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1 **ESG Greenwashing Behaviour in the Electric Vehicle Supply Chain: Insights**
2 **from evolutionary game theory**

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6 **Abstract** :This study explores the governance of greenwashing behaviour within the Environmental,
7 Social, and Governance (ESG) framework of the New Energy Vehicle (NEV) supply chain.
8 Employing an evolutionary game theory model, we examine the strategic interactions between NEV
9 Components Suppliers (NEVSSs), NEV Manufacturers (NEVMs), and Government Regulatory
10 Agencies (GRAs). We derive the conditions for evolutionarily stable strategies (ESS) and conduct
11 sensitivity analysis to assess the impact of key factors on the evolution of optimal strategies. Our
12 findings reveal the dynamic changes in ESG practices and greenwashing of supply chain enterprises
13 under different market and regulatory environments. The results demonstrate that ESG practices in
14 the supply chain exhibit distinct phased characteristics, transitioning from greenwashing behaviour
15 in the initial stages to proactive ESG practices in the maturity stage. This research highlights the
16 significant influence of market forces on companies' ESG strategic choices, suggesting that the
17 government should implement appropriate regulatory and incentive strategies at different stages to
18 guide enterprises from greenwashing towards authentic ESG practices. This study provides
19 theoretical insights and practical guidance for policymakers and corporate strategists to promote
20 sustainable development in the NEV industry.

21 **Keywords:** ESG Greenwashing; Governance; New Energy Vehicle; Supply Chain; Evolutionary
22 Game.

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23 **1. Introduction**

24 With the rapid industrialization of society, the demand for energy has surged, leading to
25 significant resource depletion and environmental degradation (Yuan et al., 2015; Zou et al., 2016).
26 Research indicates that automobiles account for approximately 25% of global oil consumption,
27 contribute to 80% of carbon emissions in the transportation sector (Yu et al., 2024). New Energy
28 Vehicle (NEV), as green and clean modes of transportation, not only reduce dependence on
29 traditional fossil fuels, but also lower carbon emissions in the transportation sector. This promotes
30 a more sustainable direction for energy consumption (Das et al., 2024). Therefore, NEVs are
31 considered a key driver in transforming the global energy structure.

32 In the context of global energy transformation, the importance of Environmental, Social, and
33 Governance (ESG) principles has become increasingly evident (Lee & Lee, 2022). ESG practices
34 help enterprises achieve sustainable development while addressing environmental challenges and
35 improving corporate social responsibility and governance levels (Apergis et al., 2022; Yamoah et
36 al., 2022). The development of NEV aligns closely with ESG principles, offering a natural
37 advantage in promoting sustainable practices (Giri, 2019; Liu & Yu, 2020; Zhang & Cai, 2020;).

38 The importance of ESG practices in the NEV supply chain is becoming increasingly prominent.
39 From the environmental (E) perspective, the NEV supply chain plays a significant role in realizing
40 carbon neutrality goals. Research shows that the lifecycle carbon emissions of NEVs are 40-50%
41 lower than traditional fuel vehicles, but this advantage largely depends on the greenness of the
42 supply chain (Das et al., 2024). From the social (S) perspective, the NEV supply chain involves
43 extensive labour and resource extraction and its social responsibility performance directly impacts
44 the industry's reputation and sustainable development (Kraude & Narasimhan, 2024). In terms of

45 governance (G), transparent corporate governance and efficient risk management are crucial for
46 attracting investment and maintaining brand image (Asante-Appiah, 2020). Therefore,
47 implementing comprehensive ESG practices in the NEV supply chain is significant for the long-
48 term sustainable development of the industry and the realization of global environmental goals.

49 However, the NEV industry faces challenges such as policy uncertainties, fluctuating subsidies
50 (Baars et al., 2020), technological hurdles (Hua et al., 2021), market competition pressures (Wang
51 et al., 2020), and supply chain management (Sun et al., 2022; Gu et al., 2024). These challenges
52 have led some companies to engage in greenwashing—making misleading claims about their
53 environmental practices to reduce costs (Yu et al., 2020).

54 Greenwashing in the NEV supply chain manifests in diverse forms, posing significant
55 challenges to industry integrity. Common greenwashing behaviours include subsidy fraud,
56 exaggerated carbon reduction claims, and selective environmental information disclosure (Liao &
57 Wu, 2024). These practices not only mislead consumers and stakeholders but also hinder sustainable
58 development, exacerbating environmental pollution, resource waste, and social injustice (Liu & Li,
59 2024). Furthermore, they undermine genuine ESG efforts and negatively impact the industry's
60 reputation and effectiveness in achieving sustainable development goals (Lee & Raschke, 2023).

61 Considering that the NEV supply chain involves multiple stakeholders, including GRAs
62 NEVs, and NEVMs, effective interaction and cooperation among these stakeholders are key to
63 ensuring the authenticity and effectiveness of ESG practices (Wang et al., 2020). Governments can
64 promote the development of NEVs and gain environmental benefits through policy support.
65 Additionally, decisions regarding the production of NEVs must account for market dynamics, policy
66 environments, and operational costs (Shi, 2020) adapting flexibly to rapid changes. Therefore,

67 governments worldwide urgently need to implement effective governance against greenwashing
68 behaviours to regulate ESG practices within the supply chain, ensuring sustainable development
69 throughout production and sales processes.

70 Despite the growing importance of ESG practices in the NEV industry, there is a lack of
71 research focusing on the dynamic interactions among stakeholders in ESG practices and
72 greenwashing governance within this sector. This study aims to address this research gap by
73 exploring the dynamic interactions between key stakeholders in the NEV supply chain and
74 examining the evolution of corporate ESG practices and greenwashing behaviours under different
75 market and regulatory environments. Our research contributes to the literature by providing a novel
76 tripartite evolutionary game model that captures the complex interactions between these
77 stakeholders, offering insights into effective governance strategies for promoting authentic ESG
78 practices.

79 To address these issues, we pose three key research questions: (1) What are the main factors
80 influencing ESG practice strategies within the NEV supply chain? (2) How can government policies
81 be designed and implemented to effectively guide enterprises towards ESG practices? (3) What
82 measures can effectively mitigate greenwashing behaviour in the NEV supply chain? We employ a
83 tripartite evolutionary game model to analyze the strategic interactions among NEV component
84 suppliers (NEVSSs), NEV manufacturers (NEVMs), and government regulatory agencies (GRAs).
85 Using Lyapunov's first law, we derive the conditions for Evolutionarily Stable Strategies (ESS) and
86 conduct sensitivity analysis to assess the impact of key factors on the evolution of optimal strategies.

87 Our findings reveal the dynamic evolution of ESG practices and greenwashing behaviours
88 under varying market and regulatory environments. The study shows that market sensitivity to

89 environmental issues significantly impacts corporate ESG behaviour, underscoring the key role of
90 market mechanisms in driving sustainable development. Governments should adopt appropriate
91 regulatory and incentive strategies at different stages to promote green technology, reduce ESG
92 costs for enterprises, and comprehensively regulate the supply chain. Finally, this article proposes
93 phased government regulatory strategies to govern ESG greenwashing in the NEV supply chain.

94 Theoretically, this study pioneers the application of evolutionary game theory to the NEV
95 industry, establishing an innovative tripartite evolutionary game model that reveals the dynamic
96 interactions among g GRAs, NEVSs, and NEVMs.

97 This study contributes significantly to both theory and practice in ESG practices and
98 greenwashing behaviours within the NEV supply chain. Theoretically, this study pioneers the
99 application of evolutionary game theory to the NEV industry, establishing an innovative tripartite
100 evolutionary game model that reveals the dynamic interactions among GRAs, NEVSs, and NEVMs.
101 This model not only integrates market forces, regulatory pressures, and corporate strategies but also
102 provides a dynamic framework for the evolution of ESG practices and greenwashing behaviours.
103 Practically, the findings offer valuable guidance for policymakers in designing phased regulatory
104 approaches and for businesses in adapting their ESG strategies to different industry development
105 stages. This contributes to mitigating greenwashing behaviours, enhancing ESG practices, and
106 ultimately promoting sustainable development in the NEV sector.

107 The remainder of this study is structured as follows: Section 2 reviews the literature to identify
108 research gaps. Section 3 describes the construction process of the tripartite evolutionary game model.
109 Section 4 analyzes the evolutionary stability strategy of the tripartite evolutionary game model.
110 Section 5 presents the numerical simulation. Section 6 presents the discussion. The conclusions and

111 policy implications are summarized in section 7.

112 **2. Literature review**

113 This section provides a comprehensive review of the existing literature on ESG practices and
114 greenwashing in the NEV industry. It explores the unique characteristics of ESG implementation
115 within the NEV supply chain, examines the various forms and impacts of greenwashing specific to
116 this sector, and investigates the roles and interactions of key stakeholders. Through this analysis, we
117 identify significant research gaps and highlight opportunities for future studies, particularly
118 regarding governance strategies to address greenwashing in the NEV supply chain.

119 **2.1 ESG practices in the NEV industry**

120 The NEV industry, as a representative of green transportation, exhibits distinctive ESG
121 practices. In terms of environmental (E) aspects, the NEV industry primarily focuses on reducing
122 carbon emissions and improving energy efficiency. Studies demonstrate that NEVs significantly
123 reduce lifecycle carbon emissions compared to conventional vehicles (Andersson & Börjesson,
124 2021). The industry is actively developing more efficient battery technologies and implementing
125 closed-loop recycling systems to further enhance energy efficiency and mitigate environmental
126 impacts(Liu et al., 2022; Xiong & Cheng, 2023; Xiao et al., 2024).

127 Regarding social (S) aspects, NEV companies contribute through employment generation,
128 employee welfare improvement, and community engagement (Purcell et al., 2021; Zhang et al.,
129 2024). Many NEVMs are addressing labour and environmental issues in the supply chain, such as
130 ethical sourcing of materials and transitioning to more sustainable battery technologies (OFweek,
131 2021). In corporate governance (G), NEV companies are enhancing effectiveness by optimizing
132 internal structures, increasing transparency, and strengthening risk management (Széchenyi István

133 University & Ercsey, 2016; Thomas, 2019).

134 **2.2 Greenwashing behaviours and impacts**

135 Despite the adoption of positive ESG practices, greenwashing in the NEV industry remains a
136 significant concern. It stems from a complex interplay of factors, including policy uncertainties,
137 high production and battery costs, technological hurdles, market competition pressures, evolving
138 consumer expectations, and supply chain management challenges (Baars et al., 2020; Hua et al.,
139 2021; Szabo & Webster, 2021; Sun et al., 2022; Gu et al., 2024).

140 These pressures often lead companies to engage in greenwashing practices, which manifest in
141 various forms within the NEV industry (Williams, 2024). Common tactics include overstating the
142 eco-friendliness of electric vehicles, neglecting full life-cycle assessments, misrepresenting raw
143 material sourcing, particularly regarding conflict minerals in battery production (Kumar & Suresh,
144 2024); using vague "eco-friendly" terms, inflating recyclability claims, especially for
145 batteries (Cremades & Casals, 2022); and understating the environmental impact of EV charging,
146 particularly in fossil fuel-dependent regions (Rahman, 2021; Guzek et al., 2024).

147 These practices are widespread across the industry, affecting both leading NEV companies and
148 traditional automakers. For instance, Land Rover, Toyota, Lexus, and Audi have been criticized for
149 potentially exaggerating their vehicles' environmental benefits in advertisements (Hickman, 2021).
150 Even Tesla, a leading NEV company, has faced environmental controversies, including regulatory
151 violations, emissions control issues, and its removal from the S&P 500 ESG Index (Reuters, 2021;
152 Financial Times, 2021; EPA, 2022). Wang (2024) employed AI models to detect Tesla's
153 greenwashing behaviour, further illustrating the complexity of this issue in the NEV sector.

154 The impacts of greenwashing behaviours are significantly negative. Compared to genuine

155 environmental actions, greenwashing lowers consumer reputation evaluations of companies (Du,
156 2015), misleads markets and consumers, and leads to inappropriate resource allocation (Lee &
157 Raschke, 2023), undermines the implementation of carbon reduction measures (Liu & Yu, 2020;
158 Baldi & Pandimiglio, 2022), and can lead to legal consequences (Cherry & Sneirson, 2012). In the
159 NEV industry, greenwashing is particularly problematic as environmental attributes are a primary
160 market selling point (Patala et al., 2019). If left unchecked, it will severely hinder the true sustainable
161 development of the industry.

162 While the NEV industry demonstrates significant progress in ESG practices, the prevalence of
163 greenwashing poses a substantial threat to its sustainable development. Therefore, it is crucial to
164 govern ESG greenwashing behaviours within the supply chain and actively promote genuine
165 sustainability efforts in the NEV sector.

166 **2.3 Greenwashing governance**

167 To address greenwashing, it is essential to explore efficient strategies to govern greenwashing.
168 Existing studies primarily focus on external regulation and internal governance. From the
169 perspective of external regulation, reducing greenwashing requires legislation and uniform
170 international standards(Zhang, 2023a; Zhang et al., 2023). Studies have demonstrated that
171 sustainability ratings, government penalty mechanisms, and rigorous scrutiny by media and NGOs
172 can effectively curb corporate greenwashing (Parguel et al., 2011; Zhang, 2023b; Seele & Gatti,
173 2017; Tan & Zhu, 2022). For internal governance, increasing the number of independent directors
174 and institutional investors, establishing robust environmental management systems, and
175 implementing independent environmental audit can effectively curb corporate greenwashing (Lyon
176 & Maxwell, 2011; Yu et al., 2020; Chen et al., 2024). However, most studies analyze greenwashing

177 governance from a single perspective, neglecting the interaction and cooperation among
178 stakeholders (Dhaliwal et al., 2014; Tsang, 2023). There is a lack of research on industry-specific
179 governance strategies that account for the unique challenges of the NEV sector.

180 **2.4 Evolutionary game model and ESG research**

181 ESG practices involve dynamic interactions among multiple stakeholders (Dhaliwal, 2014;
182 Das et al., 2024). Previous ESG research has primarily focused on its performance and economic
183 outcomes. These studies have mostly employed systematic literature reviews, quantitative methods
184 (e.g., panel data models and regression analyses), case studies, content analysis of company reports
185 and disclosures, and comparative studies across industries and countries (Friede et al., 2015; Ashwin
186 Kumar et al., 2016; Savio et al., 2023). While these approaches have provided valuable insights,
187 they are limited in capturing the dynamic process of ESG practice, particularly within the continuous
188 interaction and evolution of multiple stakeholders (Alam et al., 2019; Naseer et al., 2023; Tsang,
189 2023). This study adopts evolutionary game theory to address these limitations.

190 The evolutionary game model, which combines traditional game theory with dynamic
191 evolutionary processes, has been widely applied in economics, environmental studies, and logistics
192 (Friedman, 1991; Liu et al., 2021; Wu et al., 2024). It offers several advantages in analyzing ESG
193 practices and greenwashing behaviours in the NEV supply chain. This approach enables the
194 examination of strategy evolution over time, reflecting the adaptive nature of firm behaviour
195 (Friedman, 1991). It also incorporates bounded rationality, aligning with real-world decision-
196 making processes in complex environments (Weibull, 1997). Moreover, it allows for analysis at the
197 population level of firms, providing insights into industry-wide dynamics and the emergence of
198 dominant strategies (Nowak et al., 2004). The concept of evolutionarily stable strategies (ESS)

199 facilitates the identification of long-term equilibria and their stability (Smith, 1982). Additionally,
200 it helps reveal complex interactions between enterprises, governments, and other stakeholders (Liu
201 et al., 2023; Zhang et al., 2024).

202 The dynamic nature of the NEV industry, characterized by rapidly changing technology,
203 regulations, and market demands, makes evolutionary game theory an ideal approach for studying
204 ESG practices and greenwashing behaviours among its diverse stakeholders. By employing
205 evolutionary game theory, this study aims to provide a more comprehensive and dynamic
206 understanding of ESG practices and greenwashing behaviours in the NEV supply chain, addressing
207 gaps in existing research and offering new insights for both theoretical development and practical
208 applications for effective governance strategies.

209 **2.5 Research gap**

210 In summary, despite the increasing research on ESG in recent years, there is a lack of focus on
211 the dynamic interactions among stakeholders in ESG practices. Additionally, studies specifically
212 addressing ESG practices and greenwashing governance within the NEV industry remain relatively
213 scarce. Significant differences in greenwashing governance measures across industries highlight a
214 clear deficiency in industry-specific governance methods. Therefore, it is crucial to conduct in-depth
215 studies on greenwashing governance strategies tailored to the stakeholders in the NEV industry. By
216 introducing the evolutionary game model, this study explores how various factors influence the
217 strategic choices of GRAs, NEVSs, and NEVMs. It provides new perspectives and methods for ESG
218 practice and greenwashing governance. Our research offers theoretical foundations and practical
219 guidance for policy-making and corporate strategy formulation, aiming to address the unique
220 challenges of greenwashing in this sector, ultimately enhancing the credibility and effectiveness of

221 ESG practices and achieving genuine sustainable development in the NEV industry.

222 **3. Evolutionary game model analysis**

223 **3.1 Model description**

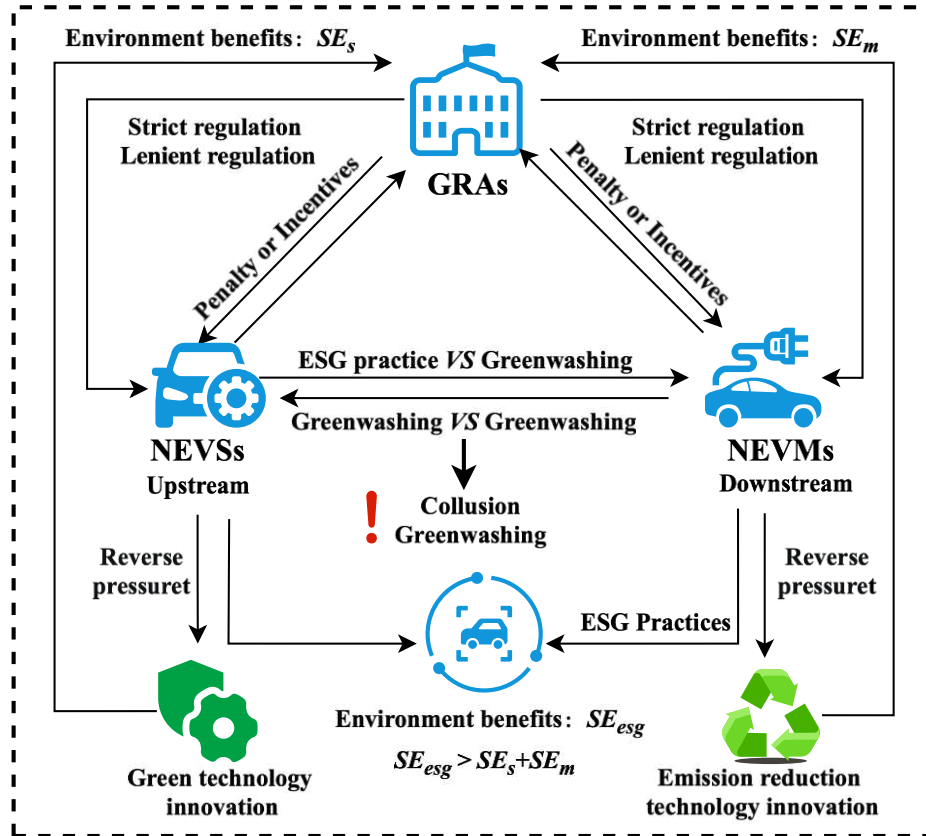
224 In the face of intense market competition, enterprises in the supply chain must choose between
225 high-cost ESG practices and lower-cost greenwashing strategies. We suppose that divergent
226 strategies among upstream and downstream enterprises may lead to risks such as partner loss and
227 reputational damage for those engaging in greenwashing. Besides, if all entities within the supply
228 chain adopt greenwashing, collusive behaviour may emerge, significantly hindering the industry's
229 sustainable development. Conversely, if all enterprises choose ESG practices, the entire supply
230 chain can achieve sustainable development.

231 The government, as a regulatory entity, plays a decisive role in promoting ESG practices and
232 preventing greenwashing behaviours. Through the enactment and stringent enforcement of
233 environmental regulations, the government can foster genuine ESG compliance and deter
234 companies from making superficial environmental claims. Insufficient regulatory enforcement may
235 lead companies to opt for the lower cost greenwashing strategy of the NEV industry, ultimately
236 undermining the environmental integrity and market credibility. Therefore, the government must
237 carefully balance maintaining stringent environmental standards with promoting industry
238 development.

239 This study categorizes government regulatory strategies into stringent and lenient types.
240 This division reflects two extreme scenarios of government regulatory intensity in the NEV sector,
241 ranging from strict to lenient (Xia et al., 2024). This binary classification captures regulatory
242 trends and enables the simulation of market reactions across policy cycles. By comparing

243 outcomes under different regulatory intensities, we provide a basis for dynamic strategy
 244 formulation. This approach, widely adopted in similar studies (Li & Gao, 2022; Zou et al., 2023;
 245 Zhao et al., 2024), enhances the comparability and consistency of research findings across the
 246 field.

247 In summary, this study constructs a two-tier supply chain comprising NEVs and NEVMs,
 248 employing a tripartite evolutionary game model to analyze the dynamic behaviours and strategic
 249 interactions among stakeholders from a supply chain perspective. The focus is on how government
 250 regulatory policies can guide ESG practices and govern greenwashing behaviour in the supply chain.
 251 This approach aims to develop comprehensive analytical methods and incentive policies to prevent
 252 potential collusive greenwashing. Fig. 1 illustrates the strategic interactions among stakeholders
 253 within the NEV supply chain.



254 Fig. 1. The game relationship between Governments, NEVs and NEVMs.
 255

256 **3.2 Model assumptions and parameter settings**

257 (1) Behavioural strategies of participants in evolutionary game

258 In the evolutionary game, each participant is assumed to be boundedly rational, aiming to
259 maximise its own utility through two pure strategies. Specifically, the strategy set for NEVSs is
260 $N_1 = \{\text{ESG Practices}(x), \text{Greenwashing}(1-x)\}$. Similarly, the strategy set for NEVMs is $N_2 = \{\text{ESG}$
261 $\text{practices}(y), \text{Greenwashing}(1-y)\}$. The strategy set for GRAs is $N_3 = \{\text{Strict regulation}(z), \text{Lenient}$
262 $\text{regulation}(1-z)\}$. Where $x(t), y(t), z(t) \in [0,1]$ are all probabilities functions of time t .
263 Throughout the game, Players continuously adjust strategies based on repeated trials and
264 observations, converging to optimal strategies over time.

265 (2) Parameter settings

266 To facilitate the modeling, we make the following assumptions are made based on the
267 behavioral strategies of the participants to describe the benefits and costs for NEVSs, NEVMs, and
268 GRAs. Table 1 shows the specific parameter symbols and their meanings.

269 For NEVSs and NEVMs, we denote basic production and manufacturing costs as C_s and C_m ,
270 and basic revenues as R_s and R_m , respectively. When choosing ESG practices, enterprises need to
271 incur additional costs (ΔC_s for NEVSs, ΔC_m for NEVMs) due to increased production and
272 manufacturing expenses, R&D costs, and operating and advertising costs. Similarly, these practices
273 also generate additional revenues (ΔR_s for NEVSs, ΔR_m for NEVMs). Greenwashing involves
274 speculative costs (C_{ss} for NEVSs, C_{ms} for NEVMs) and potential reputational losses (L_s, L_m).

275 When the strategies of NEVSs and NEVMs are different, e.g., if NEVSs chooses to greenwash
276 while NEVMs choose ESG practices, NEVSs suffer reputational damage L_s and the cost of lost
277 customers R_{pl} . Conversely, if NEVMs choose to greenwash while NEVSs adopt ESG practices,

278 the NEVSs are indirectly affected, though they have already mitigated some reputational risk
279 through their ESG practices. To quantify this, we introduce a reputational risk coefficient R_{sc} to
280 measure the indirect impact of greenwashing on reputation. This is quantified as $R_{sc}L_m$ for
281 NEVMs and $R_{sc}L_s$ for NEVSs, representing the indirect reputational impact of one party's
282 greenwashing on the other.

283 We assume that the additional costs of ESG practices are greater than the speculative costs of
284 greenwashing, i.e., $\Delta C_s > C_{ss}$ and $\Delta C_m > C_{ms}$. We introduce risk coefficients R_{pl} to represent
285 the risk of losing partners, R_{mr} to measure market sensitivity to greenwashing, and R_{sc} to
286 quantify the indirect impact on supply chain reputation.

287 When both NEVSs and NEVMs adopt greenwashing strategies, collusive greenwashing can
288 occur, providing short-term benefits such as cost savings (C_{co}) from reduced compliance costs or
289 shared investments. We assume that $C_{co} < \Delta C_s$ and $C_{co} < \Delta C_m$. Collusive greenwashing can also
290 yield market advantages, resulting in additional revenues R_{co} .

291 The regulatory costs for GRAs are represented by C_g for strict regulation and θC_g for lenient
292 regulation, where $\theta \in [0,1]$. Under strict regulation, firms engaged in greenwashing face penalties
293 (P_s, P_m), while those adhering to ESG practices receive rewards (B_s, B_m). The environmental
294 benefits of ESG practices are represented as SE_s and SE_m when adopted individually by NEVSs
295 or NEVMs, respectively. When the entire supply chain implements ESG practices, the resulting
296 environmental benefit is denoted as SE_{esg} . Notably, $SE_{esg} > SE_s + SE_m$, which captures the
297 synergistic effects inherent in sustainable supply chains. When both NEVSs and NEVMs implement
298 ESG practices, it enables better supply chain integration, optimizing resource use and processes
299 (Gunasekaran et al., 2015), facilitates comprehensive life cycle management (Ostojic & Traverso,

300 2024), spurs joint innovations (Tian & Shi, 2024) and create economies of scale in sustainable
301 practices (Samuel et al., 2021). These synergies potentially yield greater environmental benefits
302 than the sum of individual efforts, supporting our assumption that $SE_{esg} > SE_s + SE_m$.

303 **Table 1**

304 Model parameter descriptions

Game player	Symbol	Parameter description
NEVSs	$C_s, \Delta C_s$	The basic production cost and extra cost for ESG practices of NEVSs.
	$R_s, \Delta R_s$	The basic revenue and extra revenue from ESG practices of NEVSs.
	L_s	Loss of reputation for NEVSs due to greenwashing.
	C_{ss}	Speculative cost for NEVSs.
NEVMs	$C_m, \Delta C_m$	The basic production cost and extra cost for ESG practices of NEVMs.
	$R_m, \Delta R_m$	The baseline revenue and extra revenue from ESG practices of NEVMs.
	L_m	Loss of Reputation due to greenwashing for NEVMs.
	C_{ms}	Speculative cost for NEVMs.
Supply Chain Shared Parameters	C_{co}	Cost savings from collusive greenwashing.
	R_{co}	Extra revenue from collusive greenwashing.
	R_{pl}	The potential loss incurred by the greenwashing party due to the increased likelihood of losing supply chain partners.
	R_{mr}	Market reaction coefficient, measuring sensitivity to greenwashing.
GRAs	R_{sc}	Reputation risk coefficient that indicates indirect impact on supply chain reputation ($R_{sc} \in [0,1]$).
	C_g	The cost of strict supervision by government regulators.
	θ	The cost of coefficient of loose supervision by government regulators ($\theta \in [0,1]$).
	B_s, B_m	The rewards of government for NEVSs and NEVMs practising ESG.
	P_s, P_m	The penalties imposed by the government on NEVSs and NEVMs practising greenwashing.
	SE_s, SE_m	Environmental benefits to the government from the ESG practices of NEVSs and NEVMs, respectively.
	SE_{esg}	Environmental benefits to the government from entire supply chain ESG practices.
	C_E	The damage to the environment caused by supply chain greenwashing.

305 Given these assumptions and parameters, the three-party evolutionary game model for the NEV
306 supply chain yields eight strategy combinations. Table 2 presents the resulting payoff matrix.

307 **Table 2**

308 The payoff matrix for the tripartite game

NEVSs	NEVMs	GRAs	
		Strict Regulation (z)	Lenient Regulation ($1 - z$)
ESG (x)	ESG (y)	$R_s + \Delta R_s - C_s - \Delta C_s + B_s$ $R_m + \Delta R_m - C_m - \Delta C_m + B_m$	$R_s + \Delta R_s - C_s - \Delta C_s$ $R_m + \Delta R_m - C_m - \Delta C_m$

		$SE_{esg} - C_g - B_s - B_m$	$SE_{esg} - \theta C_g$
	Greenwashing (1 - y)	$R_s + \Delta R_s - C_s - \Delta C_s + B_s - R_{sc}L_s$ $R_m - C_m - P_m - L_m - C_{ms} - R_{pl} - R_{mr}R_m$ $SE_s - C_g - B_s + P_m$	$R_s + \Delta R_s - C_s - \Delta C_s - \theta R_{sc}L_s$ $R_m - C_m - L_m - C_{ms} - \theta R_{pl} -$ $\theta R_{mr}R_m$ $SE_s - \theta C_g$
	ESG (y)	$R_s - C_s - P_s - L_s - C_{ss} - R_{pl} - R_{mr}R_s$ $R_m + \Delta R_m - C_m - \Delta C_m + B_m - R_{sc}L_m$ $SE_m - C_g + P_s - B_m$	$R_s - C_s - L_s - C_{ss} - \theta R_{pl} - \theta R_{mr}R_s$ $R_m + \Delta R_m - C_m - \Delta C_m - \theta R_{sc}L_m$ $SE_m - \theta C_g$
Greenwashing (1 - x)	Greenwashing (1 - y)	$R_s - C_s - P_s - L_s - C_{ss} - R_{mr}R_s + C_{co} + R_{co}$ $R_m - C_m - P_m - L_m - C_{ms} - R_{mr}R_m + C_{co} +$ R_{co} $P_s + P_m - C_g - C_E$	$R_s - C_s - L_s - C_{ss} + C_{co} + R_{co} -$ $\theta R_{mr}R_s$ $R_m - C_m - L_m - C_{ms} + C_{co} + R_{co} -$ $\theta R_{mr}R_m$ $-\theta C_g - C_E$

309 4. Evolutionary stability analysis

310 4.1 Construction of replicator dynamics equations

311 For NEVSs, the payoff functions for adopting the ESG practices strategy and the greenwashing
312 strategy are denoted as U_{11} and U_{12} respectively. Thus, we have the following equation:

$$313 U_{11} = \Delta R_s - \Delta C_s - C_s + R_s + B_s z - [\theta(1 - y - z + yz) + z(1 - y)]L_s \quad (1)$$

$$314 U_{12} = (1 - y)(R_{co} + C_{co}) - C_s - C_{ss} - L_s + R_s - P_s z - [\theta(1 - z) + z]R_{mr}R_s - [\theta y(1 - z) + yz]R_{pl} \quad (2)$$

315 The average expected payoff function for NEVSs, U_1 , is calculated as: $U_1 = xU_{11} +$
316 $(1 - x)U_{12}$. The replicator dynamics equation, which is a differential equation representing the
317 growth rate of probability over time, for NEVSs is given by:

$$318 F(x) = \frac{dx}{dt} = x[U_{11} - U_1] = x(1 - x)[C_{ss} - C_{co} - \Delta C_s + \Delta R_s + L_s - R_{co} - \theta L_s R_{sc} + \theta R_{mr}R_s + (C_{co} + R_{co} + \theta L_s R_{sc} + \theta R_{pl})y +$$

$$319 (B_s + P_s + (1 - \theta)(R_{mr}R_s - L_s R_{sc}))z + (1 - \theta)(R_{pl} + L_s R_{sc})yz] \quad (3)$$

320 Similarly, the replicator dynamics equations for NEVMs and GRAs can be derived as follows:

$$321 F(y) = \frac{dy}{dt} = y[U_{21} - U_2] = y(1 - y)[C_{ms} - C_{co} - \Delta C_m + \Delta R_m + L_m - R_{co} - \theta(L_m R_{sc} - R_{mr}R_m) + (C_{co} + R_{co} + \theta(L_m R_{sc} +$$

$$322 R_{pl})x + (B_m + P_m - (\theta - 1)(L_m R_{sc} + R_{mr}R_m))z + (1 - \theta)(R_{pl} + L_m R_{sc})xz] \quad (4)$$

$$323 F(z) = \frac{dz}{dt} = z[U_{31} - U_3] = z(z - 1)[(1 + \theta)C_g - P_m - P_s + (B_s + P_s)x + (B_m + P_m)y] \quad (5)$$

324 Here, U_{21} and U_{22} represent the payoff functions for NEVMs when adopting ESG practices
325 and greenwashing strategies, respectively. Similarly, U_{31} and U_{32} denote the payoff functions for
326 GRAs when implementing strict and lenient regulation strategies, respectively. Detailed formulas
327 and derivations for these functions are provided in Appendix A.

328 **4.2 Analysis of game evolution path**

329 This section analyses the evolutionary stability strategies of NEVSs, NEVMs, and GRAs.

330 4.2.1 Evolutionary stability analysis of NEVSs

331 The stability of the replicator dynamics equation for NEVSs must satisfy $F(x) = 0$ and
 332 $dF(x)/dx < 0$. At this point, x is the evolutionary stable point for NEVSs. Based on equation (1),
 333 we obtain:

334
$$\frac{dF(x)}{dx} = (1 - 2x)(A_1 + B_1y + C_1z + D_1yz) \quad (6)$$

335 Where $A_1 = C_{ss} - C_{co} - \Delta C_s + \Delta R_s + L_s - R_{co} - \theta(L_s R_{sc} - R_{mr} R_s)$, $B_1 = (C_{co} + R_{co} +$
 336 $\theta(L_s R_{sc} + R_{pl}))$, and $C_1 = B_s + P_s - (1 - \theta)(L_s R_{sc} + R_{mr} R_s)$, $D_1 = (1 - \theta)(R_{pl} + L_s R_{sc})$. To
 337 further simplify the analysis, we let $I(z) = (A_1 + B_1y + C_1z + D_1yz)$.

338 If $0 < z = z^* = \frac{-A_1 - B_1y}{C_1 + D_1y} < 1$, $I(z^*) = 0$, and $F(x) = 0$ is always satisfied, this indicates
 339 that the game system is in a stable state, as shown in Fig. 2(a). The surface in the figure divides the
 340 strategy space into two regions, I and II, with the ESS of the supply chain on the shaded surface.
 341 This implies that if the probability of strict government regulation is fixed at z^* , the probability of
 342 ESG practice among NEVSs in the supply chain is uncertain but stable. If $0 < z < z^* = \frac{-A_1 - B_1y}{C_1 + D_1y} <$
 343 1 , $I(z) < 0$, then $F'(0) < 0$, $F'(1) > 0$. In this case, $x^* = 0$ is the ESS, corresponding to the
 344 replicator dynamics equation shown in Fig. 2(b). Here, the initial state of the NEVSs is in region II
 345 of the strategy space, and they will eventually choose greenwashing. If $0 < z^* = \frac{-A_1 - B_1y}{C_1 + D_1y} < z <$
 346 1 , $I(z) > 0$, then $F'(0) > 0$, $F'(1) < 0$. In this scenario, $x^* = 1$ is the ESS, corresponding to the
 347 replicator dynamics equation shown in Fig. 2(c). Here, the initial state of NEVSs is in region I of
 348 the strategy space, and they will ultimately choose ESG practices.

349 4.2.2 Evolutionary stability analysis of NEVMs

350 The stability analysis for the replicator dynamics equation for NEVMs must satisfy $F(y) = 0$
 351 and $dF(y)/dy < 0$. At this point, y is the evolutionary stable point for NEVMs. Based on
 352 equation (2), we derive:

353 $\frac{dF(y)}{dy} = (1 - 2y)(A_2 + B_2x + C_2z + D_2xz)$ (7)

354 Where $A_2 = C_{ms} - C_{co} - \Delta C_m + \Delta R_m + L_m - R_{co} - \theta(L_m R_{sc} - R_{mr} R_m)$, $B_1 = C_{co} +$
 355 $R_{co} + \theta(L_m R_{sc} + R_{pl})$, and $C_1 = B_m + P_m + (1 - \theta)(R_{mr} R_m - L_m R_{sc})$, $D_1 = (1 - \theta)(R_{pl} +$
 356 $L_m R_{sc})$. To further simplify the analysis, we let $J(z) = (A_2 + B_2x + C_2z + D_2xz)$.

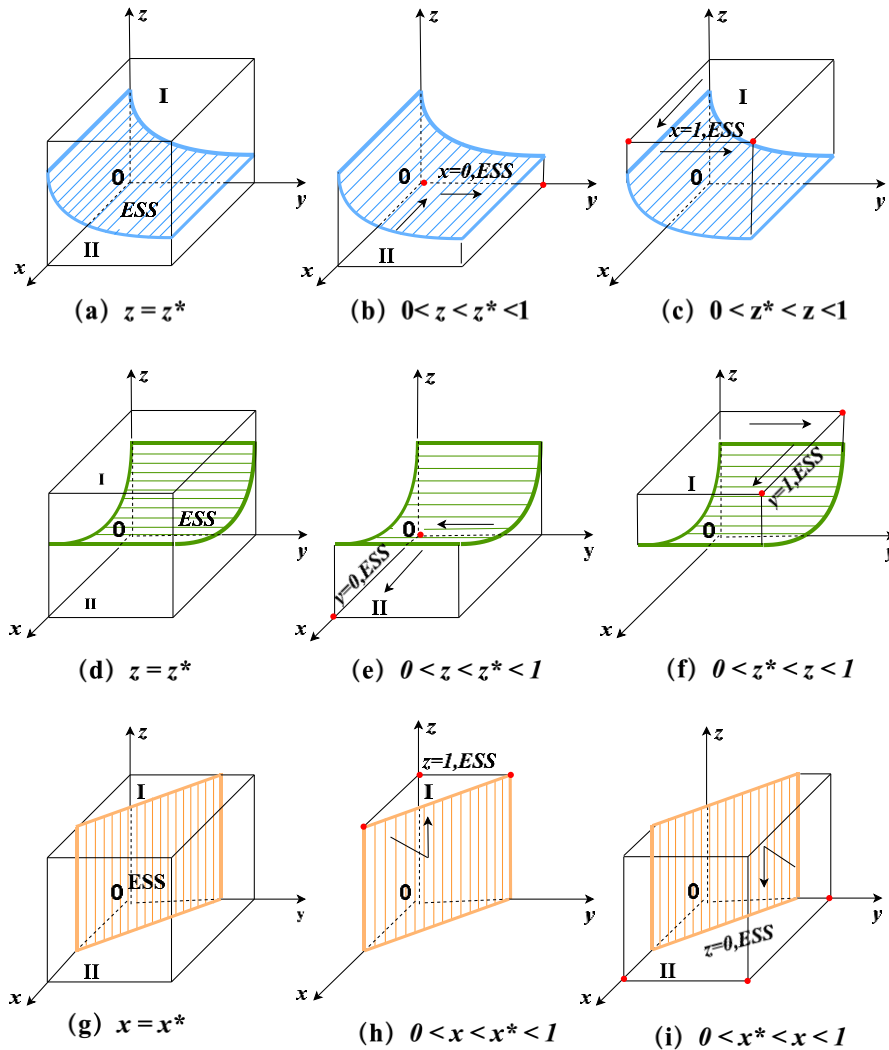
357 If $0 < z = z^* = \frac{-A_2 - B_2x}{C_2 + D_2x} < 1, J(z^*) = 0$, and $F(y) = 0$ is always satisfied, this indicates that
 358 the game system is in a stable state, as shown in Fig. 2(d). The shaded area in the figure divides the
 359 strategy space into two regions, I and II, with the ESS of the supply chain located on the shaded
 360 area. This implies that if the probability of strict government regulation is fixed at z^* , the probability
 361 of ESG practice among NEVSs in the supply chain is uncertain, but stable. If $0 < z < z^* =$
 362 $\frac{-A_2 - B_2x}{C_2 + D_2x} < 1, J(z) < 0$, then $F'(0) < 0, F'(1) > 0$. In this case, $y^* = 0 = 0$ is the ESS,
 363 corresponding to the replicator dynamics equation shown in Fig. 2(e). Here, the initial state of
 364 NEVMs is in region II of the strategy space, and they will eventually choose greenwashing. If $0 <$
 365 $z^* < z < 1, J(z) > 0$, then $F'(0) > 0, F'(1) < 0$. In this scenario, $y^* = 1$ is the ESS,
 366 corresponding to the replicator dynamics equation shown in Fig. 3(f). Here, the initial state of
 367 NEVMs is in the region I of the strategy space, and they will eventually choose ESG practices.

368 4.2.3 Evolutionary stability analysis of GRAs

369 The stability of the replicator dynamics equation for the government must satisfy $F(z) = 0$
 370 and $dF(z)/dz < 0$. At this point, z is the evolutionarily stable point for the government. Based
 371 on equation (3), we derive: $dF(z)/dz = (2z - 1)[(1 + \theta)C_g - P_m - P_s + (B_s + P_s)x + (B_m +$
 372 $P_m)y]$. Let $K(x) = (1 + \theta)C_g + P_s(x - 1) + P_m(y - 1) + B_sx + B_my$, when $x^* =$
 373 $\frac{[P_s + P_m - C_g - \theta C_g - (B_m + P_m)y]}{(B_s + P_s)}$, $K(x) = 0$.

374 If $0 < x = x^* < 1, K(x^*) = 0$, and $F(z) = 0$ is always satisfied, this indicates that the game
 375 system is in a stable state, as shown in Fig. 2(g). The shaded area in the figure divides the strategy
 376 space into two regions, I and II, with the government's ESS located on the shaded area. This implies
 377 that if the probability of ESG practice by NEVSs is fixed at x^* , the probability of the government
 378 choosing strict regulation is uncertain, but stable. If $0 < x < x^* < 1$, and $K(x) < 0$, then $F'(0) >$

379 $0, F'(1) < 0$. In this case, $z^* = 1$ is the ESS, corresponding to the replicator dynamics equation
 380 shown in Fig. 2(h). Here, the initial state of the government is in region I of the strategy space, and
 381 it will eventually choose the strict regulation strategy. If $0 < x^* < x < 1$, and $K(x) > 0$, then
 382 $F'(0) < 0, F'(1) > 0$. In this scenario, $z^* = 0$ is the ESS, corresponding to the replicator
 383 dynamics equation shown in Fig. 2(i). Here, the initial state of the government is in region II of the
 384 strategy space, and it will eventually choose the lenient regulation strategy.



385
 386

Fig. 2. Dynamic evolution path of NEVs, NEVMs, GRAs strategies.

387 4.3 System stability analysis

388 Based on the above analysis, the equation system $F(x), F(y), F(z)$ is constructed into a three-
 389 dimensional dynamic system $F(x, y, z)$:

$$\begin{cases}
F(x) = x(1-x) \left[C_{ss} - C_{co} - \Delta C_s + \Delta R_s + L_s - R_{co} - \theta L_s R_{sc} + \theta R_{mr} R_s + (C_{co} + R_{co} + \theta L_s R_{sc} + \theta R_{pl}) y \right. \\
\quad \left. + (B_s + P_s + (1-\theta)(R_{mr} R_s - L_s R_{sc})) z + (1-\theta)(R_{pl} + L_s R_{sc}) y z \right] \\
F(y) = y(1-y) \left[C_{ms} - C_{co} - \Delta C_m + \Delta R_m + L_m - R_{co} - \theta(L_m R_{sc} - R_{mr} R_m) + (C_{co} + R_{co} + \theta(L_m R_{sc} + R_{pl})) x \right. \\
\quad \left. + (B_m + P_m - (\theta-1)(L_m R_{sc} + R_{mr} R_m)) z + (1-\theta)(R_{pl} + L_m R_{sc}) x z \right] \\
F(z) = z(z-1) [(1+\theta)C_g - P_m - P_s + (B_s + P_s)x + (B_m + P_m)y]
\end{cases} \quad (8)$$

391 Setting $F(x, y, z) = 0$ yields 8 pure strategy equilibrium points (E_1 to E_8), as ESS exists
392 only in pure strategies (Friedman, 1991). These points represent the dynamic evolutionary
393 equilibrium strategies. According to Lyapunov's first law, a local equilibrium point is confirmed to
394 be gradually stable only if all the eigenvalues of the Jacobian matrix of the system are negative. The
395 eigenvalues of each equilibrium point are calculated, as shown in Table 3. The Jacobian matrix is:

$$J = \begin{bmatrix} \frac{\partial F(x)}{\partial x} & \frac{\partial F(x)}{\partial y} & \frac{\partial F(x)}{\partial z} \\ \frac{\partial F(y)}{\partial x} & \frac{\partial F(y)}{\partial y} & \frac{\partial F(y)}{\partial z} \\ \frac{\partial F(z)}{\partial x} & \frac{\partial F(z)}{\partial y} & \frac{\partial F(z)}{\partial z} \end{bmatrix} \quad (9)$$

397 **Table 3**
398 Jacobian matrix eigenvalues corresponding to each equilibrium point.

Equilibrium Point	λ_1	λ_2	λ_3	stability
(0,0,0)	$P_m - C_g + P_s + \theta C_g$	$C_{ms} - C_{co} - \Delta C_m + \Delta R_m + L_m - R_{co} - \theta L_m R_{sc} + \theta R_{mr} R_m$	$C_{ss} - C_{co} - \Delta C_s + \Delta R_s + L_s - R_{co} - \theta L_s R_{sc} + \theta R_s R_{mr}$	Conditional ESS
(1,0,0)	$P_m - C_g - B_s + \theta C_g$	$C_{ms} - \Delta C_m + \Delta R_m + L_m + \theta R_{pl} + \theta R_m R_{mr}$	$C_{co} - C_{ss} + \Delta C_s - \Delta R_s - L_s + R_{co} + \theta L_s R_{sc} - \theta R_s R_{mr}$	Conditional ESS
(0,1,0)	$P_s - C_g - B_m + \theta C_g$	$C_{ss} - \Delta C_s + \Delta R_s + L_s + \theta R_{pl} + \theta R_s R_{mr}$	$C_{co} - C_{ms} + \Delta C_m - \Delta R_m - L_m + R_{co} + \theta L_m R_{sc} - \theta R_m R_{mr}$	Conditional ESS
(0,0,1)	$C_g - P_m - P_s - \theta C_g$	$B_m - C_{co} + C_{ms} - \Delta C_m + \Delta R_m + L_m + P_m - R_{co} + R_m R_{mr} - L_m R_{sc}$	$B_s - C_{co} + C_{ss} - \Delta C_s + \Delta R_s + L_s + P_s - R_{co} + R_s R_{mr} - L_s R_{sc}$	Conditional ESS
(1,0,1)	$B_s + C_g - P_m - \theta C_g$	$B_m + C_{ms} - \Delta C_m + \Delta R_m + L_m + P_m + R_{pl} + R_m R_{mr}$	$C_{co} - B_s - C_{ss} + \Delta C_s - \Delta R_s - L_s - P_s + R_{co} - R_s R_{mr} + L_s R_{sc}$	Conditional ESS
(0,1,1)	$B_m + C_g - P_s - \theta C_g$	$B_s + C_{ss} - \Delta C_s + \Delta R_s + L_s + P_s + R_{pl} + R_s R_{mr}$	$C_{co} - B_m - C_{ms} + \Delta C_m - \Delta R_m - L_m - P_m + R_{co} - R_m R_{mr} + L_m R_{sc}$	Conditional ESS
(1,1,0)	$\theta C_g - B_s - C_g - B_m$	$\Delta C_m - C_{ms} - \Delta R_m - L_m - \theta R_{pl} - \theta R_m R_{mr}$	$\Delta C_s - C_{ss} - \Delta R_s - L_s - \theta R_{pl} - \theta R_s R_{mr}$	Conditional ESS
(1,1,1)	$B_m + B_s + C_g - \theta C_g$	$\Delta C_m - C_{ms} - B_m - \Delta R_m - L_m - P_m - R_{pl} - R_m R_{mr}$	$\Delta C_s - C_{ss} - B_s - \Delta R_s - L_s - P_s - R_{pl} - R_s R_{mr}$	instability

399
400 By analyzing the eigenvalues of the Jacobian matrix yields five key propositions. Through
401 system stability analysis, this study aligns the five propositions with different stages of ESG
402 development in the NEV industry, demonstrating the evolution of corporate behaviours strategies at
403 each stage, as shown in Table 4.

404 **Table 4**
405 Stability conditions of equilibrium points.

Equilibrium Point	Stability Conditions	Proposition	Stage
(0,0,0)	$P_s \downarrow, P_m \downarrow, \Delta C_s \uparrow, \Delta C_m \uparrow, R_{co} \uparrow, C_{co} \uparrow$	<i>Proposition 1</i>	Initial
(1,0,0)	$P_s \sim, P_m \sim, \Delta C_s \sim, \Delta R_s \uparrow, \Delta C_m \sim, R_{co} \sim, C_{co} \sim$	<i>Proposition 2</i>	Transitional
(0,1,0)	$P_s \sim, P_m \sim, \Delta C_s \sim, \Delta R_m \uparrow, \Delta C_m \sim, R_{co} \sim, C_{co} \sim$	<i>Proposition 2</i>	Transitional

(0,0,1)	$P_s \uparrow, P_m \uparrow, \Delta R_s < \Delta C_s, \Delta R_m < \Delta C_m$	Proposition 3	Transitional
(1,0,1)	$P_m \uparrow, B_s \downarrow, \Delta C_s \sim, \Delta C_m \sim, \Delta R_s \uparrow, \Delta R_m \sim, R_{c0} \sim, C_{co} \sim$ $\Delta(\Delta R_s - \Delta C_s) \uparrow$	Proposition 3	Transitional
(0,1,1)	$P_s \uparrow, B_m \downarrow, \Delta C_s \sim, \Delta C_m \sim, \Delta R_s \sim, \Delta R_m \uparrow, R_{c0} \sim, C_{co} \sim$ $\Delta(\Delta R_m - \Delta C_m) \uparrow$	Proposition 4	Transitional
(1,1,0)	$\Delta R_s > \Delta C_s; \Delta R_m > \Delta C_m$	Proposition 5	Mature

Note : \uparrow means the value increases, \downarrow means the value decreases, \sim means the value keeps the same, and $\Delta(\Delta - \Delta)$ means the differential difference.

Proposition 1: When $C_g - (P_m + P_s) > \theta C_g, \Delta R_s - \Delta C_s - \theta L_s R_{sc} < R_{c0} - (C_{ss} - C_{co}) - L_s - \theta R_s R_{mr}, \Delta R_m - \Delta C_m - \theta L_m R_{sc} < R_{c0} - (C_{ms} - C_{co}) - L_m - \theta R_s R_{mr}$, the corresponding evolutionarily stable strategy is {Greenwashing, Greenwashing, Lenient Regulation}, denoted as $E_1(0,0,0)$.

This proposition indicates that when the cost of strict regulation is significantly high for GRAs and the penalties for greenwashing by NEVSs and NEVMs are relatively low, the GRAs tend to adopt a lenient regulatory strategy, while companies opt for greenwashing to reduce costs and rapidly increase market competitiveness. This scenario typically occurs in environments lacking effective regulation and market pressure, as illustrated in Fig. 3(a). For policymakers, it emphasizes the need to establish regulatory mechanisms, particularly in the industry's early stages. For companies, this underscores the importance of prioritizing long-term sustainability over short-term cost-saving, given the dynamic nature of regulatory and market environments in maturing industries.

Proposition 2: When $C_g + B_s - P_m > \theta C_g, \Delta R_s - \Delta C_s - \theta L_s R_{sc} > R_{c0} - (C_{ss} - C_{co}) - L_s - \theta R_s R_{mr}, \Delta R_m - \Delta C_m < -(C_{ms} + L_m + \theta R_{pl} + \theta R_m R_{mr})$, the evolutionary stable strategy is {ESG Practices, Greenwashing, Lenient Regulation}, denoted as $E_2(1,0,0)$.

This proposition suggests that as ESG investment concepts deepen, even under lenient government regulation, NEVSs may opt for voluntary ESG information disclosure. The benefits of this will outweigh the indirect impact of greenwashing by supply chain partners, resulting in a mixed strategy where NEVSs choose ESG Practices. The evolutionary result is shown in Fig. 3(b). Similarly, when $P_s - C_g - B_m < -\theta C_g, \Delta R_s - \Delta C_s < -(C_{ss} + L_s + \theta R_{pl} + \theta R_s R_{mr}), \Delta R_s - \Delta C_s < -(C_{ss} + L_s + \theta R_{pl} + \theta R_s R_{mr})$, and $\Delta R_m - \Delta C_m - \theta L_m R_{sc} > R_{c0} - (C_{ms} - C_{co}) - L_m - \theta R_m R_{mr}$, the equilibrium point $E_3(0,1,0)$ is the ESS, corresponding to the evolutionarily stable strategy {Greenwashing, ESG Practices, Lenient Regulation}.

432 This finding implies that market forces can drive ESG adoption even under lenient government
 433 regulation. For policymakers, this suggests complementing direct regulation with strategies to
 434 nurture market demand for ESG practices, such as enhancing consumer environmental awareness
 435 through public education and transparent information disclosure. For companies, proactive ESG
 436 adoption may confer competitive advantages, particularly in environmentally conscious markets.
 437 However, firms must also remain vigilant about potential reputational impacts from their supply
 438 chain partners' behaviours.

439 **Proposition 3:** When $(P_m + P_s) - C_g > -\theta C_g$, $\Delta R_m - \Delta C_m + B_m - L_m R_{sc} < R_{c0} -$
 440 $(C_{ms} - C_{co}) - L_m - P_m - R_m R_{mr}$, $\Delta R_s - \Delta C_s + B_s - L_s R_{sc} < R_{c0} - (C_{ss} - C_{co}) - L_s - P_s -$
 441 $R_s R_{mr}$, the corresponding evolutionarily stable strategy is {Greenwashing, Greenwashing, Strict
 442 Regulation}, denoted as $E_4(0,0,1)$.

443 This proposition indicates that under strict regulation, the total revenue from penalties exceeds
 444 that from lenient regulation, prompting the government to adopt a strict regulatory strategy.
 445 However, due to policy implementation lag, the economic benefits of ESG practices remain lower
 446 than the economic incentives for collusive greenwashing, leading stakeholders in the supply chain
 447 to tend towards collusive greenwashing. The evolutionary outcome of this scenario is illustrated in
 448 Fig. 3(c). This finding reveals the potential unintended effects of stringent regulation, where firms
 449 may engage in collective deception if ESG costs outweigh greenwashing risks. For policymakers,
 450 this suggests complementing punitive measures with incentives to reduce ESG implementation
 451 costs. For corporations, it emphasizes cultivating supply chain-wide transparency and integrity to
 452 prevent collective deceptive practices.

453 **Proposition 4:** When $(B_s + C_g) - P_m > \theta C_g$, $\Delta R_s - \Delta C_s - L_s R_{sc} + B_s > R_{c0} - (C_{ss} -$
 454 $C_{co}) - L_s - P_s - R_s R_{mr}$, and $\Delta R_m - \Delta C_m < -(B_m + C_{ms} + L_m + P_m + R_{pl} + R_m R_{mr})$, the
 455 corresponding evolutionarily stable strategy is {ESG Practices, Greenwashing, Strict Regulation},
 456 denoted as $E_5(1,0,1)$.

457 Proposition 4 indicates that under strict government regulation, NEVSs opt for ESG practices
 458 due to higher benefits, while NEVMs may choose to greenwash if ESG costs are excessive. In this
 459 case, the equilibrium point $E_5(1,0,1)$ is the ESS, corresponding to the evolutionarily stable

460 strategy {ESG Practices, Greenwashing, Strict Regulation}. Similarly, when $\theta C_g > (B_m + C_g) -$
461 P_s , $\Delta R_s - \Delta C_s < -(B_s + C_{ss} + L_s + P_s + R_{pl} + R_s R_{mr})$, and $\Delta R_m - \Delta C_m - L_m R_{sc} + B_m >$
462 $R_{c0} - (C_{ms} - C_{co}) - L_m - P_m - R_m R_{mr}$, the equilibrium point $E_6(0,1,1)$ is the ESS,
463 corresponding to the evolutionarily stable strategy {Greenwashing, ESG Practices, Strict
464 Regulation}. The evolutionary outcome of this scenario is depicted in Fig. 3(d). For policymakers,
465 it suggests tailoring regulations to specific segments, potentially offering more support for those
466 with higher ESG implementation costs. For businesses, this highlights the critical importance of
467 supply chain collaboration. ESG practices adopted by upstream entities may create both pressures
468 and opportunities for downstream counterparts. Consequently, firms need to develop comprehensive
469 supply chain ESG strategies.

470 **Proposition 5:** When $\theta C_g < C_g + (B_s + B_m)$, $\Delta R_m > \Delta C_m$, $\Delta R_s > \Delta C_s$, the corresponding
471 evolutionarily stable strategy is {ESG Practices, ESG Practices, Lenient Regulation}, i.e.,
472 $E_7(1,1,0)$.

473 This proposition delineates an ideal state where the entire supply chain voluntarily adopts ESG
474 practices under moderate regulation. Due to the continuous strict regulation in the previous stage,
475 the risk of greenwashing in the supply chain increases, reducing the extra cost savings and economic
476 incentives from collusive greenwashing. Concurrently, strict regulation coupled with rewards and
477 subsidies for ESG practices has stimulated supply chain entities to improve green innovation
478 technologies, thereby reducing the costs of ESG practices. The evolutionary outcome of this
479 scenario is illustrated in Fig. 3(e). For policymakers, this suggests that the ultimate regulatory goal
480 should be to nurture a self-disciplined industry ecosystem. A gradual transition from strict regulation
481 to market-oriented incentive mechanisms can be considered. For businesses, this highlights the
482 importance of integrating ESG practices into core operations. Companies should focus on
483 innovations that reduce ESG implementation costs and develop business models where these
484 practices create economic value.

485 Based on the above analysis, $E_7(1,1,0)$ represents an ideal state where NEVSs and NEVMs
486 can effectively self-regulate under the government's lenient regulation strategy. In this state, the
487 entire supply chain actively adheres to ESG principles without engaging in greenwashing practices.
488 In conclusion, these five propositions collectively illustrate the dynamic evolution of ESG practices

489 in the NEV industry supply chain. They demonstrate a progression from an initial state of
 490 widespread greenwashing (Proposition 1) through various transitional stages (Propositions 2-4) to
 491 a mature state of voluntary ESG adoption (Proposition 5). This evolution is driven by the interplay
 492 of regulatory pressures, market forces, and changing cost-benefit dynamics of ESG practices.
 493 Policymakers are advised to adopt a nuanced approach that combines regulatory mechanisms with
 494 market-oriented incentives, while businesses are encouraged to view ESG practices as a long-term
 495 strategic imperative rather than a mere compliance issue.

496 5. Numerical simulation

497 5.1 System evolution trajectory simulation

498 This section validates the theoretical results and analysis of Section 3 through numerical
 499 simulation experiments. Based on the replicator dynamics equations and ESS conditions, MATLAB
 500 R2022a is used to simulate the dynamic strategy evolution paths of stakeholders and explore the
 501 impact of various factors on their decision-making. To ensure the reasonableness of the numerical
 502 examples, the model parameter values are calibrated based on relevant literature parameters (Table
 503 5) (Zheng et al., 2023; Liu et al., 2023; Zhang et al., 2024).

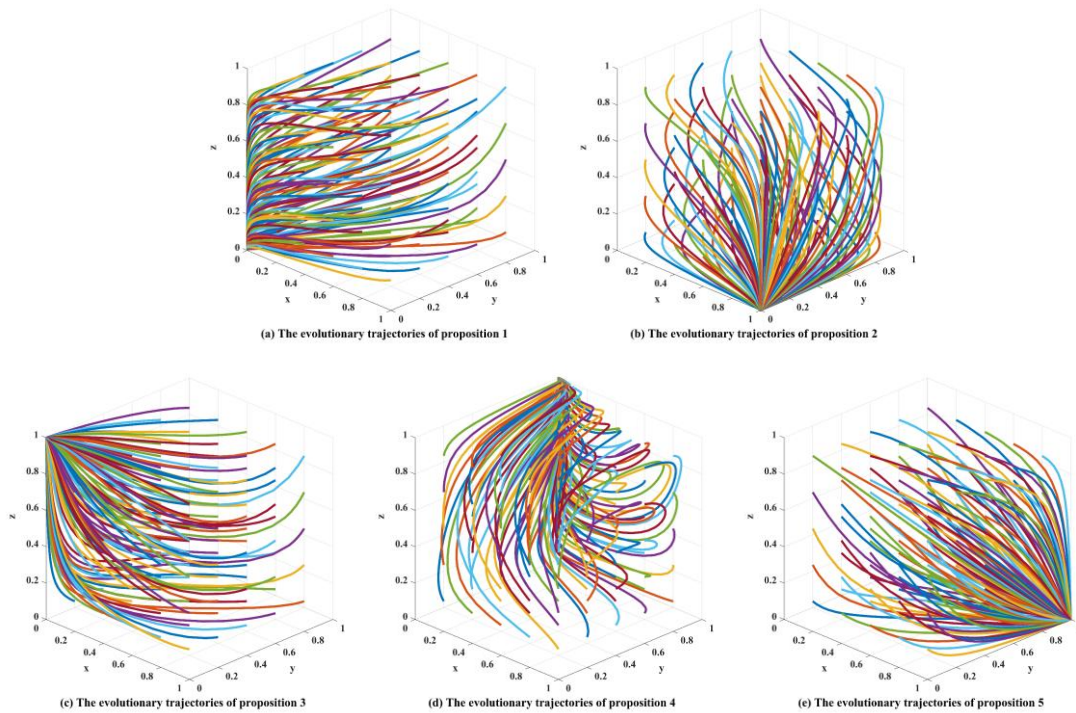
504 **Table 5**

505 Parameter settings for different ESS scenarios.

Parameter	Array 1	Array 2	Array 3	Array 4	Array 5
ΔC_s	70	20	80	80	50
ΔR_s	50	50	50	50	60
ΔC_m	70	20	80	50	50
ΔR_m	50	5	50	60	60
C_g	10	20	30	30	20
P_s, P_m	2	2	20	20	2
R_{co}, C_{co}	10	10	5	5	3

506 Setting the initial probabilities of (x, y, z) to $(0.5, 0.5, 0.5)$, the evolution paths of arrays 1-5
 507 are shown in Fig. 3(a)-(e). All x, y, z curves converge to different ESS points. System simulation
 508 is used to model and observe the system's evolutionary behaviour of the system under specific
 509 parameter conditions, while sensitivity analysis further explores the impact of parameter changes

510 on system behaviour. By combining these two methods, we can gain a more comprehensive
 511 understanding of the dynamic process of ESG practices in the supply chain and how to promote
 512 sustainable development by adjusting key parameters. Therefore, the following sensitivity analysis
 513 aims to further explore the impact of different factors on the ESS.



514
 515 **Fig. 3.** Evolutionary paths of the tripartite game

516 **5.2 Sensitivity analysis**

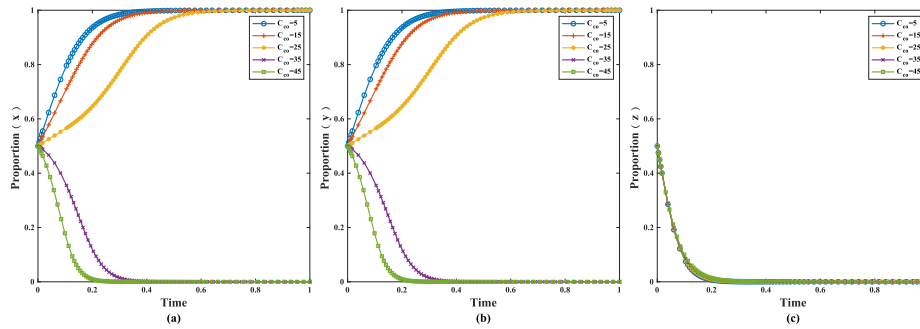
517 **5.2.1 Single-factor sensitivity analysis**

518 In this section, the primary influencing factors selected include the cost savings of collusive
 519 greenwashing (C_{co}), the benefits of collusive greenwashing (R_{co}), the costs of supplier ESG
 520 practices (ΔC_s), the costs of NEVMs ESG practices (ΔC_m). These factors are used to explore the
 521 evolutionary characteristics of the system. Based on the previous analysis, our goal is to achieve the
 522 strategy combination $E_7(1,1,0)$ by promoting the participants in the evolutionary game. Therefore,
 523 the initial values of the relevant parameters are consistent with Table 5.

524 (1) The cost savings of collusive greenwashing

525 The cost savings of collusive greenwashing mainly refer to the expenses saved by enterprises
 526 in avoiding compliance costs. For example, companies might save on operating and maintenance

527 costs by not investing in environmental technology or facilities, or they might reduce procurement
 528 costs by using cheaper materials and production processes with lower environmental standards. To
 529 study the impact of different C_{CO} on the strategy choices of the three parties in the supply chain
 530 under $E_7(1,1,0)$, different cost savings C_{CO} are set to (5,15,25,35,45). Fig. 4 shows the
 531 simulation results for different C_{CO} settings.



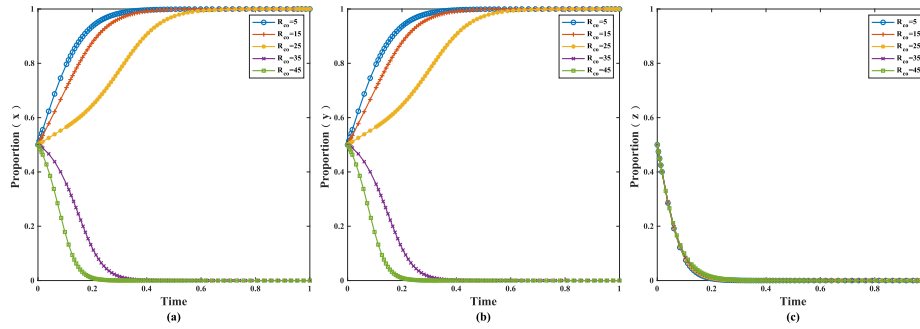
532
 533 **Fig. 4.** Evolutionary results under different C_{CO}

534 In Fig. 4(a)-(b), when $C_{CO} \leq 25$, the speed at which x and y converge to 1 gradually slows
 535 down as C_{CO} increases; when $C_{CO} > 25$, the speed of convergence accelerates, and x and y
 536 converge to 0. This indicates that the supply chain tends to adopt greenwashing behaviour as C_{CO}
 537 increases. Fig. 4(c) shows that the probability z of the government's strict regulation strategy
 538 increases slowly with C_{CO} . This may be because the government recognizes the increase in
 539 greenwashing behaviour and attempts to curb this trend by strengthening regulation. However, the
 540 slow growth rate of z indicates that the government's efforts to enhance regulation do not keep pace
 541 with the increase in greenwashing behaviour by NEVSs and NEVMs, possibly due to a regulatory
 542 lag, which prevents the government from fully curbing collusive greenwashing behaviour. This
 543 finding highlights the need for companies to carefully weigh short-term gains against long-term
 544 risks of greenwashing. Policymakers should create stronger regulations to make greenwashing costs
 545 exceed its benefits, encouraging genuine ESG practices.

546 (2) The benefits of collusive greenwashing

547 When collusion within the supply chain involves greenwashing, enterprises typically gain
 548 direct financial benefits by reducing environmental investments. The extra benefits of collusive
 549 greenwashing are mainly reflected in two aspects: firstly, reducing environmental investments
 550 reduces production costs, increasing marginal profits in the short run; secondly, under lenient

551 regulation, violating environmental regulations allows enterprises to produce at lower costs, gaining
 552 market competitiveness through price reductions. To describe the impact of the additional benefits
 553 of collusive greenwashing R_{CO} on the strategy choices of the three parties in the supply chain under
 554 $E_7(1,1,0)$, R_{CO} is set to (5,15,25,35,45). Fig. 5 shows the simulation results for different R_{CO}
 555 settings.

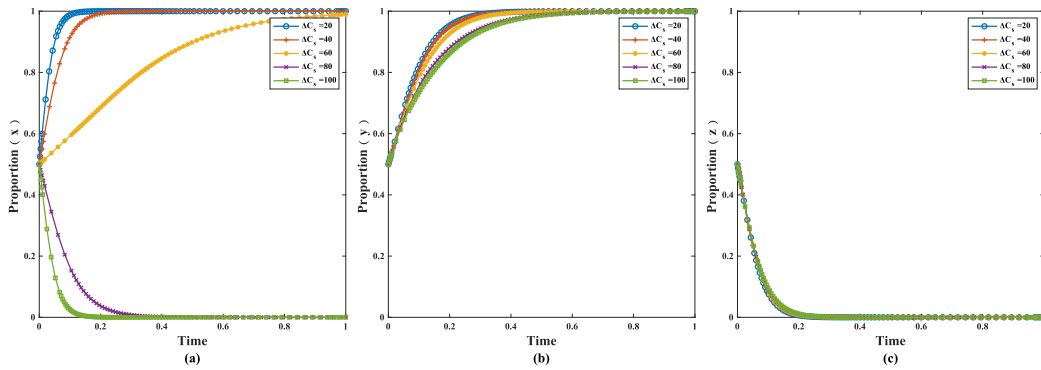


556
 557 **Fig. 5.** Evolutionary results under different R_{CO}

558 As shown in Fig. 5, as R_{CO} increases, enterprises in the supply chain are more inclined to
 559 adopt greenwashing strategies, while the probability of government regulation decreases, although
 560 the rate of decline is relatively slow. This may reflect a real-world situation, under the lure of high
 561 benefits, other participants in the supply chain might forsake environmental responsibility, and
 562 although the government attempts to maintain regulation, the regulatory effort may be insufficient
 563 to completely prevent greenwashing behaviour. In this scenario, corporate decision-makers must
 564 recognize that while greenwashing may offer short-term gains, it potentially jeopardizes long-term
 565 business sustainability and reputation. Concurrently, it is necessary to strengthen policy incentives
 566 and regulatory measures to effectively curb greenwashing behaviour in the supply chain and
 567 promote genuine ESG practices.

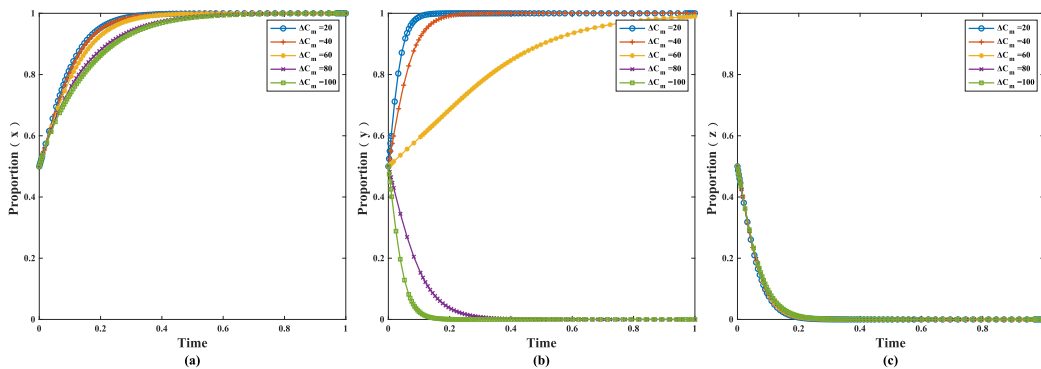
568 (3) The ESG practice costs in the supply chain

569 To describe the impact of the ESG practice costs ΔC_S and ΔC_m on the strategy choices of the
 570 three parties under the condition $E_5(1,1,0)$, ΔC_S and ΔC_m are set to (10, 15, 20, 30, 40). Fig. 6-7
 571 show the simulation results for different practice cost settings.



572
573

Fig. 6. Evolutionary results under different ΔC_s



574
575

Fig. 7. Evolutionary results under different ΔC_m

576 As shown in the figures, when the cost of ESG practice in the supply chain increases, the
 577 probability of choosing ESG practice strategies decreases significantly for both upstream and
 578 downstream supply chain participants. This impact is more pronounced for the party experiencing
 579 the cost increase and has cascading effects on the strategic decisions of its supply chain partners.
 580 These findings underscore the imperative for businesses to prioritize cost-efficient ESG
 581 implementation strategies. Policymakers and businesses should collaborate to balance cost
 582 pressures and maintain the momentum for sustainable development in the NEV supply chain
 583 through differentiated support policies, dynamic cost management, and technological innovation.

584 5.2.2 Two-factor sensitivity analysis

585 In the scenario represented by $E_1(0,0,0)$, NEVs and NEVMs in the supply chain collude to
 586 engage in greenwashing while the GRAs implement lenient regulation. From the perspective of
 587 sustainable development, this scenario is highly unfavourable. This reveals the widespread
 588 falsification of ESG reports in the NEV industry. Driven by lenient government regulation and
 589 market disorder, this practice harms consumer interests, hinders sustainable development goals, and

590 significantly deviates from the national dual carbon targets. The main purpose of this section is to
 591 explore how to prevent $E_1(0,0,0)$ from becoming a stable point by adjusting key factors. Table 6
 592 shows the evolution path and stability of the system under different two-factor sensitivity analysis.

593 **Table 6**
 594 **System evolution path and stability.**

Two-factor sensitivity analysis	System strategy evolution	stability
$(B_s \& P_s) \uparrow$	$(0,0,0) \rightarrow (*,0,*)$	instability
$(R_{sc} \& L_s) \uparrow$	Unchanged	ESS
$(R_{mr} \& R_s) \uparrow$	$(0,0,0) \rightarrow (1,*,0)$	instability

595 *Note: \uparrow means the value increases, * represents evolutionary strategy instability*

596 (1) The impact of reward and penalty on tripartite game strategies

597 To explore whether the system can deviate from the stable point $E_1(0,0,0)$ and establish a
 598 new stable point when the government strengthens regulatory incentives for a specific link in the
 599 supply chain. It also demonstrates the impact of government rewards (B_s) for ESG practices and
 600 penalties (P_s) for greenwashing on the strategic choices of three parties under $E_1(0,0,0)$. Let $B_s =$
 601 $P_s = (2,12,22)$. The simulation results are shown in Appendix B. Fig. S1. The results indicate that
 602 although increasing regulatory incentives for one part of the supply chain causes the system to
 603 deviate from the stable point $E_1(0,0,0)$, it does not establish a new stable point. This suggests that
 604 merely strengthening regulatory incentives for one segment of the supply chain may not be sufficient
 605 to drive the entire system toward a new stable state. These findings highlight the necessity for the
 606 government to comprehensively regulate ESG practices across the entire NEV industry supply chain.
 607 For policymakers, this means the need to design more comprehensive regulatory frameworks that
 608 consider the interplay between upstream and downstream in the supply chain.

609 (2) The impact of reputation risk on tripartite game strategies

610 To explore whether the system deviates from the stable point $E_1(0,0,0)$ to reach a new stable
 611 point when one party's greenwashing behaviour leads to an increase in the other party's indirect
 612 reputational loss. $R_{sc}L_s$ represents the indirect reputation risk loss caused by a partner's
 613 greenwashing behaviour. Let $R_{sc} = (0.3, 0.5, 0.8)$, and $L_s = (2, 7, 12)$. The simulation results are
 614 shown in Appendix B. Fig. S2. Despite the indirect impact of the reputation risk coefficient on the
 615 partner's revenue, the cooperative relationship within the supply chain remains strong, and both
 616 parties may continue to collude in greenwashing. This result underscores the complexity of internal
 617 relationships within supply chains. Policymakers should consider designing policy instruments that

618 can effectively disrupt collusion within supply chains, such as strengthening information disclosure
 619 requirements or establishing cross-enterprise ESG evaluation systems.

620 (3) The impact of market response on tripartite game strategies

621 To explore whether the increase of corporate revenue and market response coefficient will
 622 prompt the system to deviate from the initial stable point $E_1(0,0,0)$ and form a new stable point.
 623 The simulation results are shown in Appendix B. Fig. S3. Let market response coefficient $R_{mr} =$
 624 $(0.2,0.6,1)$, and the corporate revenue $R_s = (20,60,100)$. The results indicate that as corporate
 625 revenue R_s increases, the system tends to deviate from the initial stable point $E_1(0,0,0)$ and move
 626 towards a new stable state $(1,0,0)$. This suggests that a strong market reaction to greenwashing
 627 significantly encourages NEVSs to adopt ESG practice strategies. It demonstrates that even in the
 628 absence of strict government regulation, NEVSs have sufficient motivation to implement ESG
 629 measures to avoid reputation loss and sales decline when the market is highly sensitive to
 630 greenwashing behaviour. This finding emphasizes the critical role of market mechanisms in driving
 631 corporate sustainable development. For companies, it underscores the need to pay closer attention
 632 to market responses to ESG practices, positioning ESG strategies as core elements in enhancing
 633 brand value and market competitiveness.

634 5.2.3 Multi-factor sensitivity analysis

635 $E_1(0,0,0)$ and $E_4(0,0,1)$ represent scenarios where NEVSs and NEVMs in the supply chain
 636 engage in collusive greenwashing, while GRAs may adopt either lenient or strict regulation. From
 637 a sustainability perspective, these strategy set are suboptimal. This section aims to explore the
 638 evolutionary paths from the current states $E_1(0,0,0)$ and $E_4(0,0,1)$ towards the ideal state
 639 $E_7(1,1,0)$. Table 7 shows the evolution path and stability of the system under different multi-factor
 640 sensitivity analysis.

641 **Table 7**
 642 **System evolution path and stability.**

Multi-factor sensitivity analysis	System strategy evolution	stability
$(C_g \& B_s \& B_m) \uparrow$	$(0,0,0) \rightarrow (0,0,0)$	ESS
$(C_g \& P_s \& P_m) \uparrow$	$(0,0,0) \rightarrow (0,0,1)$	ESS
$(C_{co} \& R_{co}) \uparrow$	$(0,0,1) \rightarrow (*,*,*)$	instability
$(\Delta C_s \& \Delta C_m \& B_s \& B_m) \uparrow$	$(0,0,1) \rightarrow (1,1,0)$	ESS

643 *Note: \uparrow means the value increases, $*$ represents evolutionary strategy instability*

644 (1) The impact of different government incentives on the system evolution strategy

645 This section examines the impact of different government incentives on the system evolution
646 strategy, considering two main scenarios. The first scenario involves government subsidies for
647 corporate ESG practices being greater than the penalties for greenwashing, with parameters set to
648 $C_g = (10,20,30), B_s = B_m = (2,12,22)$. The second scenario involves government penalties for
649 corporate greenwashing being greater than the subsidies for ESG practices, with parameters set to
650 $C_g = (10,20,30), P_s = P_m = (2,12,22)$.

651 By comparing these two scenarios, the specific effects of different incentives on the evolution
652 of the supply chain can be observed. The simulation results are shown in Appendix B. Fig. S4-S5.
653 When the supply chain colludes in greenwashing, increasing rewards and subsidies for companies
654 implementing ESG practices alone may not effectively mitigate greenwashing behaviour. Instead,
655 it may lead to adverse events such as fraudulent subsidy and arbitrage. Increasing penalties for
656 greenwashing, on the other hand, increases government revenue and potentially shifts the stable
657 point from $E_1(0,0,0)$ to $E_4(0,0,1)$. This indicates that strengthening punitive measures may be
658 more effective than merely increasing rewards in addressing greenwashing issues in the supply
659 chain. For policymakers, this implies the need to design a regulatory system that balances rewards
660 and punishments, with an emphasis on increasing the costs of non-compliance for greenwashing.
661 Business managers should recognize that, in the long term, genuine ESG practices are more
662 beneficial to corporate development than short-term greenwashing.

663 (2) The evolution path analysis from transition to maturity stage

664 From the previous analysis, increasing government regulation, particularly penalties for
665 greenwashing, can facilitate the transition from the stable point $E_1(0,0,0)$ to $E_4(0,0,1)$. Next, the
666 conditions required for the transition from $E_1(0,0,0)$ to $E_7(1,1,0)$ are explored. In state
667 $E_4(0,0,1)$, if the government continues to strengthen regulation and penalty, based on the principle
668 that profit is inversely proportional to risk, the increased risk within the supply chain will reduce
669 the cost savings and additional benefits of collusive greenwashing, thereby decreasing its economic
670 attractiveness. By setting $C_{co} = R_{co} = (10,6,2)$, the simulation results are shown in Appendix B.
671 Fig. S6. Although increased government regulation reduces the economic attractiveness of
672 greenwashing, causing a deviation from the stable point, it does not completely transition to a new

673 stable point. This suggests that strengthening regulation alone is not sufficient to achieve a full
674 transition and that the conditions required for the market to transition from an unstable state to a
675 new stable should be further explored.

676 Combining the previous single-factor and two-factor sensitivity analyses, it is clear that simply
677 controlling one end of the supply chain will not achieve comprehensive ESG practices throughout
678 the supply chain. By readjusting the supply chain parameter configurations, setting $\Delta C_s = \Delta C_m =$
679 $(70,60,50)$, $B_s = B_m = (1,8,15)$ show that reducing ESG practice costs and increasing rewards
680 can transition the game to the ideal stable point $E_7(1,1,0)$ (Appendix B. Fig. S7). This process
681 demonstrates that low-cost ESG practices combined with government incentives drive companies
682 to continuously improve green innovation technologies, thereby reducing the cost of ESG practice.
683 These findings suggest that policymakers should adopt a multi-pronged approach, including
684 strengthening regulations, providing incentives, and supporting technological innovation. Business
685 managers should actively invest in green innovation technologies, continuously reducing the costs
686 of ESG practices, while seeking government support and industry cooperation to collectively
687 promote sustainable development across the entire supply chain.

688 In summary, the numerical simulations corroborate and extend the insights gained from the
689 theoretical propositions. The simulations highlight the critical role of reducing ESG implementation
690 costs, providing targeted incentives, and fostering market mechanisms that reward genuine ESG
691 practices. These findings underscore the need for policymakers to design flexible regulatory
692 frameworks that can adapt to the evolving dynamics of the NEV industry. For enterprises in the
693 NEV supply chain, the results emphasize the importance of investing in green innovation
694 technologies and developing long-term ESG strategies that anticipate.

695 **6. Discussion**

696 Our findings reveal that ESG practices in the NEV supply chain exhibit distinct phased
697 characteristics, transitioning from greenwashing in the initial stages to proactive ESG practices in
698 maturity. This novel insight advances our understanding of the dynamic nature of ESG
699 implementation in emerging industries.

700 During the growth stage, enterprises often lack the motivation for proactive ESG due to the

701 immature understanding and demands of the market concerning ESG. During the transition stage,
702 as market awareness and emphasis on ESG increase, and the government begins to strengthen the
703 formulation and enforcement of related regulations, enterprises start to gradually engage in ESG
704 practices. In this stage, companies begin to attempt ESG measures, but their actions might still be
705 exploratory or reactive changes driven by government and market pressures. This reflects the
706 transitional behaviour of companies adapting to new market demands and government policies,
707 shifting from purely cost considerations to ESG practices.

708 In the maturity stage, companies recognize the long-term benefits of ESG practices, such as
709 enhanced brand reputation and consumer trust (Asante-Appiah, 2020). ESG practices become an
710 integral part of corporate strategy, and companies proactively engage in ESG practices, thereby
711 promoting sustainable development within the NEV supply chain. Unlike traditional models
712 advocating for continuous strict government regulation(Zhang et al., 2022; Su, 2022; Liu et al.,
713 2023). Our study suggests that the government may adopt a more lenient regulatory strategy as
714 corporate proactivity in ESG compliance increases. This allows the government to reallocate
715 regulatory resources to emerging markets or less mature industries, optimizing overall resource
716 allocation.

717 Government strategies to combat greenwashing are critical throughout the development of
718 ESG practices. Our research finds that during the development of ESG practices, the government's
719 strategies for combating greenwashing adjust according to different practice stages. Initially, strict
720 punitive measures are essential to shift the supply chain from collusive greenwashing towards
721 genuine ESG practices. As the industry matures, the focus shifts towards subsidies and rewards,
722 encouraging green technological innovations and reducing ESG implementation costs. This phased
723 approach underscores the importance of dynamic government strategies in promoting supply chain
724 sustainability. Current academic research on government strategies for greenwashing governance
725 tends to offer relatively singular incentive policies, either focusing on punitive mechanisms as the
726 main strategy (Sun and Zhang, 2019; Zhang et al., 2022) or emphasizing reward and subsidy (Lu
727 and Yue, 2022; Liu et al., 2023; Zhang et al., 2024). Each approach reveals the effects of different
728 policy measures. However, our study proposes a phased ESG greenwashing governance strategy
729 that better aligns with the development of the NEV industry, providing theoretical and practical

730 guidance for formulating relevant policies to guide companies in ESG practices and strategic
731 planning.

732 This study examines the dynamic evolutionary mechanisms of ESG practices and
733 greenwashing behaviours in the NEV supply chain. We employed a macroscopic modelling
734 approach, using parameters such as total revenue, total cost, reputation risk coefficient, and partner
735 loss risk to reflect interactions among supply chain members, thus simplifying specific transaction
736 details. To better elucidate these interactions, we incorporated procurement parameters (P and Q)
737 into the model, enhancing its representation of transactional behaviours of supply chain member.
738 The revised model (detailed in Appendix C) maintains our core conclusions while offering new
739 insights into how transaction scale influences ESG practice adoption decisions. Results indicate that
740 supply chain transaction details only affect local revenue distribution without altering the system's
741 equilibrium state, further validating the robustness of our conclusions.

742 By employing game theory, this study provides a quantitative analytical framework to assess
743 the specific impacts of different policies on supply chain behaviour, complementing existing
744 qualitative analyses and case study-based research (Li et al., 2019; Lee & Raschke, 2023; Zhang et
745 al., 2023; Wang, 2024). Nevertheless, the model's assumptions in this study are simplified and may
746 not fully capture the complexity of reality. Future research should incorporate social network models
747 to analyze scenarios involving a broader range of stakeholders, enhancing the model's applicability
748 to real-world conditions. Additionally, we acknowledge that the limitation of our current study is
749 the lack of empirical validation, and we suggest that future research focus on testing and refining
750 the model using real-world data from the NEV industry to enhance its practical applicability.

751 **7. Conclusions and Policy Implications**

752 This section summarizes key conclusions and provides policy recommendations based on these
753 findings.

754 **7.1 Major findings**

755 (1) Phased Characteristics of ESG Practices in the Supply Chain

756 The ESG practices in the NEV supply chain demonstrate distinct phased characteristics. In the
757 early stages, companies often engage in greenwashing to reduce costs due to immature regulatory

758 and market awareness of ESG. During the transitional period, as the market's emphasis on ESG
759 increases and government regulation strengthens, companies transition to proactive ESG measures.
760 In the mature stage, companies have a deeper understanding of ESG, technological advancements
761 reduce the costs of ESG practices, and companies actively adopt and implement these measures.

762 (2) The dynamic stability of the supply chain depends on the interdependence

763 The dynamic stability of the supply chain relies not only on the strategy of a single participant
764 but also on the interdependence of all participants' strategies. If only one party of the supply chain
765 receives government incentives while others do not face corresponding incentives or pressures, the
766 overall behavioural pattern remains unchanged. Therefore, to achieve sustainable development, it is
767 necessary for the government to implement comprehensive ESG regulatory strategies across the
768 entire supply chain.

769 (3) Phased policy adjustments - From greenwashing to supply chain ESG practices

770 During the growth phase of ESG practices, the government's primary objective is to guide the
771 supply chain towards ESG practices. Simple reward and subsidy mechanisms may be ineffective
772 due to the difficulty of quantifying ESG practices and the risk of abuse. Strict punitive measures
773 significantly promote environmentally friendly behaviors by increasing non-compliance costs. As
774 the transition phase progresses towards maturity, it is recommended that the government focus more
775 on subsidies to encourage companies to adopt and improve green technologies, thereby reducing
776 the cost of ESG practices. As the cost of ESG practices decreases, companies are more likely to
777 adopt these practices proactively.

778 (4) The significant role of market forces in ESG practices and greenwashing

779 Market forces exert a significant influence on companies' strategic choices between ESG
780 practices and greenwashing. As market sensitivity to environmental issues increases, NEVMs face
781 pressure to implement substantial ESG measures rather than superficial greenwashing. This
782 emphasizes the important role of market and consumer awareness in influencing sustainable
783 corporate practices, which can be more effective than traditional government regulatory measures.
784 The natural market mechanism, which is based on consumer choice and the natural punishment of
785 dishonest behaviour—effectively forces companies to adopt more responsible ESG actions.
786 Furthermore, the model analysis indicates that as companies become more sensitive to market

787 reactions (increased R_{mr}) and their revenues rise, their perceived risk of greenwashing increases,
788 leading them to avoid greenwashing and turn to genuine ESG practices. This indicates that in
789 instances where market responses are pronounced and company revenues are considerable,
790 companies' behaviour will naturally tend towards more responsible and sustainable practices.

791 **7.2 Policy recommendations**

792 (1) Phased Comprehensive Regulatory Framework

793 In the growth phase of ESG practice, the government should establish a strict regulatory
794 framework, imposing heavy fines and sanctions on companies prone to greenwashing. This
795 increases the risks and costs associated with greenwashing, thereby discouraging such behaviour.
796 During the transition period, a more flexible policy approach is needed. The government can
797 gradually reduce direct penalties for greenwashing and instead adopt indirect incentives, such as tax
798 breaks or subsidies for companies that successfully implement ESG practices. At maturity, the
799 government should encourage and support companies in reducing ESG practice costs through
800 technological innovation while maintaining a certain level of regulation to ensure the long-term
801 sustainability of the industry. Meanwhile, to ensure the sustainable development of the entire
802 industry, it is imperative that the government implements a comprehensive regulatory framework
803 that encompasses the entire supply chain. This framework must ensure that all links in the chain,
804 from raw NEVSs to end NEVMs, comply with ESG standards.

805 (2) Public education and market guidance

806 The government should enhance public education to increase consumer awareness of the
807 importance of ESG, guiding market demand towards green consumption. It is recommended that
808 public campaigns and media should promote environmental awareness related to NEVs and set
809 consumer expectations for corporate ESG practices. This would create societal pressure against
810 greenwashing.

811 (3) Support for technological R&D and innovation

812 The government should allocate more resources to support R&D related to ESG, including the
813 use of clean energy, waste recycling, and the development of environmentally friendly materials.
814 Through financial support and tax incentives, companies can be motivated to pursue green
815 technological innovations, reducing the costs associated with ESG practices and enhancing their

816 market competitiveness.

817 (4) Strategic adaptation for the NEV supply chain members

818 Drawing on these findings, we propose the following recommendations for NEV Component
819 Suppliers (NEVSSs) and NEV Manufacturers (NEVMs): First, our analysis reveals that supply chain
820 stability depends on the interdependence of participants' strategies. NEVSSs and NEVMs should
821 align their ESG approaches to mitigate instabilities arising from unilateral actions. Secondly, firms
822 should adapt their ESG strategies according to the industry's developmental stage. During the initial
823 phase of stringent regulation, companies should focus on compliance and foundational ESG
824 practices. As the industry transitions, firms need to proactively implement ESG measures and
825 enhance reputation risk management. Thirdly, supply chain members should continuously monitor
826 market sensitivity to environmental issues. Our model indicates that the market reaction coefficient
827 (R_{mr}) significantly influences firms' strategic choices. Companies should establish effective
828 mechanisms to respond promptly to evolving market expectations regarding ESG practices. Finally,
829 NEVSSs and NEVMs should strive to reduce the costs associated with ESG practices. Firms should
830 invest in green technology innovations and actively seek government support to achieve more cost-
831 effective ESG practices. By implementing these recommendations, NEV supply chain members can
832 better manage greenwashing risks, seize market opportunities, and contribute to the industry's
833 sustainable development.

834 **Declaration of competing interest**

835 The authors declare that they have no known competing financial interests' relationships that could
836 have appeared to influence the work reported in this paper.

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1077

1 **Appendix A.**

2 In response to this valuable feedback, we have added the complete formulas for U_{21} , U_{22} , U_2 ,
3 U_{31} , U_{32} , and U_3 to the appendix of our manuscript. These formulas provide a comprehensive
4 mathematical representation of the payoff functions for NEVMs and GRAs.

5 For NEVMs, the payoff functions for adopting "ESG practices" strategy and "greenwashing"
6 strategy are U_{21} and U_{22} respectively, thus obtaining the following equation:

$$7 \quad U_{21} = (R_m + \Delta R_m - C_m - \Delta C_m + B_m)xz + (R_m + \Delta R_m - C_m - \Delta C_m)x(1 - z) + (R_m + \Delta R_m - \\ 8 \quad C_m - \Delta C_m + B_m - R_{sc}L_m)(1 - x)z + (R_m + \Delta R_m - C_m - \Delta C_m - \theta R_{sc}L_m)(1 - x)(1 - z) \quad (1)$$

$$9 \quad U_{22} = (R_m - C_m - P_m - L_m - C_{ms} - R_{pl} - R_{mr}R_m)xz + (R_m - C_m - L_m - C_{ms} - \theta R_{pl} - \\ 10 \quad \theta R_{mr}R_m)x(1 - z) + (R_m - C_m - P_m - L_m - C_{ms} - R_{mr}R_m + C_{co} + R_{co})(1 - x)z + (R_m - C_m - \\ 11 \quad L_m - C_{ms} + C_{co} + R_{co} - \theta R_{mr}R_m)(1 - x)(1 - z) \quad (2)$$

12 The average expected payoff function for NEVMs is U_2 , calculated as: $U_2 = yU_{21} +$
13 $(1 - y)U_{22}$. Similarly, we can obtain the replicator dynamics equation for NEVMs:

$$14 \quad F(y) = \frac{dy}{dt} = y[U_{21} - U_2] = -y(y - 1)[C_{ms} - C_{co} - \Delta C_m + \Delta R_m + L_m - R_{co} - \theta L_m R_{sc} + \\ 15 \quad \theta R_{mr}R_m + (C_{co} + R_{co} + \theta L_m R_{sc} + \theta R_{pl})x + (B_m + P_m + (1 - \theta)(R_{mr}R_m - L_m R_{sc}))z + (1 - \\ 16 \quad \theta)(R_{pl} + L_m R_{sc})z] \quad (3)$$

17 For GRAs, the payoff functions for adopting "strict regulation" strategy and "lenient regulation"
18 strategy are U_{31} and U_{32} respectively, thus obtaining the following equation:

$$19 \quad U_{31} = (SE_{esg} - C_g - B_s - B_m)xy + (SE_s - C_g - B_s + P_m)x(1 - y) + (SE_m - C_g + P_s - B_m)(1 - \\ 20 \quad x)y + (P_s + P_m - C_g - C_E)(1 - x)(1 - y) \quad (4)$$

$$21 \quad U_{32} = (SE_{esg} - \theta C_g)xy + (SE_s - \theta C_g)x(1 - y) + (SE_m - \theta C_g)(1 - x)y + (-\theta C_g - C_E)(1 - \\ 22 \quad x)(1 - y) \quad (5)$$

23 The average expected payoff function for GRAs is U_3 calculated as: $U_3 = zU_{31} +$
24 $(1 - z)U_{32}$. Similarly, we can obtain the replicator dynamics equation for g GRAs:

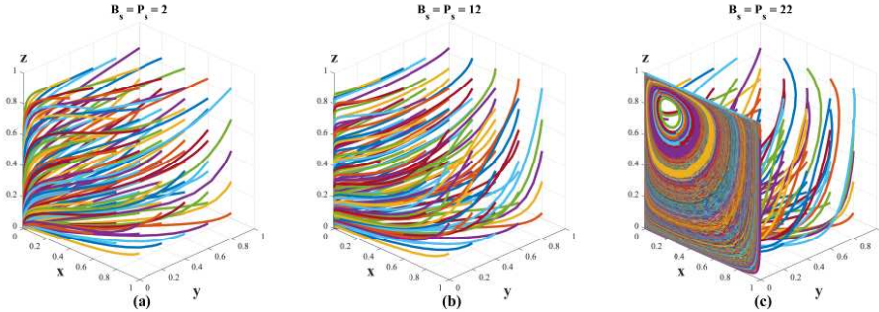
$$25 \quad F(z) = \frac{dz}{dt} = z[U_{31} - U_3] = z(z - 1)[(1 + \theta)C_g - P_m - P_s + (B_s + P_s)x + (B_m + P_m)y] \quad (6)$$

26

27 **Appendix B.**

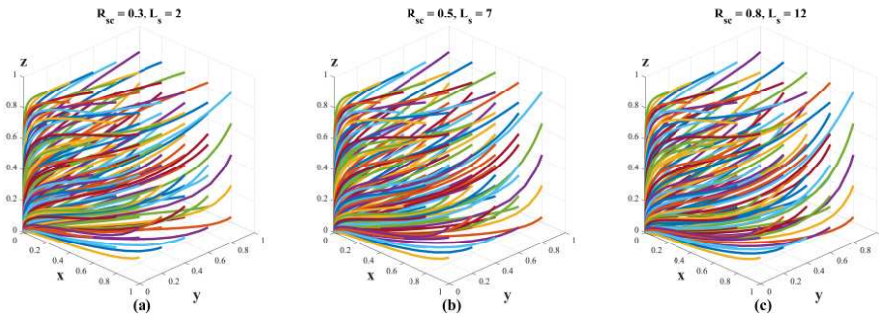
28 **1. Two-factor sensitivity analysis**

29 (1) The impact of reward and penalty on tripartite game strategies



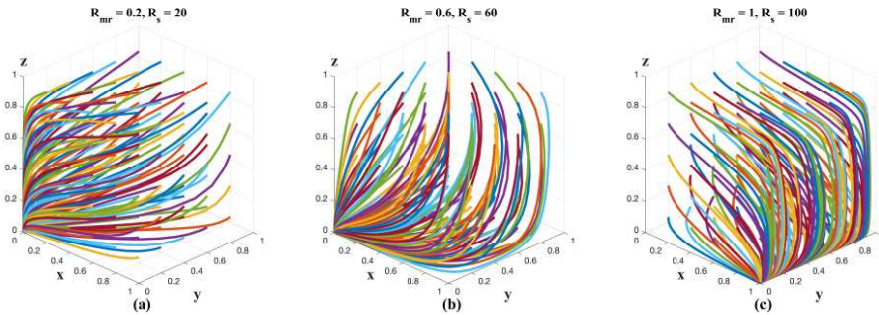
30
31 **Fig. S1:** The impact of $(B_s & P_s)$ on $E_1(0,0,0)$

32 (2) The impact of reputation risk on tripartite game strategies



33
34 **Fig. S2:** The impact of $(R_{sc} & L_s)$ on $E_1(0,0,0)$

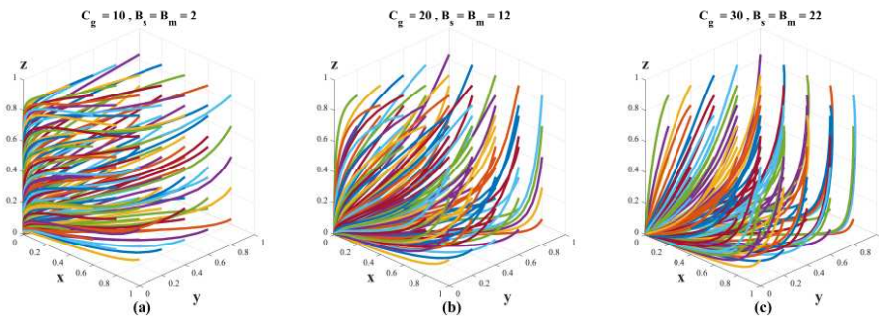
35 (3) The impact of market response on tripartite game strategies



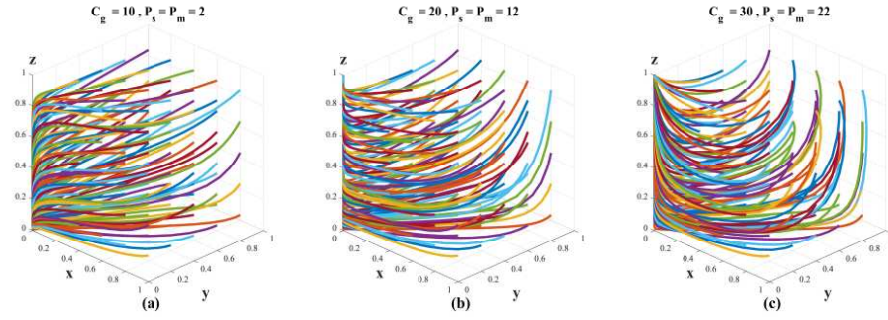
36
37 **Fig. S3:** The impact of $(R_{mr} & R_s)$ on $E_1(0,0,0)$

38 **2. Multi-factor sensitivity analysis**

39 (1) The impact of different government incentives on the system evolution strategy



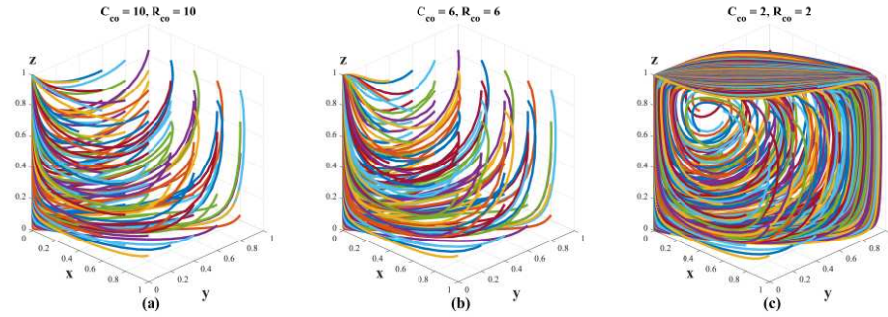
40
41 **Fig. S4:** The impact of $(C_g & B_s & B_m)$ on $E_1(0,0,0)$



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43

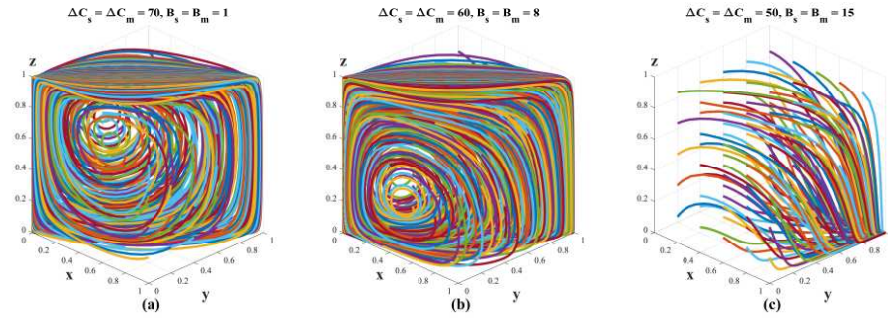
Fig. S5: The impact of $(C_g \& P_s \& P_m)$ on $E_1(0,0,0)$

44 (2) The evolution path analysis from transition to maturity stage



45
46

Fig. S6: The impact of $(C_{co} \& R_{co})$ on $E_4(0,0,1)$



47
48

Fig. S7: The impact of $(\Delta C_s \& \Delta C_m \& B_s \& B_m)$ on $E_4(0,0,1)$

49 **Appendix C.**

50 **Evolutionary stability analysis of the modified model**

51 **1. Incorporation of procurement parameters**

52 We have added procurement parameters (P and Q), where P represents the unit price paid by
 53 NEVMs to NEVSs for product procurement, and Q denotes the quantity of products procured
 54 by NEVMs from NEVSs. These two parameters directly reflect the transactional behavior
 55 between NEVMs and NEVSs. In the original model, R_s represented the total revenue of
 56 NEVSs. In the revised model, NEVSs' total revenue is predominantly composed of sales
 57 income. PQ represents the total sales revenue NEVSs receive from NEVMs. we posit that
 58 $R_s \approx PQ$, predicated on the fundamental assumption that the primary revenue stream for
 59 NEVSs is derived from product sales to NEVMs.

60 The payoff functions when NEVSs and NEVMs choose different strategies ("ESG practices"
 61 strategy and "greenwashing") are represented by U_{11}, U_{12} and U_{21}, U_{22} , respectively. The
 62 modified payoff functions now explicitly include the procurement payment term ($P * Q$). This
 63 adjustment directly reflects the impact of procurement activities on the revenue of supply chain
 64 members, allowing the model to better capture supply chain interactions (see the modified
 65 Table C-1 for details).

66 **Table C-1**

67 Model parameter descriptions

Game player	Symbol	Parameter description
NEVSs	P	Unit product purchase price paid by NEVMs to NEVSs
	Q	Quantity of products procured by NEVMs from NEVSs.
	$C_s, \Delta C_s$	The basic production cost and extra cost for ESG practices of NEVSs.
	ΔR_s	The extra revenue from ESG practices of NEVSs.
	L_s	Loss of reputation for NEVSs due to greenwashing.
	C_{ss}	Speculative cost for NEVSs.
NEVMs	$C_m, \Delta C_m$	The basic production cost and extra cost for ESG practices of NEVMs.
	$R_m, \Delta R_m$	The baseline revenue and extra revenue from ESG practices of NEVMs.
	L_m	Loss of Reputation due to greenwashing for NEVMs.
	C_{ms}	Speculative cost for NEVMs.
Supply Chain Shared Parameters	C_{co}	Cost savings from collusive greenwashing.
	R_{co}	Extra revenue from collusive greenwashing.
	R_{pl}	The potential loss incurred by the greenwashing party due to the increased likelihood of losing supply chain partners.
	R_{mr}	Market reaction coefficient, measuring sensitivity to greenwashing.
	R_{sc}	Reputation risk coefficient that indicates indirect impact on supply chain reputation ($R_{sc} \in [0,1]$).
GRAs	C_g	The cost of strict supervision by government regulators.
	θ	The cost of coefficient of loose supervision by government regulators ($\theta \in [0,1]$).

B_s, B_m	The rewards of government for NEVSs and NEVMs practising ESG.
P_s, P_m	The penalties imposed by the government on NEVSs and NEVMs practising greenwashing.
SE_s, SE_m	Environmental benefits to the government from the ESG practices of NEVSs and NEVMs, respectively.
C_E	The damage to the environment caused by supply chain greenwashing.
SE_{esg}	Environmental benefits to the government from entire supply chain ESG practices.

68 Based on the parameter configuration, we can still derive eight strategy combinations for the
69 three-party evolutionary game model involving NEVSs, NEVMs and GRAs. We have
70 recalculated the payoffs under different strategy set and constructed a new payoff matrix (as
71 shown in Table C-2).

72 **Table C-2**

73 The payoff matrix for the tripartite game

NEVSs	NEVMs	GRAs	
		Strict Regulation (z)	Lenient Regulation ($1-z$)
ESG (y)	ESG (x)	$(PQ - C_s) + (\Delta R_s - \Delta C_s) + B_s$	$(PQ - C_s) + (\Delta R_s - \Delta C_s)$
		$(R_m - C_m - PQ) + (\Delta R_m - \Delta C_m) + B_m$	$(R_m - C_m - PQ) + (\Delta R_m - \Delta C_m)$
Greenwashing ($1-y$)	Greenwashing ($1-x$)	$SE_{esg} - (C_g + B_s + B_m)$	$SE_{esg} - \theta C_g$
		$(PQ - C_s - R_{sc}L_s) + (\Delta R_s - \Delta C_s) + B_s$	$(PQ - C_s - \theta R_{sc}L_s) + (\Delta R_s - \Delta C_s)$
ESG (y)	Greenwashing ($1-y$)	$(R_m - C_m - PQ - C_{ms}) - (R_{pl} + L_m + R_{mr}R_m) - P_m$	$(R_m - C_m - PQ - C_{ms}) - (\theta R_{pl} + L_m + \theta R_{mr}R_m)$
		$(SE_s + P_m) - (C_g + B_s)$	$SE_s - \theta C_g$
Greenwashing ($1-x$)	Greenwashing ($1-y$)	$(PQ - C_s - C_{ss}) - (R_{pl} + L_s + R_{mr}PQ) - P_s$	$(PQ - C_s - C_{ss}) - (\theta R_{pl} + L_s + \theta R_{mr}PQ)$
		$(R_m - C_m - PQ - R_{sc}L_m) + (\Delta R_m - \Delta C_m) + B_m$	$(R_m - C_m - PQ - \theta R_{sc}L_m) + (\Delta R_m - \Delta C_m)$
		$(SE_m + P_s) - (C_g + B_m)$	$SE_m - \theta C_g$
		$(PQ - C_s) + (R_{co} + C_{co} - C_{ss}) - (L_s + R_{mr}PQ) - P_s$	$(PQ - C_s) + (R_{co} + C_{co} - C_{ss}) - (L_s + \theta R_{mr}PQ)$
		$(R_m - C_m - PQ) + (R_{co} + C_{co} - C_{ms}) - (L_m + R_{mr}R_m) - P_m$	$(R_m - C_m - PQ) + (R_{co} + C_{co} - C_{ms}) - (L_m + \theta R_{mr}R_m)$
		$(P_s + P_m) - (C_g + C_E)$	$-\theta C_g - C_E$

74 2. Construction of replicator dynamics equations

75 Based on the modified model, we have conducted a renewed analysis of system stability and
76 sensitivity. The process begins with calculating the payoff functions and replicator dynamics
77 equations for NEVSs, NEVMs, and GRAs. We then construct a three-dimensional dynamical
78 system equation, determine the system's equilibrium points, and finally derive the
79 Evolutionarily Stable Strategy (ESS) for the tripartite evolutionary game model.

80 First, for the NEVSs, the payoff functions for adopting the "ESG practice" strategy and the
81 "greenwashing" strategy are denoted as U_{11} , and U_{12} , respectively. The average expected
82 payoff function is represented as U_1 , and the replicator dynamics equation is denoted as $F(x)$.
83 These relationships are expressed in the following equations:

$$84 U_{11} = PQ + \Delta R_s - \Delta C_s - C_s + zB_s - (1-y)[zR_{sc}L_s + (1-z)\theta R_{sc}L_s] \quad (7)$$

$$85 U_{12} = PQ - C_s - L_s - C_{ss} - P_s z - R_{pl}[yz + \theta y(1-z)] - R_{mr}PQ + (1-y)(C_{co} + R_{co}) \quad (8)$$

$$86 U_1 = xU_{11} + (1-x)U_{12} \quad (9)$$

$$\begin{aligned}
87 \quad F(x) &= \frac{dx}{dt} = x[U_{11} - U_1] = x(1-x)[\Delta R_s - \Delta C_s + L_s + C_{ss} + P_s z + R_{pl}[yz + \theta y(1-z)] + \\
88 \quad &R_{mr}PQ + zB_s - (1-y)[zR_{sc}L_s + (1-z)\theta R_{sc}L_s] - (1-y)(C_{co} + R_{co})] \quad (10)
\end{aligned}$$

89 Similarly, for the NEVMs, the payoff functions for adopting the "ESG practice" strategy and
90 the "greenwashing" strategy are denoted as U_{21} and U_{22} respectively. The average expected
91 payoff function is represented as U_2 , and the replicator dynamics equation is denoted as $F(y)$.
92 These relationships are expressed in the following equations:

$$93 \quad U_{21} = R_m + \Delta R_m - C_m - \Delta C_m - PQ + zB_m - (1-x)[zR_{sc}L_m + (1-z)\theta R_{sc}L_m] \quad (11)$$

$$94 \quad U_{22} = R_m - C_m - PQ - L_m - C_{ms} - P_m z - R_{pl}[xz + \theta x(1-z)] - R_{mr}R_m + (1-x)(C_{co} + R_{co})$$

$$95 \quad U_2 = yU_{21} + (1-y)U_{22} \quad (12)$$

$$\begin{aligned}
96 \quad F(y) &= \frac{dy}{dt} = y[U_{21} - U_2] = y(1-y)[\Delta R_m - \Delta C_m + L_m + C_{ms} + P_m z + R_{pl}[xz + \theta x(1-z)] + \\
97 \quad &R_{mr}R_m + zB_m - (1-x)[zR_{sc}L_m + (1-z)\theta R_{sc}L_m] - (1-x)(C_{co} + R_{co})] \quad (13)
\end{aligned}$$

98 For the GRAs, the payoff functions for adopting the "strict regulation" strategy and the "lenient
99 regulation" strategy are denoted as U_{31} and U_{32} respectively. The average expected payoff
100 function is represented as U_3 and the replicator dynamics equation is denoted as $F(z)$. These
101 relationships are expressed in the following equations:

$$\begin{aligned}
102 \quad U_{31} &= -C_g + xySE_{esg} + x(1-y)SE_s + (1-x)ySE_m - B_s x - B_m y + P_m(1-y) + P_s(1-x) - \\
103 \quad &C_E(1-x)(1-y) \quad (14)
\end{aligned}$$

$$104 \quad U_{32} = -\theta C_g + xySE_{esg} + x(1-y)SE_s + (1-x)ySE_m - C_E(1-x)(1-y)$$

$$105 \quad U_3 = zU_{31} + (1-z)U_{32} \quad (15)$$

$$106 \quad F(z) = \frac{dz}{dt} = z(1-z)[-(1-\theta)C_g - B_s x - B_m y + P_m(1-y) + P_s(1-x)] \quad (16)$$

107 3. System stability analysis

108 We construct a three-dimensional dynamical system $F(x, y, z)$ by combining the equations
109 $F(x)$, $F(y)$, and $F(z)$:

$$110 \quad \begin{cases} F(x) = x(1-x) \left[\begin{array}{l} \Delta R_s - \Delta C_s + L_s + C_{ss} + P_s z + R_{pl}[yz + \theta y(1-z)] + R_{mr}PQ \\ + zB_s - (1-y)[zR_{sc}L_s + (1-z)\theta R_{sc}L_s] - (1-y)(C_{co} + R_{co}) \end{array} \right] \\ F(y) = y[U_{21} - U_2] = y(1-y) \left[\begin{array}{l} \Delta R_m - \Delta C_m + L_m + C_{ms} + P_m z + R_{pl}[xz + \theta x(1-z)] + R_{mr}R_m \\ + zB_m - (1-x)[zR_{sc}L_m + (1-z)\theta R_{sc}L_m] - (1-x)(C_{co} + R_{co}) \end{array} \right] \\ F(z) = z(1-z)[(\theta - 1)C_g - B_s x - B_m y + P_m(1-y) + P_s(1-x)] \end{cases} \quad (17)$$

111 Setting $F(x, y, z) = 0$, we obtain 8 pure strategy local equilibrium points. According to
112 Lyapunov's First law, we can confirm that a local equilibrium point is an Evolutionarily Stable
113 Strategy (ESS) only when all eigenvalues of the system's Jacobian matrix are negative. We
114 substitute these 8 equilibrium points into the Jacobian matrix and calculate the eigenvalues for
115 each equilibrium point, as shown in Table C-3.

116

117 **Table C-3**

118 Jacobian matrix eigenvalues corresponding to each equilibrium point.

Equilibrium Point	λ_1	λ_2	λ_3	stability
(0,0,0)	$P_m - C_g + P_s + \theta C_g$	$C_{ms} - C_{co} - \Delta C_m + \Delta R_m + L_m - R_{co} - \theta L_m R_{sc} + R_m R_{mr}$	$C_{ss} - C_{co} - \Delta C_s + \Delta R_s + L_s - R_{co} - \theta L_s R_{sc} + PQR_{mr}$	Conditional ESS
(1,0,0)	$P_m - C_g - B_s + \theta C_g$	$C_{ms} - \Delta C_m + \Delta R_m + L_m + \theta R_{pl} + R_m R_{mr}$	$C_{co} - C_{ss} + \Delta C_s - \Delta R_s - L_s + R_{co} + \theta L_s R_{sc} - PQR_{mr}$	Conditional ESS
(0,1,0)	$P_s - C_g - B_m + \theta C_g$	$C_{ss} - \Delta C_s + \Delta R_s + L_s + \theta R_{pl} + PQR_{mr}$	$C_{co} - C_{ms} + \Delta C_m - \Delta R_m - L_m + R_{co} + \theta L_m R_{sc} - R_m R_{mr}$	Conditional ESS
(0,0,1)	$C_g - P_m - P_s - \theta C_g$	$B_m - C_{co} + C_{ms} - \Delta C_m + \Delta R_m + L_m + P_m - R_{co} + R_m R_{mr} - L_m R_{sc}$	$B_s - C_{co} + C_{ss} - \Delta C_s + \Delta R_s + L_s + P_s - R_{co} + PQR_{mr} - L_s R_{sc}$	Conditional ESS
(1,0,1)	$B_s + C_g - P_m - \theta C_g$	$B_m + C_{ms} - \Delta C_m + \Delta R_m + L_m + P_m + R_{pl} + R_m R_{mr}$	$C_{co} - B_s - C_{ss} + \Delta C_s - \Delta R_s - L_s - P_s + R_{co} - PQR_{mr} + L_s R_{sc}$	Conditional ESS
(0,1,1)	$B_m + C_g - P_s - \theta C_g$	$B_s + C_{ss} - \Delta C_s + \Delta R_s + L_s + P_s + R_{pl} + PQR_{mr}$	$C_{co} - B_m - C_{ms} + \Delta C_m - \Delta R_m - L_m - P_m + R_{co} - R_m R_{mr} + L_m R_{sc}$	Conditional ESS
(1,1,0)	$\theta C_g - B_s - C_g - B_m$	$\Delta C_m - C_{ms} - \Delta R_m - L_m - \theta R_{pl} - R_m R_{mr}$	$\Delta C_s - C_{ss} - \Delta R_s - L_s - \theta R_{pl} - PQR_{mr}$	Conditional ESS
(1,1,1)	$B_m + B_s + C_g - \theta C_g$	$\Delta C_m - C_{ms} - B_m - \Delta R_m - L_m - P_m - R_{pl} - R_m R_{mr}$	$\Delta C_s - C_{ss} - B_s - \Delta R_s - L_s - P_s - R_{pl} - PQR_{mr}$	instability

119 Through eigenvalue analysis of the Jacobian matrix, we derived five propositions. The
 120 following is a comparative analysis of these propositions obtained from the modified model
 121 against the original propositions:

122 **Proposition 1 (Early market stage):** The modified conditions are: When $C_g - (P_m + P_s) >$
 123 θC_g , $\Delta R_s - \Delta C_s - \theta L_s R_{sc} < R_{co} - (C_{ss} - C_{co}) - L_s - PQR_{mr}$, $\Delta R_m - \Delta C_m - \theta L_m R_{sc} <$
 124 $R_{co} - (C_{ms} - C_{co}) - L_m - R_s R_{mr}$, the corresponding evolutionarily stable strategy is
 125 {Greenwashing, Greenwashing, Lenient Regulation}, denoted as $E_1(0,0,0)$. The primary
 126 modification is the replacement of $\theta R_s R_{mr}$ with PQR_{mr} in the original model, more
 127 accurately reflecting the relationship between market reaction and transaction scale. The
 128 condition $(P_m + P_s) > \theta C_g$ remains unchanged, indicating that when the cost of strict ESG
 129 regulation is substantially high, the government still opts for a lenient regulatory strategy. In
 130 this scenario, when the government's punitive measures for supply chain greenwashing are
 131 relatively mild and the cost of ESG practices is considerably high, even though $PQR_{mr} >$
 132 $\theta R_s R_{mr}$, it can still result in $\lambda_2 < 0$, driving collusion in greenwashing within the supply chain.
 133 Consequently, the core conclusion of the proposition remains unaltered, demonstrating that
 134 under specific conditions, supply chain members and the government still tend to choose
 135 greenwashing and lenient regulation, respectively.

136 **Proposition 2 (Transitional stage):** The modified conditions are: When $C_g + B_s - P_m > \theta C_g$,
 137 $\Delta R_s - \Delta C_s - \theta L_s R_{sc} > R_{co} - (C_{ss} - C_{co}) - L_s - PQR_{mr}$, $\Delta R_m - \Delta C_m < -(C_{ms} + L_m +$
 138 $\theta R_{pl} + R_m R_{mr})$, the evolutionarily stable strategy is {ESG Practices, Greenwashing, Lenient
 139 Regulation}, denoted as $E_2(1,0,0)$. Similarly, when $C_g + B_m - P_s > \theta C_g$, $\Delta R_m - \Delta C_m -$
 140 $\theta L_m R_{sc} > R_{co} - (C_{ms} - C_{co}) - L_m - R_m R_{mr}$, $\Delta R_s - \Delta C_s < -(C_{ss} + L_s + \theta R_{pl} +$
 141 $PQR_{mr})$, the equilibrium point $E_3(0,1,0)$ is the ESS, corresponding to the evolutionarily
 142 stable strategy {Greenwashing, ESG Practices, Lenient Regulation}. This proposition describes
 143 scenarios where, under lenient regulation, one party in the supply chain opts for ESG practices
 144 while the other chooses greenwashing.

145 The primary modifications involve replacing $\theta R_s R_{mr}$ with PQR_{mr} , and $\theta R_m R_{mr}$ with
 146 $R_m R_{mr}$. These adjustments more accurately describe the different situations faced by NEVSS

147 and NEVMs in response to market reactions. The conditions $C_g - (P_m + P_s) > \theta C_g$ and $C_g +$
148 $B_m - P_s < \theta C_g$ remain unchanged, indicating that for the GRAs, adopting a lenient strategy
149 ensures $\lambda_1 < 0$. With $PQR_{mr} > \theta R_s R_{mr}$, $\lambda_2 < 0$ still holds. Given the assumption that
150 $\Delta R_m > \Delta C_m$, the condition $\Delta R_m - \Delta C_m < -(C_{ms} + L_m + \theta R_{pl} + R_m R_{mr})$ holds, ensuring
151 $\lambda_3 < 0$. Consequently, E_2 is the ESS, and by similar reasoning, E_3 is also the ESS. Therefore,
152 the basic structure and conclusions of the proposition remain unchanged after modifying the
153 model.

154 **Proposition 3 (Transitional stage):** When $(P_m + P_s) - C_g > -\theta C_g$, $\Delta R_m - \Delta C_m + B_m -$
155 $L_m R_{sc} < R_{c0} - (C_{ms} - C_{co}) - L_m - P_m - R_m R_{mr}$, $\Delta R_s - \Delta C_s + B_s - L_s R_{sc} < R_{c0} -$
156 $(C_{ss} - C_{co}) - L_s - P_s - PQR_{mr}$, the corresponding evolutionarily stable strategy is
157 {Greenwashing, Greenwashing, Strict Regulation}, denoted as $E_4(0,0,1)$.

158 The primary modification lies in replacing $R_s R_{mr}$ with PQR_{mr} , while other conditions
159 remain unchanged. Consequently, $\lambda_1 < 0$ and $\lambda_2 < 0$ from the original proposition can be
160 maintained. The original parameter represented the NEVSs' total revenue, which derives from
161 the NEVMs' procurement within the supply chain. Therefore, it can be assumed that $R_s \approx PQ$.
162 This allows for the preservation of $\lambda_3 < 0$ from the original proposition. According to
163 Lyapunov's first law, E_4 remains an ESS. The revised model more accurately reflects the
164 relationship between the supply chain members' market response and transaction scale.
165 However, the core conclusion of the proposition remains intact, indicating that during the
166 transitional phase, even in the face of strict regulation, supply chain members may still opt for
167 greenwashing behavior.

168 **Proposition 4 (Transitional stage):** When $(B_s + C_g) - P_m > \theta C_g$, $\Delta R_s - \Delta C_s - L_s R_{sc} +$
169 $B_s > R_{c0} - (C_{ss} - C_{co}) - L_s - P_s - PQR_{mr}$, $\Delta R_m - \Delta C_m < -(B_m + C_{ms} + L_m + P_m +$
170 $R_{pl} + R_m R_{mr})$, the corresponding evolutionarily stable strategy is {ESG Practices,
171 Greenwashing, Strict Regulation}, denoted as $E_5(1,0,1)$. Similarly, when $\theta C_g > (B_m +$
172 $C_g) - P_s$, $\Delta R_s - \Delta C_s < -(B_s + C_{ss} + L_s + P_s + R_{pl} + PQR_{mr})$, $\Delta R_m - \Delta C_m - L_m R_{sc} +$
173 $B_m > R_{c0} - (C_{ms} - C_{co}) - L_m - P_m - R_m R_{mr}$, the equilibrium point $E_6(0,1,1)$ is the ESS,
174 corresponding to the evolutionarily stable strategy {Greenwashing, ESG Practices, Strict
175 Regulation}.

176 The main modification is the replacement of $R_s R_{mr}$ with PQR_{mr} while other conditions
177 remain unchanged. This indicates that $\lambda_1 < 0$ and $\lambda_1 < 0$ from the original proposition are
178 maintained. With $R_s \approx PQ$, $\lambda_2 < 0$ is preserved from the original proposition. Consequently,
179 E_5 and E_6 remain as ESS. Although new parameters have been introduced, the fundamental
180 structure and conclusions of the proposition remain unchanged. This suggests that as the
181 intensity of government regulation increases, supply chain members begin to explore ESG
182 practices.

183 **Proposition 5 (Market mature stage):** When $\theta C_g < C_g + (B_s + B_m)$, $\Delta R_m > \Delta C_m >$,
184 $\Delta R_s - \Delta C_s > -C_{ss} - L_s - R_{pl} - PQR_{mr}$, the corresponding evolutionarily stable strategy is
185 {ESG Practices, ESG Practices, Lenient Regulation}, i.e., $E_7(1,1,0)$. The core modification is
186 evident in the replacement of $R_s R_{mr}$ with PQR_{mr} , while other conditions remain unchanged.
187 This means that $\lambda_1 < 0$ and $\lambda_2 < 0$ are maintained. Based on the original assumption that
188 $\Delta R_s > \Delta C_s$, it follows that $\lambda_3 < 0$ hold, confirming E_7 as the ESS. The revised model more

189 accurately describes the relationship between the supply chain members' market response and
190 transaction scale. However, it does not alter the core conclusion of the original proposition.
191 Both versions describe that in the mature stage of ESG development, the government will adopt
192 a lenient regulatory strategy, and supply chain members will choose to implement ESG
193 practices.

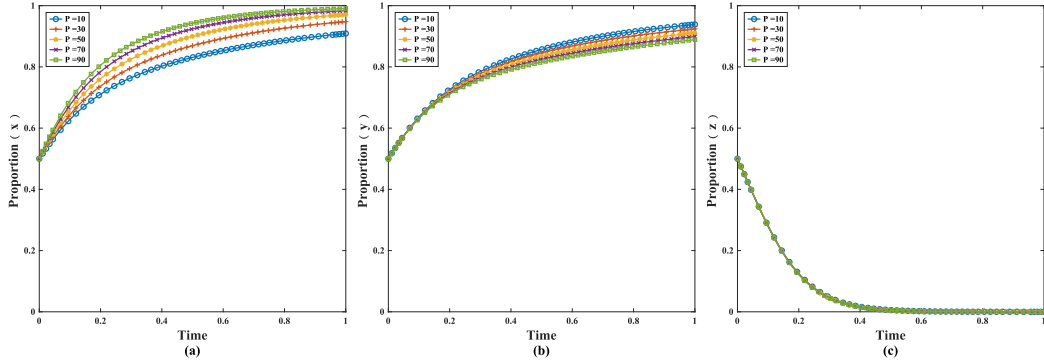
194 In conclusion, through a systematic stability analysis of the modified model, we can observe
195 that despite the addition of procurement parameters P and Q , the core conclusions and
196 fundamental logical structure of the model remain unchanged. The five propositions continue
197 to correspond to different stages of ESG development in the NEV industry. This demonstrates
198 the robustness of the original model's design in capturing supply chain interactions through
199 simplified transaction details.

200 **4. Sensitivity analysis**

201 Given that the modified model maintains consistency with the original model in its core
202 conclusions, we conducted a simple sensitivity analysis on the newly added parameters P and
203 Q to demonstrate their impact on system evolution.

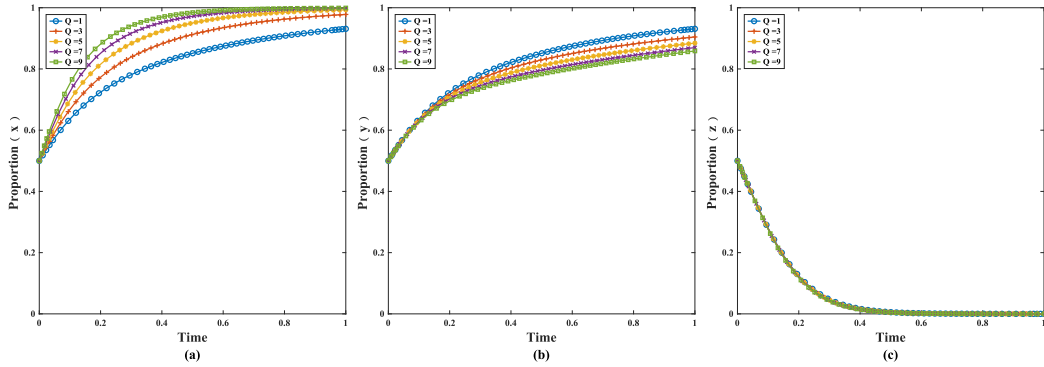
204 First, we performed single-factor sensitivity analyses on P and Q separately, studying the
205 effects of different procurement scales on strategy selection by the three parties in the supply
206 chain. Under the conditions of $E_7(1,1,0)$, we set different procurement cost prices P
207 at (10, 30, 50, 70, 90) and different procurement quantities Q at (1, 3, 5, 7, 9). We chose a
208 broad range of parameters to cover various possible scenarios. The simulation results under
209 different P and Q values are presented in Fig. S8-S9. For procurement price P (Fig.S8), as
210 P increases, x (probability of NEVs choosing ESG practices) and y (probability of
211 NEVMs choosing ESG practices) show a slight decrease, but the magnitude of change is small
212 (not exceeding 5%). z (probability of government choosing strict regulation) remains almost
213 unaffected. For procurement quantity Q (Fig. S9), the impact pattern on x and y is similar to
214 that of P , but with even smaller effects. Similarly, z remains relatively stable.

215 These results indicate that while an increase in procurement scale slightly reduces the
216 probability of supply chain members choosing ESG practices, the extent of this influence is
217 limited. This may be because as transaction scale expands, enterprises tend to prioritize
218 economic benefits, but the long-term gains from ESG practices remain attractive. Consequently,
219 the addition of new parameters does not alter the overall equilibrium state and evolutionary
220 trend of the system, further validating the robustness of the original model's conclusions.



221
222

Fig. S8. Evolutionary results under different P



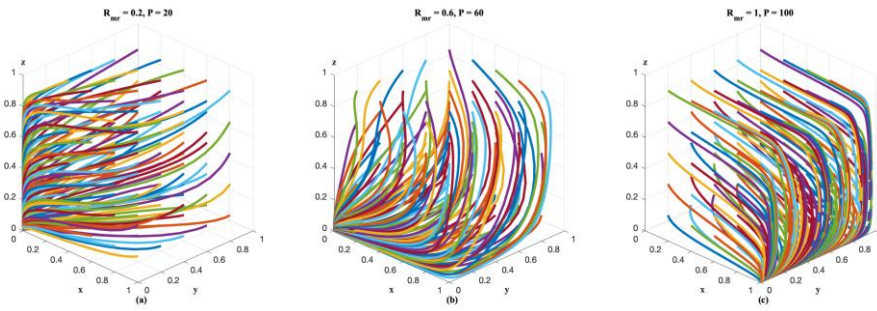
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Fig. S9. Evolutionary results under different Q

225 To gain a deeper understanding of the relationship between market reaction and transaction
 226 scale, we conducted a two-factor sensitivity analysis and compared it with the original model.
 227 During our stability analysis, we found that the main difference between the propositions in the
 228 modified model and the original propositions was the replacement of $\theta R_S R_{mr}$ or $R_S R_{mr}$
 229 with PQR_{mr} , which better reflects the relationship between transaction scale and market
 230 reaction. Therefore, while keeping the quantity of products procured by NEVMs from NEVSs
 231 constant, we performed a two-factor sensitivity analysis on R_{mr} and P , comparing the results
 232 with the two-factor sensitivity analysis of R_S and R_{mr} in the original model. We set the
 233 market reaction coefficient $R_{mr} = (0.3, 0.5, 0.8)$ and the transaction price $P = (20, 60, 120)$
 234 to explore how these factors influence system evolution under the condition where $E_1(0, 0, 0)$
 235 is the initial stable point. Fig. S10 presents the new simulation results. The results demonstrate
 236 that as the transaction price P and market reaction coefficient R_{mr} increase, the system
 237 gradually deviates from $E_1(0, 0, 0)$, tending towards a new stable state $(1, 0, 0)$.

238 Notably, in the modified model, when both P and R_{mr} are at high levels ($P = 120, R_{mr} =$
 239 0.8), the system transitions more rapidly towards the $(1, 0, 0)$ state. This indicates that under
 240 conditions of large-scale transactions and high market sensitivity, NEVSs have a greater
 241 incentive to adopt ESG practices. This trend is similar to the effects of R_S and R_{mr} in the
 242 original model (Fig. S3 in Appendix B), indicating that the modified model maintains the
 243 evolutionary characteristics of the original conclusions, both emphasizing the crucial role of

244 market mechanisms in driving corporate ESG practices.



245
246

Fig. S10: The impact of $(R_{mr} \& P)$ on $E_1(0,0,0)$

247 In summary, the newly added procurement parameters (P and Q) primarily affect local revenue
248 distribution without altering the overall equilibrium state and evolutionary trends of the system.
249 The modified model maintains the original dynamic evolutionary characteristics, further
250 confirming the robustness of the conclusions. However, the incorporation of these parameters
251 enhances the model's capacity to describe the actual operations of the supply chain and the
252 interactions among supply chain members, making it more closely aligned with reality and
253 enabling a more comprehensive analysis of the dynamic evolutionary process of ESG practices
254 in the NEV supply chain.