioned with high centrality and low structural holes in their SCN exhibit distinctive CSR practice combinations, thereby extending configuration theory to the study of environmental innovation. We further use the NK fitness landscape model to simulate how CSR practices evolve over time, uncovering both the optimal sequence and the path-dependent patterns that lead to high environmental innovation. Our findings show that the impact of CSR practices depends not only on *what* is implemented but also on *the order* in which practices are introduced. Shareholder-oriented practices play a crucial foundational role in the early stages, while supplier-oriented practices only reach their full potential once other prerequisite practices are in place. This dynamic perspective sheds light on why firms differ in environmental innovation performance and provides practical guidance for managers seeking to design effective CSR practice bundles.

ACKNOWLEDGMENT

This study was funded by the National Natural Science Foundation of China (grant number 72473013).

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