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Research article

Towards organic collaborative governance for a more sustainable environment: Evolutionary game analysis within the policy implementation of China's net-zero emissions goals

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ABSTRACT

Many countries in the world have pledged to achieve net-zero emissions goals, implementing a range of relevant policies. As the key implementers in these initiatives, the collaboration between government and enterprise is crucial for the realization of net-zero emissions goals and better sustainable environment. However, the heterogeneous interests of these stakeholders often lead to a game. This research constructs an evolutionary game model to analyze the interactions between government and enterprises, utilizing field studies from China and extensive literature review, to illustrate the behavioral strategies and game dynamics of the two parties. The results show that optimal outcomes are achieved when the government effectively engages enterprises, who in turn actively participate in these initiatives. In addition, this study explores how adjusting game parameters, optimizing the distribution of costs and benefits, and establishing incentive-compatible mechanisms can align the strategic behaviors of both parties towards a more stable equilibrium. This approach facilitates a more organic collaborative governance for better sustainable environment, which has proved fundamental for the robust implementation of net-zero emissions policies. The insights provided in this research broaden the theoretical boundaries of climate governance and policy implementation, providing practical guidelines for policy implementers engaged in net-zero emissions and sustainable environment.

1. Introduction

Climate change is increasingly evolving into a serious crisis with profound implications for the future development of humankind (Karl and Trenberth, 2003). This evolving crisis is characterized by the frequent occurrence of extreme and abnormal weather events such as cold waves, hurricanes, torrential rains and floods, and high temperature heat waves, causing irreversible harm to the environmental sustainability, and making human living conditions increasingly harsh (Romanello et al., 2021). In this context, net-zero emissions has been gaining international consensus as a policy orientation that can significantly mitigate climate warming effects (Tan et al., 2024). Many countries in the world have committed net-zero emissions goals. As the world's second-largest economy and the top carbon emitter, China's pledge to achieve net-zero emissions goals by 2060 is a significant step forward in global climate governance (Udeagha and Muchapondwa, 2023; Dong et al., 2024). This commitment is projected to reduce global temperature increases by approximately 0.2–0.3 °C, contributing substantially to the efforts to control the 1.5 °C warming limit (CAT, 2023). As in many countries, China has implemented a "1+N" net-zero emissions policy framework to guide its efforts (Zhou et al., 2022). Considering the challenge of net-zero emissions goals, numerous policy documents in China emphasize the promotion of collaborative governance through a "government-led and enterprise-participation" approach.

The implementation of net-zero emissions policies positions

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governments as both the policymakers and the subjects, while enterprises are typically the objects of these policies. In practice, the government often requires enterprise to implement net-zero emissions goals through various regulatory policy (Davidson et al., 2021; Zhao et al., 2022). In general, the primary measures for enterprise to decarbonize include purchasing decarbonization equipment, strengthening decarbonization technological innovation, reducing production capacity, and eliminating high-carbon industries (Enkvist et al., 2008; Begg et al., 2018; Kim et al., 2022; Anderson et al., 2023), all of which would increase costs or reduce profits. In this scenario, enterprises, primarily driven by short-term profit motives, may show reluctance to actively pursue decarbonization. This divergence in objectives between governments, which aim for net-zero emissions, and enterprises, which seek immediate financial returns, can sometimes manifest as strategic interactions (Gajdzik et al., 2023), particularly evident in our field study within Chinese enterprises. Unfortunately, despite the significance of these interactions, the literature lacks an in-depth discussion of the dynamics and internal mechanisms of this strategic interplay within the context of the policy implementation to net-zero emissions goals.

In light of these considerations, this study addresses critical research questions concerning the mechanisms and behavioral logic underlying the interactions between governments and enterprises in the implementation of net-zero emissions policies. Specifically, it examines how organic collaborative governance can be achieved between these entities. Utilizing an evolutionary game theory approach, this study analyzes the heterogeneous interests, strategy choices, and behavioral interactions within the context of China's net-zero emissions policy. Additionally, we explore the influence mechanisms of government-enterprise collaboration and propose optimization strategies for effective governance. This approach not only aims to integrate administrative and social resources more effectively but also accelerates the achievement of net-zero emissions and sustainable development globally. The contributions of this study are threefold: (1) It expands our understanding of net-zero emissions governance, with a focus on China but applicable globally. (2) It provides empirical evidence and mathematical support for government-enterprise collaboration in this context. (3) It offers optimization strategies that could inform practitioners and policymakers engaged in enhancing collaborative environmental and climate governance.

2. Literature review

Since the introduction of net-zero emissions, many scholars have been at the forefront, conducting early exploratory research on the policy implementers of net-zero emissions and their collaboration (Williams et al., 2021; Davidson et al., 2021). It is widely acknowledged by both academics and policymakers that countries around the world are facing significant challenges and difficulties in implementing policies to net-zero emissions (Liu et al., 2022). Under the traditional monocentric governance paradigm, a single government often struggles to address these challenges effectively (Carlisle and Gruby, 2019). Therefore, enterprises, as direct producers of carbon emissions, should and must become active participants in the implementation of these policies (Song and Long, 2022). More importantly, enhancing the collaborative governance between government bodies and businesses is essential to effectively implement net-zero emissions policies and to truly improve their effectiveness (Jimenez, 2019; Wu et al., 2023). Although the existing literature acknowledges the importance of collaboration between government and enterprise in implementing policies of net-zero emissions (Zhou and Qian, 2022), it often overlooks the heterogeneous interests of these stakeholders and the strategic games (and potential conflicts) that may arise from their interactions. In contrast to Western countries where the policymaking stage is often deemed most critical, in China, policy implementation is the more crucial phase of the policy process, serving as the primary arena where implementers engage and strategize in their interactions (Wu and Yang, 2017).

In response to China's inclusion of net-zero emissions into its "central and provincial ecological environment protection inspections" policy, and influenced by the hierarchical authority structure and the "pressurized system" (Rong, 1998), governments at all levels in China are under great pressure to implement the policy of net-zero emissions. This pressure therefore induces various levels of government to elevate—-from top to bottom—the standards of net-zero emissions goals, ultimately transferring the pressure of decarbonization on enterprises. As China is still in the nascent stages of implementing its net-zero emissions policy, the product price signals are insufficient to internalize the external cost of carbon emissions. Additionally, the industrial chain has yet to evolve into a competitive market structure based on carbon emissions, leading to relatively high costs for enterprises initiating emissions reductions and a constraint on enterprise profits. As a result, there is less incentive for enterprises to actively promote the policy implementation of net-zero emissions. Accordingly, in the face of net-zero emissions pressure transferred by the government, enterprises often adopt a variety of formal and informal gaming strategies to bargain with the government, such as "selective implementation", "symbolic decarbonization", "campaign carbon emission reduction", "inter-enterprise conspiracy", etc. (Xu and Xu, 2021; Teng and Xie, 2023; Lan and Zhang, 2024), thus reducing or delaying their decarbonization responsibilities.

In general, although the existing literature involves the investigation of net-zero emissions policy implementers and their collaboration, it mostly focuses on the importance of the collaboration of policy implementers, but fails to systematically explain and discuss the mechanisms underlying the game of interests and collaboration between the government and enterprise. Furthermore, there is a notable deficiency of in-depth exploration, particularly concerning the practical policy implementation of China's net-zero emissions goals. In fact, in the field of policy implementation to net-zero emissions, the government and enterprises poses numerous heterogeneous interests. It is thus imperative for scholars to clarify the intrinsic mechanisms of their interactions, grounded in these heterogeneous interests, to identify the conditions necessary for organic collaboration. To address this gap, this study establishes an evolutionary game model of government and enterprise based on field study and literature research. With the help of mathematical modeling and deduction, it reveals the internal dynamics of the game of interests between the two sides, thereby identifying the prerequisites for achieving organic collaboration between them.

3. Method and model

The evolutionary game theory provides the best analytical basis for examining the interactions and dynamic evolution of multiple actors (Friedman, 1998; Zhang et al., 2023b). By utilizing evolutionary game theory to analyze the game of interests and conditions for collaboration among policy implementers is both scientific in theoretical methodology and has obvious analytical advantages (Bardach, 1978; Zhou et al., 2023).

3.1. Game parties and model assumptions

The game involves two parties: the government and the enterprise. The former encompasses governmental and administrative departments at all levels (denoted by a); while the latter refers to enterprises directly producing carbon emissions (denoted by b). Both parties involved in the policy implementation game operate under bounded rationality; that is, while they aim to maximize their respective interests, they do not exhibit "complete rationality" as described by Schmidt (2004). Instead, their decisions are influenced by factors such as incomplete information, limited cognitive capacity, and constraints related to time and cost. This makes the bounded rationality model particularly suitable for analyzing the strategic interactions between governments and enterprises.

First, governments at all levels aim to achieve their net-zero emissions goals timely in order to avoid accountable issues and potentially receive performance appraisals and administrative awards. To this end, the government strives to build social consensus and enhance collective identity by actively encouraging enterprise to participate in governance (Pestoff and Hulgård, 2016). This approach not only reduces the government's costs associated with implementing net-zero emissions policies and compensates for public governance shortcomings but also leverages the market efficiency advantages of enterprise participants. Furthermore, the inclusion of the enterprise to collaborate in the promotion of net-zero emissions policy serves as an important mechanism for improving legitimacy (Sørensen and Torfing, 2009) and deepening democracy (Fung and Wright, 2003).

Second, the enterprise seeks to maximize its profitability as an independent legal entity within the legal framework. They recognize that implementing net-zero emissions policies will likely increase the short-term costs of the enterprise (e.g., the cost of purchasing decarbonization equipment and strengthening technological innovation) while also decreasing profits of the enterprise (e.g., the reduction of production capacity or the elimination of high-carbon industries). Consequently, enterprises (particularly non-public ones) prefer that the net-zero emissions goals set by the government will be as low as possible, and as slow as possible. They also aim to communicate their challenges and hardships to the government to ensure understanding and potentially secure a reduction or postponement of their net-zero emissions goals. Notably, enterprises are more likely to actively respond to government initiatives and reduce emissions under the following two circumstances: (1) if the government introduces financial and tax incentives to promote the policy implementation of net-zero emissions (André and Valenciano-Salazar, 2022), or (2) if carbon emissions are effectively reflected in product pricing influencing market competition (Zhou and Qian, 2022).

3.2. Evolutionary game model construction

Public policy implementation often involves extensive bargaining and trade-offs among multiple stakeholders (Zhao, 2022). Consequently, policy implementers, including governments representing public interests and enterprises representing private interests, frequently engage in strategic games (Bardach, 1978; Bevan and Hood, 2006). Given this context, many scholars advocate the use of evolutionary game theory as a crucial theoretical and methodological tool for analyzing the interactions between governments, enterprises, and other policy actors (O'Toole Jr, 2000; McGill and Brown, 2007; Ding and Wei, 2023). The use of evolutionary game strategy and parameterization offers a valuable approach for analyzing decision-making process in real-world situations (Madani, 2010). Consequently, this article presents authentic scenarios derived from field study and literature research, which are the most common and effective methods used in academia (Sandholm, 2020; Zhou et al., 2023).

For the field study component, semi-structured interviews were conducted with government and enterprise employees, as well as detailed examination of the documents and materials referenced in the interviews. This included 23 government officials from departments such as development and reform, ecology and environment, market regulation, industry and information, energy, transportation, housing and construction, natural resources, agriculture and rural areas, etc.; and 27 enterprise employees from industries including energy, petrochemicals, iron and steel, transportation, construction, and agriculture, respectively. The field study aimed to focus on the initial attitude, strategy evolution and final decision-making process of both parties regarding the net-zero emissions goals and its policy implementation.

In terms of literature research, this study systematically reviewed existing literature related to the implementation of net-zero emissions policies. A total of 290 core journal articles, research reports, government news and enterprise summary materials were analyzed. The purpose of the literature research was to focus on the strategic choices, decision-making motivations, realistic considerations, cost investments, and expected benefits associated with the government and enterprises as they navigate the policy implementation of net-zero emissions goals.

Informed by the insights gathered through both the field study and literature research, this study defines the strategic options available to the government and enterprises involved in the game. The government's game strategy is categorized as either "positive absorption" or "negative absorption", representing proactive or reluctant engagement in collaborative climate governance, respectively. Concurrently, the strategies for enterprises are defined as "active response" or "passive response," indicating the level of their participation in achieving net-zero emissions goals (Fig. 1).

In describing the role of the government, the term (1) "positive absorption" refers to a shift away from traditional bureaucratic norms and the entrenched "subject-object" relationship in governance. Instead, it embraces a collaborative approach, encouraging active participation and integration of enterprises in policy implementation. Under this situation, the government actively engages or absorbs enterprise to participate in the implementation of net-zero emissions policy, facilitating their shift from passive to active decarbonization strategies. Undoubtedly, once the "subject-object relationship" between the government and the enterprise is weakened, the government will no longer overemphasize its domination and control over the object of governance (enterprise). On the contrary, the government tends to give enterprise a certain degree of autonomy to decarbonize, which is more conducive to the formation of a collaborative governance relationship between the two parties.

Conversely, (2) "Negative absorption" indicates the government's reluctance or refusal to positively engage enterprise to participate in the implementation of net-zero emissions policies, nor does the government seek collaborative governance support from the enterprise. This kind of "negative absorption" also includes scenarios where the government might engage in symbolic, selective, or alternative forms of absorption, despite higher-level directives encouraging active engagement. This strategy reflects a governmental stance that does not positively support collaborative governance, potentially leading to less effective policy implementation. It is assumed that the proportion of the government choosing "positive absorption" is $x = x(t)$, while the proportion of "negative absorption" is $1 - x = 1 - x(t)$.

In terms of enterprise strategy: (1) "active response" denotes that enterprises are willing to actively respond to the government's absorption behavior and voluntarily implement the net-zero emissions policy. From the field study it has been indicated that enterprises predominantly choose this active response strategy for two main reasons: first, the enterprise intends to actively fulfill their social responsibility of decarbonization by proactively implementing the government's net-zero emissions policy, which not only improves their market and societal reputation but also enhances their standing with the government; secondly, active engagement allows enterprises to better communicate their demands to the government in order to seek an appropriate reduction of its decarbonization goal, or more convenient access to the government's financial subsidies and administrative recognition.

On the other hand, (2) "Passive response" means that the enterprise is unwilling to actively implement the government's net-zero emissions policy, and has no intention of collaborating with the government to promote the policy implementation. Many enterprise managers explained during interviews that a "passive response" often serves as both a strategy for bargaining over decarbonization terms and reflects an ongoing strategic game between enterprise and the government, as well as reflects the reason why both sides are playing the game in the first place. They point out that in the initial stages of China's net-zero emissions policy implementation, the financial incentives and tax benefits of the net-zero emissions policy conducted by the government are not sound, and at the same time, carbon emissions have not yet been embedded into the products, prices, and or competitive market

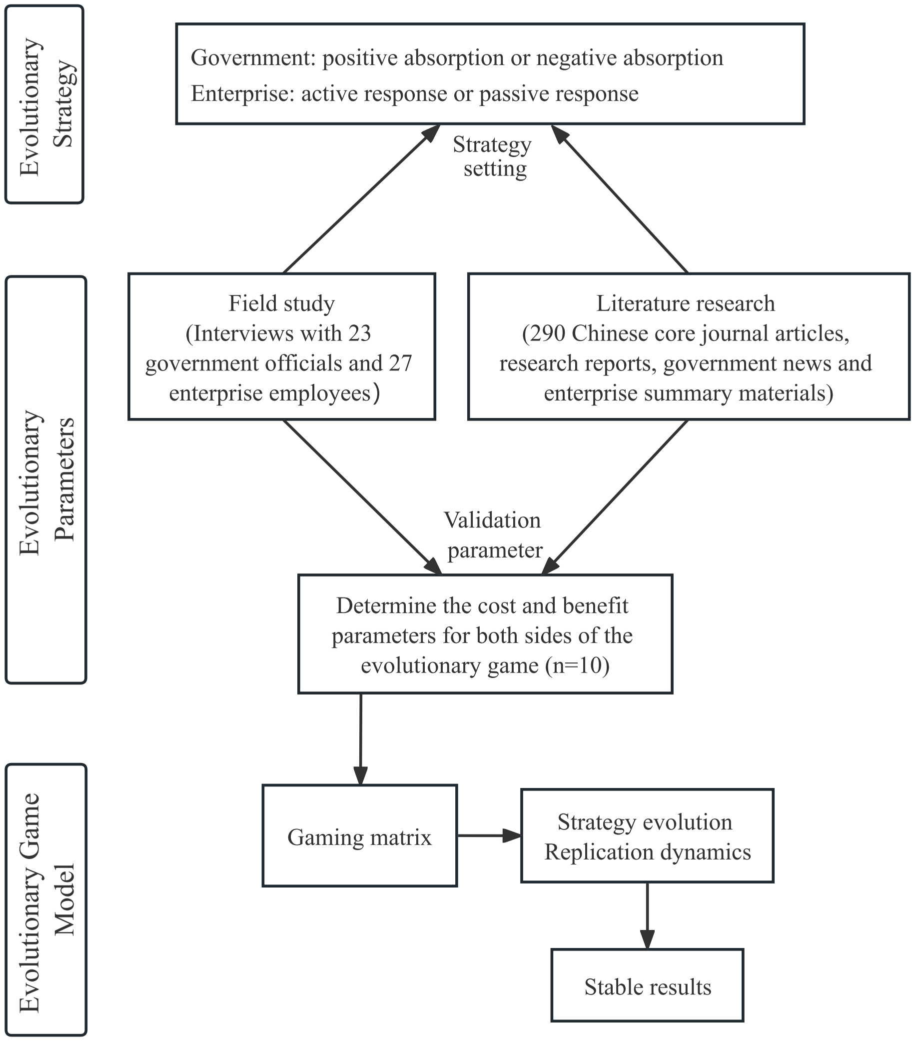

Fig. 1. Research methods and framework.

structures. This leads to insufficient incentives for many enterprises to decarbonize. From a practical point of view, non-public enterprises, especially those sensitive to decarbonization, tend to choose a "passive response" strategy in the short term. Assuming that the proportion of the enterprise adopting the "active response" strategy is $y = y(t)$, then the proportion of those choosing the "passive response" strategy is $1 - y = 1 - y(t)$.

4. Results

The results of the study encompass four main areas: (1) parameter setting and game matrix, (2) the dynamic game evolution between the government and enterprises, (3) the trends in the game strategies of the two sides, and (4) analysis of the stability and result of the evolutionary game system.

4.1. Parameter setting and game matrix

Informed by the field study and literature research, we established the parameters and game matrix based on principles of scientific accuracy and objectivity (Weibull, 1997; Zhang et al., 2023a).

4.1.1. Parameter setting

Based on the model assumptions in the previous section, our approach aims to maintain simplicity and analyzability, ensuring that the game parameters align with both theoretical logic and practical application (Zhou et al., 2023). Ultimately, this study defines a total of 10 game parameters, as outlined in Table 1.

4.1.2. Game matrix

Based on the above identified game strategies and parameters of both parties, this study constructs a game matrix for the government and enterprise interactions. To facilitate the analysis and discussion, "a" is used to denote the government and "b" is used to denote the enterprise (Table 2).

Firstly, when the government opts for "negative absorption" and the enterprise for "passive response", neither side is interested in collaborating on net-zero emissions policy implementation. However, similar to many countries, China has continued to advance its environmental governance and decarbonization policies even before the introduction of the "1+N" net-zero emissions policy framework. Since 1992, China has evolved through various stages of decarbonization policy development, including: sustainable development, energy savings and emission reductions, new industrialization, scientific development concepts, a resource-saving and environmentally friendly society, the carbon market, the circular economy, the ecological civilization, beautiful China, a comprehensive green transformation, and finally, achieving net-zero emissions (Fig. 2). It is worth noting that many of the previous policy measures remain active, such as the strengthening of "dual control" over total energy volume and intensity, requiring all listed enterprises to

Table 1
All parameters in the evolutionary game model.

No.	Parameters	Strategies				Definitions
		Government		Enterprise		
		Positive absorption	Negative absorption	Active response	Passive response	
1	M		●		●	Benefits of the government
2	N		●		●	Benefits of the enterprise
3	A	●			●	Costs of the government
4	B	●			●	Benefits of the enterprise
5	C		●	●		Benefits of the government
6	D		●	●		Costs of the enterprise
7	A_1	●		●		Costs of the government
8	D_1	●		●		Costs of the enterprise
9	P	●		●		Benefits of the government
10	Q	●		●		Benefits of the enterprise

Notes: "●" denotes the strategy chosen by both sides in the game.

Table 2
Game matrix between the government and enterprise.

		Game party "b" (Enterprise)	
		Active response (y)	Passive response ($1 - y$)
Game party "a" (Government)	Positive absorption (x)	$M - A_1 + P$, $N - D_1 + Q$	$M - A$, $N + B$
	Negative absorption ($1 - x$)	$M + C$, $N - D$	M, N

comply with carbon disclosure requirements, and controlling fossil energy consumption. Additionally, various incentive policy instruments are still in force, including carbon emissions trading markets, carbon taxes, carbon subsidies, green investment and financing, clean energy allowances, etc. Thus, even without active government absorption of the enterprise in the policy implementation of net-zero emissions, existing policies continue to exert influence. For the enterprises that choose the "passive response" strategy, they are still obliged to meet the minimum decarbonization goals due to ongoing policy mandates. Through the process of phasing out high-carbon industries and enhancing clean energy development and decarbonization technology innovation, enterprises can benefit from financial subsidies and market advantages such as carbon trading revenues, enhanced reputation for fulfilling social responsibilities, and increased market competitiveness. This study uses M and N to denote the benefits of both sides when the government chooses the strategy of "negative absorption" and the enterprise selects the strategy of "passive response", respectively.

Secondly, when the government selects "positive absorption" and the enterprise opts for "passive response", the government incurs certain costs, such as administrative resources and financial funds, to actively absorb and involve the enterprise. In the policy implementation of net-zero emissions, enterprises are often the object of policy implementation or, alternatively, the target of the decarbonization regulation. Particularly for many non-public enterprises, the initial costs and profit impacts of decarbonization often make them reluctant to actively implement net-zero emissions policies at this early stage. Consequently, it becomes relatively difficult for the government to positively absorb the enterprise, and the costs of investing in administrative resources and financial funds are inevitably higher. However, it is undeniable that once the government engages in "active absorption", increasing its investment costs, the enterprises stand to benefit accordingly. In summary, this study uses A and B to denote the government's investment costs and the enterprise's benefit. Therefore, under this strategy combination, the benefits to the government and enterprise are $M - A$ and $N + B$, respectively.

Thirdly, the combination where the government opts for "negative absorption" and the enterprise opts for "active response" illustrates still different dynamics. The government may resist involving enterprises due to traditional governance models that emphasize the distinction between "the subject and the object of governance" and a performance-oriented "short-termism" that diminishes the appeal of long-term benefits. However, enterprises may still choose an "active response" despite the government's "negative absorption". This independence stems from ongoing obligations under existing decarbonization policies and a strong sense of social responsibility or strategic foresight into the future

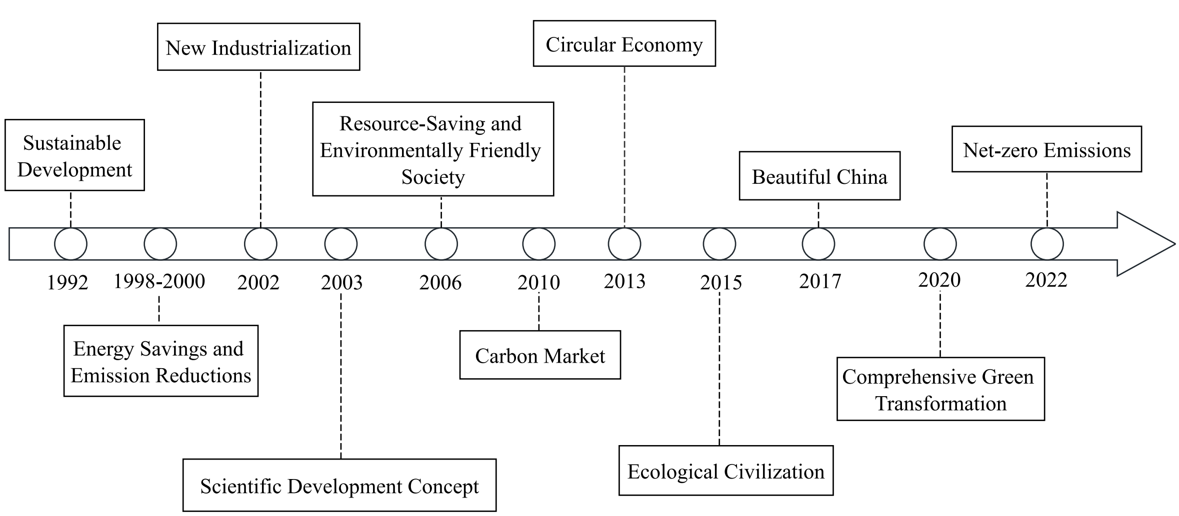

Fig. 2. The history of China's decarbonization policies.

competitiveness of their products linked to carbon emissions. Thus, even if the government is disengaged, enterprises driven by their own agendas can still advance their decarbonization efforts. In this scenario, we use D to denote the cost of the enterprise's "active response", with no additional cost to the government, which benefits from the enterprise's proactive stance in net-zero emissions policy implementation, denoted by C. Therefore, the benefits to the government and the enterprise under this strategy are $M+C$ and $N-D$, respectively.

Lastly, that the ideal scenario occurs when both the government opts for "positive absorption" and the enterprise opts for "active response". Undoubtedly, this is the most desirable combination of strategies for both sides, and it is likely to occur in the middle and late stages of the evolutionary game, i.e., in the mid-to-late stages of net-zero emissions policy implementation. Here, both sides will incur costs, with the government's costs, denoted as A_1, being higher than its cost in scenarios involving the enterprise's "passive response". In general, A_1 is greater than A. Similarly, the enterprise's cost, D_1, is greater than D at this point. In addition, the benefits of both the government and enterprise under this strategy combination are represented by P and Q, respectively. As a result, the benefits to the government and enterprises under this combination of strategies are $M-A_1+P$ and $N-D_1+Q$. With the gradual implementation of the "1+N" net-zero emissions policy, the government's fiscal and tax incentives will become more sound, and simultaneously carbon emissions will also inevitably be embedded into the products, prices, and market competition of the enterprise. At this time, the probability of the government choosing "positive absorption" and the enterprise selecting "active response" increases significantly, and both parties will realize that investing more costs than A_1 and D_1 in the process of net-zero emissions policy implementation will result in more benefits than P and Q. This scenario fosters a virtuous circle of where increased investment by both sides leads to greater benefits, thus enhancing the propensity for further cost investment and facilitating the organic collaboration between the government and enterprise in the implementation of net-zero emissions policy.

4.2. Dynamic game evolution

In the process of evolutionary games, both government and enterprise learn and imitate continuously. They dynamically adjust their behaviors according to each other's strategic choices, which in turn affects the dynamic evolutionary trends in the game, reflecting a continuous interplay that shapes the progress and outcomes of the game strategies. This section provides a detailed examination of how both parties adjust their behaviors and strategies over time, underscoring the fluid and interactive nature of the evolution game in policy implementation contexts.

4.2.1. Dynamic game evolution of the government

As for the dynamic evolution of the game party "a" (government), the benefits of the strategies of "positive absorption" and "negative absorption" are as follows:

$$U_{a_x} = (M - A_1 + P)y + (M - A)(1 - y) \tag{1}$$

$$U_{a_{1-x}} = (M + C)y + M(1 - y) \tag{2}$$

The average benefits of adopting the strategies of "positive absorption" and "negative absorption" by the government are:

$$\begin{gathered} \overline{U_a} = U_{a_x} \cdot x + U_{a_{1-x}} \cdot (1 - x) \\ = [(M - A_1 + P)y + (M - A)(1 - y)] \cdot x + [(M + C)y + M(1 - y)] \cdot (1 - x) \\ = -A_1xy + Pxy - Ax + Axy + Cy - Cxy + M \end{gathered} \tag{3}$$

If $U_{a_x} > \overline{U_a}$, it can be concluded that the strategy of "positive absorption" can bring above-average benefits, and the proportion x of "positive absorption" increases over time, while $U_{a_x} < \overline{U_a}$ means that the proportion of "positive absorption" decreases over time. At this time, $x = x(t)$ evolves according to the direction determined by the following replication differential equation:

$$\begin{gathered} G(x) = \frac{dx}{dt} = x(U_{a_x} - \overline{U_a}) \\ = x(-A_1y + Py + M - A + Ay + A_1xy - Pxy + Ax - Axy - Cy + Cxy - M) \\ = x(1 - x)[(P + A - A_1 - C)y - A] \end{gathered} \tag{4}$$

The steady-state value describes the level at which the government chooses the strategy of "positive absorption" through dynamic evolution, denoted as x^*. At this point, $\frac{dx}{dt} = 0$ must be satisfied. Two possible steady-state outcomes, $x^* = 0$ and $x^* = 1$, are solved by equation (4).

4.2.2. Dynamic game evolution of the enterprise

As for the dynamic evolution of the game party "b" (enterprise), the benefits of the strategies of "active response" and "passive response" are quantified as follows:

$$U_{b_y} = (N - D_1 + Q)x + (N - D)(1 - x) \tag{5}$$

$$U_{b_{1-y}} = (N + B)x + N(1 - x) \tag{6}$$

The average benefits of adopting "active response" and "passive response" are as follows:

$$\begin{gathered} \overline{U_b} = U_{b_y} \cdot y + U_{b_{1-y}} \cdot (1 - y) \\ = [(N - D_1 + Q)x + (N - D)(1 - x)] \cdot y + [(N + B)x + N(1 - x)] \cdot (1 - y) \\ = -D_1xy + Qxy - Dy + Dxy + Bx - Bxy + N \end{gathered} \tag{7}$$

The differential equation for the enterprise is:

$$\begin{gathered} G(y) = \frac{dy}{dt} = y(U_{b_y} - \overline{U_b}) \\ = y(-D_1x + Qx + N - D + Dx + D_1xy - Qxy + Dy - Dxy - Bx + Bxy - N) \\ = y(1 - y)[(Q + D - D_1 - B)x - D] \end{gathered} \tag{8}$$

As shown in the equation, y^* is used to represent the proportion to which the enterprise replicates the dynamic stable state. y^* must satisfy $G(y) = \frac{dy}{dt} = 0$. According to equation (8), $y^* = 0$ and $y^* = 1$ are two possible stable states.

4.3. Trends in the game strategies

In the following, the trends of game strategies of the government and the enterprise will be analyzed separately.

4.3.1. Trends in the game strategies of the government

According to dynamic equation (4), let $G(x) = \frac{dx}{dt}$; the first derivative is:

$$\begin{aligned} G'(x) &= \{x(1 - x)[(P + A - A_1 - C)y - A]\}' \\ &= [(P + A - A_1 - C)y - A](1 - 2x) \end{aligned} \tag{9}$$

When $y = \frac{A}{P+A-A_1-C}$, there is always $G(x) = 0$; that is, all x levels are stable. In this case, the replication dynamics of the government are shown in Fig. 3 (a). It suggests that when the enterprise chooses "active response" in proportion to $\frac{A}{P+A-A_1-C}$, there is no difference in benefits between the government's two strategies of "positive absorption" and "negative absorption"; namely, all x levels are at the stable state for the government.

When $y > \frac{A}{P+A-A_1-C}$, $x^* = 0$ and $x^* = 1$ are two possible stability points of x. Due to $G'(1) < 0$, $x^* = 1$ is the stable evolutionary strategy, and the replication dynamics of the government are shown in Fig. 3 (b). This suggests that when the enterprise chooses the strategy of "active response" at a higher ratio than $\frac{A}{P+A-A_1-C}$, the government will gradually

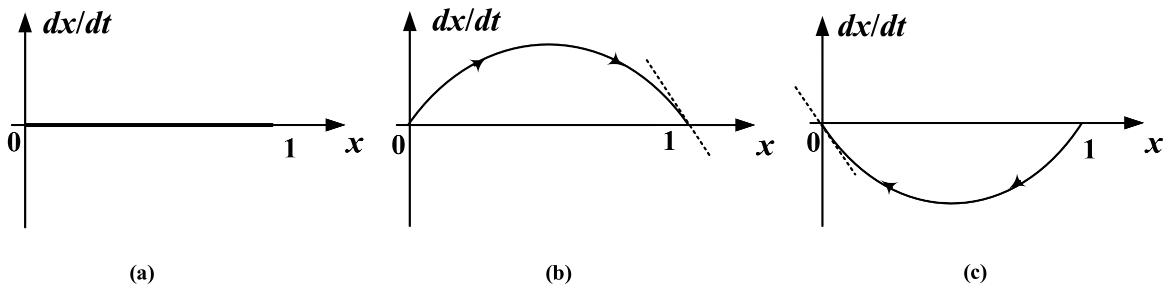

Fig. 3. Government replication of dynamic phase diagram.

change from "negative absorption" to "positive absorption"; namely, under these conditions, the government is inclined to absorb enterprises as the policy implementers of net-zero emissions.

Conversely, when $y < \frac{A}{P+A-A_1-C}$, $x^* = 0$ and $x^* = 1$ again emerge as two possible stability points of x. Because $G'(0) < 0$, $x^* = 0$ is the stable evolutionary strategy, and the replication dynamics of the government are shown in Fig. 3 (c). This indicates that if the enterprise chooses the strategy of "active response" at a lower ratio than $\frac{A}{P+A-A_1-C}$, the government strategy will gradually change from "positive absorption" to "negative absorption". In this scenario, the government does not favor absorbing the enterprise as the policy implementer of net-zero emissions.

4.3.2. Trends in the game strategies of the enterprise

According to dynamic equation (8), $G(y) = \frac{dy}{dt}$; the first derivative is defined as:

$$\begin{aligned} G'(y) &= \{y(1-y)[(Q+D-D_1-B)x-D]\}' \\ &= [(Q+D-D_1-B)x-D](1-2y) \end{aligned} \tag{10}$$

When $x = \frac{D}{Q+D-D_1-B}$, there is always $G(y) = 0$; that is, all y levels are stable. As shown in Fig. 4 (a), when the government chooses the strategy of "positive absorption" in proportion to $\frac{D}{Q+D-D_1-B}$, there is no difference in benefits between the enterprise's two strategies of actively and passively responding to the government's absorption behavior; namely, all y levels are stable in the enterprise.

When $x > \frac{D}{Q+D-D_1-B}$, $y^* = 0$ and $y^* = 1$ are two possible stability points. Due to $G'(1) < 0$, as shown in Fig. 4 (b), $y^* = 1$ becomes the stable evolutionary strategy for the enterprise. That is, at this time, when the government chooses the strategy of "positive absorption" with a ratio higher than $\frac{D}{Q+D-D_1-B}$, the enterprise will gradually shift from "passive response" to "active response". Under these circumstances, "active response" is the stable evolutionary strategy of the enterprise, signaling the enterprise's greater willingness to actively implement net-zero emissions policies. At this time, if the government is more positively supportive of the "active response" of enterprise, it will further increase the willingness of enterprises to collaborate, thus making them more proactive in promoting the policy implementation of net-zero emissions. In this case, the enterprise and government will gradually converge on their net-zero emissions goals.

Conversely, when $x < \frac{D}{Q+D-D_1-B}$, due to $G'(0) < 0$, $y^* = 0$ becomes the stable evolutionary strategy of the enterprise. In this situation, as shown in Fig. 4 (c), when the government chooses the strategy of "positive absorption" with a ratio lower than $\frac{D}{Q+D-D_1-B}$, the enterprise will gradually shift from "active response" to "passive response"; namely, "passive response" is the stable evolutionary strategy of the enterprise, indicating a reduction in their active engagement in net-zero emissions initiatives.

4.4. Stability and results of evolutionary game system

In this section, the study delves into two critical aspects of the evolutionary game system: (1) the analysis of its stability, and (2) the examination of how game parameters influence the outcomes. This approach provides a comprehensive understanding of the dynamics within the system.

4.4.1. Stability of evolutionary game

The stable state of the evolutionary game model indicates a scenario where the proportion of strategies between the game parties remains consistent, and their replication behavior is in a balanced state (McGill and Brown, 2007). The steady state value is denoted as x^* and y^*. Equations (4) and (8) describe the dynamic replication equations of the evolutionary game model, and the five equilibrium points (x,y) can be solved as follows: O (0, 0), R (0, 1), T (1, 0), S (1, 1), V $\Big(\frac{D}{Q+D-D_1-B},$

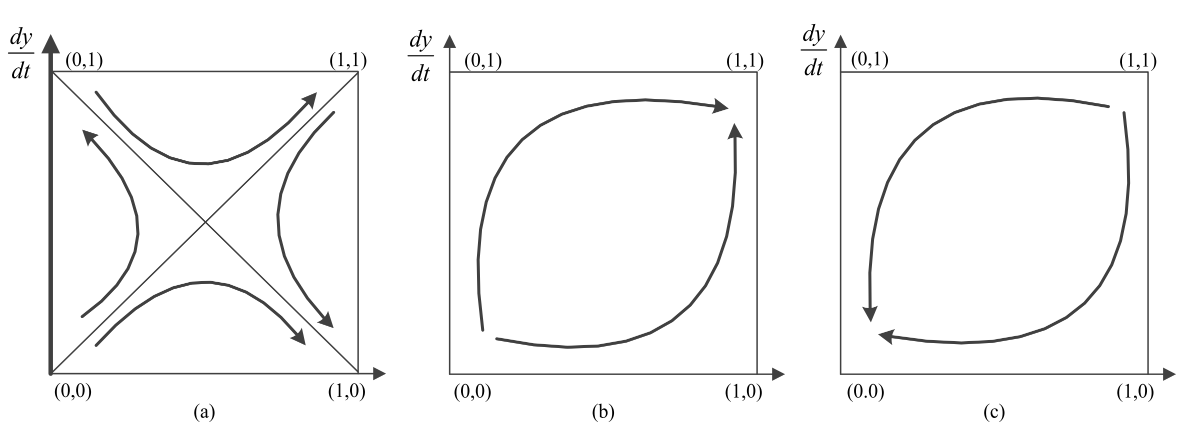

Fig. 4. Enterprise replication of dynamic phase diagram.

$\frac{A}{P+A-A_1-C}\Big)$.

Friedman (1991) suggested that the stability of the partial equilibrium point of a group dynamic system, as described by a system of differential equation, can be obtained by using a Jacobian matrix. The analysis of the Jacobian matrix's partial stability can determine the stability of the equilibrium points of the group dynamic system described by formulas (4) and (8). The determinant and its trace of the Jacobian matrix corresponding to these two formulas are respectively:

$$De(\mathrm{J}) = \begin{vmatrix} \frac{\partial G(x)}{\partial x} & \frac{\partial G(x)}{\partial y} \\ \frac{\partial G(y)}{\partial x} & \frac{\partial G(y)}{\partial y} \end{vmatrix} \text{ and } Tr(\mathrm{J}) = \frac{\partial G(x)}{\partial x} + \frac{\partial G(y)}{\partial y}$$

As shown in Table 3, only 2 equilibrium points of the evolutionary game system have partial stability; that is, the stable evolutionary strategies of the system are O $(0,0)$ and S $(1,1)$. In this case, the government chooses the strategy of "negative absorption", and the enterprise selects the strategy of "passive response". Alternatively, the government selects the strategy of "positive absorption", and the enterprise choose to "active response" to the government's absorption behavior in the process of net-zero emissions policy implementation. Moreover, the evolutionary game system also has two unstable equilibrium points R $(0,1)$ and T $(1,0)$, and one saddle point V $\left(\frac{D}{Q+D-D_1-B}, \frac{A}{P+A-A_1-C}\right)$.

The replication dynamics between the government and enterprise is depicted in Fig. 5, further illustrating the stability dynamics. And the evolution of the game system hinges on the initial proportion x_0 of "positive absorption" by the government and the initial proportion y_0 of "active response" by the enterprise. That is, the initial state of the game system determines its final convergence direction. For example, if the initial state (x_0, y_0) is located in the ORVT quadrilateral, the system will converge to the stability point O $(0,0)$ of the ESS system, where both parties adopt "negative absorption" and "passive response". In contrast, if the initial state (x_0, y_0) is within the RSTV quadrilateral, the system will converge to stability point S $(1,1)$. In the end, this will evolve into a situation where the government will choose the strategy of "active absorption", while the enterprise will also be engaging in "active response" to the absorption behavior, collaboratively promoting the policy implementation of net-zero emissions.

4.4.2. Moderating effects of game parameters on the game results

As can be seen from the analysis of the stability, the game behavior of the government and enterprise depends on their initial strategic choices. By modifying game parameters that influence initial values, the area of RSTV can be expanded, reducing the ORVT region, thereby steering the evolutionary game system towards the most favorable equilibrium state, S, with the highest probability.

Table 3
Results of partial stability analysis for the equilibrium points.

Equilibrium point	De (J)	Tr (J)	Partial stability
O $(0,0)$	+	–	Evolutionary stable strategy (ESS)
R $(0,1)$	+	+	Unstable
T $(1,0)$	+	+	Unstable
S $(1,1)$	+	–	Evolutionary stable strategy (ESS)
V $\left(\frac{D}{Q+D-D_1-B}, \frac{A}{P+A-A_1-C}\right)$	–	0	Saddle points

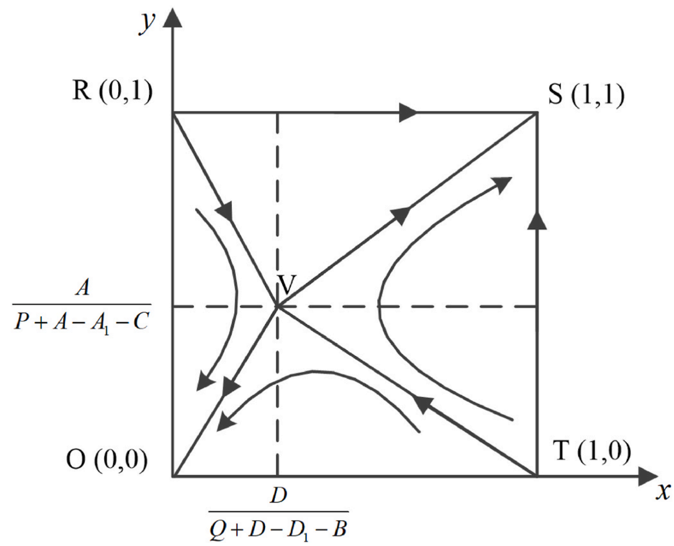

Fig. 5. Dynamics and stability of the government and enterprise.

(1) Parameters *A* and *D*

Parameter *A* represents the government's investment when it chooses the strategy of "positive absorption" and the enterprise selects "passive response". While *D* indicates the cost to the enterprise when the government chooses the strategy of "negative absorption" and the enterprise prefers "active response". At the saddle point *V*, both *A* and *D* act as numerator and denominator. Firstly, in terms of the numerator, when the *A* and *D* are increased, both lead to a larger value of the horizontal and vertical coordinates of the saddle point V, i.e., this expansion increases the area of the ORVT region while decreasing the RSTV region, favoring the evolutionary game system's progression towards the ESS stabilization point O. Second, with regard to the denominator, take D as an example, D is the additive number in the horizontal coordinate of the saddle point V. It is found that Δ_D, a simultaneous change in the numerator and denominator, does not have an inverse effect on the final result of the fractional equation, i.e., an increase in D will make the horizontal coordinate of the saddle point V larger, and this result is the same as that of the numerator analysis alone. Similarly, the vertical coordinates of saddle point V will become larger when A increases. In other words, the results of both numerator and denominator analysis show that when A and D increase, the horizontal and vertical coordinates of saddle point V will increase. At this time, the saddle point V will move to the upper right, and the area of ORVT will increase, while the region of RSTV will decrease. Accordingly, the game system evolves into a strategic combination of "negative absorption" by the government and "passive response" by the enterprise.

(2) Parameters *P* and *Q*

These two parameters represent the benefits of the two game parties when the government positively absorbs the enterprise to collaborate in the policy implementation of net-zero emissions and the enterprises respond proactively. Both the horizontal and vertical coordinates of the saddle point V decrease when P and Q increase. At this time, the saddle point will move to the lower left, i.e., the area of the ORVT decreases, and the region RSTV increases. As a result, the probability of the game system evolving to the ESS stabilization point S $(1,1)$ increases. In other words, the game system will evolve into a strategic combination of "positive absorption" by the government and "active response" by the enterprise. In this case, the government and enterprise will form a virtuous circle of mutual promotion: the government actively absorbs the enterprise → the enterprise actively response to the policy implementation of net-zero emissions → the effectiveness of the net-zero emissions policy is improved → the willingness and motivation of both parties to collaborate in the policy implementation of net-zero emissions will be stronger. At this point, the two sides will be transformed from a game to a collaboration. This transformation can maximize the organic collaboration between the government and enterprise, thus realizing a win-win situation for the policy implementation of net-zero emissions.

(3) Parameters A_1, D_1, B and C

A_1 and D_1 denote the investment costs of the two game parties when the government chooses the strategy of "positive absorption" and the enterprise selects the strategy of "active response", respectively. B is the benefit to the enterprise when the government chooses "positive absorption" and the enterprise prefers "passive response". C, in turn, represents the benefit to the government when it is negatively absorbing, and the enterprise is actively engage in the process of net-zero emissions policy implementation. When A_1, D_1, B and C increase, the horizontal and vertical coordinates of saddle point V are both larger, i.e., saddle point V will move to the upper right, the area of ORVT will increase, and the region of RSTV will decrease. Accordingly, the game system will gradually converge to the ESS stabilization point O $(0, 0)$. That is, the game system will eventually evolve strategy combinations in which the government chooses "negative absorption", and the enterprise selects "passive response" in the face of collaborative implementation of the net-zero emissions policy. Obviously, this will impede the realization of collaborative governance and may even become an obstacle to the policy implementation of net-zero emissions.

5. Discussions

This section investigates the dynamics of evolutionary game theory in the context of two-party collaboration, focusing on (1) the effect of gaming behavior on collaboration between two parties, (2) the role of cost-benefit mechanisms in government-enterprise interactions, and (3) the development of incentive-compatible mechanisms that facilitate a shift from game-based dynamics to organic collaboration.

5.1. The effect of gaming behaviour on two-party collaboration

The results indicate that adjusting game parameters significantly influences the evolution and convergence of the game system. This influence mirrors the distinct game logics and behavioral motivations of the government and enterprises. During the implementation of net-zero emissions policies, if one party exhibits a non-cooperative or passive stance, achieving the desired policy benefits becomes challenging—even if the other party bears greater costs. Under such circumstances, the investment by one party does not elicit a constructive response from the other, hindering the creation of economies of scale and collaborative impacts essential for effective policy implementation. Moreover, if this misalignment continues, it can exacerbate negative influences on the behavior of both parties. Economically, substantial scale effects and benefits are more likely when all stakeholders demonstrate a proactive and collaborative investment behavior. Conversely, relying on the unilateral cost investments of one party rarely yields optimal economic returns or policy outcomes. Notably, persistent lack of reciprocal benefits can lead a party to progressively diminish its investment, adversely affecting the long-term sustainability of net-zero emissions policies.

This is particularly evident in the beginning stages of the implementation of the net-zero policy. Initially, the high costs of decarbonization may lead enterprises to passively respond to government initiatives (Zhou and Qian, 2022). Over time, as the government introduces more policy tools and fiscal incentives and a competitive market environment emerges based on carbon emissions, enterprises are more likely to adopt an "active response" strategy. This shift facilitates the convergence towards the ideal ESS stabilization point, where the government opts for "active absorption" and enterprises engage actively. This optimal strategic alignment not only maximizes benefits for both parties but also fosters organic collaborative governance, enhancing the overall effectiveness of net-zero emissions policies.

5.2. Mechanisms of cost-benefit on government-enterprise collaboration

As can be seen from the moderating effects of game parameters, the cost and benefit under any kind of strategy choice is an important dependent variable affecting the game and the collaboration between the government and enterprise. Existing studies have also shown that the imbalance of cost-benefit expectations is an important reason for the obstruction of policy implementation (Zhou et al., 2023). The game parameters are precisely the costs and benefits of the government and enterprise in the policy implementation of net-zero emissions. The adjustment of these game parameters will lead to the imbalance of the cost-benefit expectation of the game parties, which in turn produces the policy implementation obstruction and impacts the organic collaboration between the government and enterprise. Similarly, Bardach (1978) found that in many of the policy implementation game process, the policy implementers are trying to maximize the benefits and minimize inputs, which easily produces a cost-benefit imbalance in expectation. In the process of net-zero emissions policy implementation, the objective of the game between the government and enterprise is to get a greater benefit with the lowest cost (or even no cost). Therefore, they all try to be a "free-rider" (Olson Jr, 1971) and thus reduce their own costs. Nonetheless, this will prevent a more equitable and sustainable collaborative implementation of net-zero emissions policies in the long run.

By adjusting the costs and benefits, it is more conducive to the realization of the evolutionary equilibrium and organic collaboration between the two parties (Zhou et al., 2023). Here, the cost-benefit adjustment of different game parameters is a matter of cost-benefit distribution between the government and enterprise in the process of net-zero emissions policy implementation. That is, a more optimized adjustment mechanism for the distribution of costs and benefits between the two sides will better promote the organic collaboration between the two parties. To identify the distribution of costs and benefits between the two sides, it is essential to first clarify the behavioral preferences of the government and enterprise, since the preferences affect and determine the investment costs of both parties. Subsequently, the benefits of policy actions based on their different preferences should also be analyzed, so as to better realize the organic collaboration between the two sides.

In general, there is a difference between the preferences of government and enterprise, and it is this difference that leads to the evolutionary game between the two sides in the process of net-zero emissions policy implementation. Fortunately, the results of the evolutionary game show that preferences do not always make the government and enterprise naturally opposed to each other. As long as the internal motivation of such preferences is clarified, the preferences of both sides can be gradually converged, thus resulting in organic collaboration and the sustainable development targets of public policies will be more readily realized (Florini and Pauli, 2018). In fact, when there are differences in preferences regarding net-zero emissions policy implementation, this may lead to a game of interests between the two sides, but it is not necessarily entirely counterproductive to the collaboration between the government and enterprise. In this study's Chinese field work, it was found that this situation is likely to be a "pre-psychological battle" between the two sides at the beginning of the policy implementation of net-zero emissions, where each side may be testing the other's behavioral responses and cost investments. On the contrary, even if it is not the case, this divergence of preferences is not difficult to resolve. Once the government can actively absorb the enterprise to implement the net-zero emissions policy, it is often possible to transfer the preferences of both sides (and the motivation for their preferences) into the process of policy implementation. As long as net-zero emissions policies are implemented, the divergence of preferences between the government and enterprise will continue to be addressed, which in turn continually tends to the organic collaboration between the two parties.

As the government official responsible for the policy implementation of net-zero emissions stated, "*the government should widely absorb the enterprise to implement the net-zero emissions policy, and when the enterprise is substantially involved, many problems will no longer be ambiguous. Consequently, many problems of divergent preferences and games of interests will be effectively resolved*".

In other words, once the government continuously absorbs the enterprise to jointly implement the net-zero emissions policy, it can bring the divergence of preferences between the two sides into the process of policy implementation and policy optimization, so as to actively seek the "greatest common denominator" of cost-benefit between the government and enterprise. In this way, the overall benefit effect can be improved through Pareto improvement (Couckuyt et al., 2014), and the divergence of preferences and the game of interests between the two sides can thus be minimized. Consequently, the organic collaborative governance between the government and enterprise can be gradually realized.

5.3. Incentive-compatible mechanism: from evolutionary game to organic collaboration

In the evolutionary game of net-zero emissions policy implementation, if the government can establish more incentive-based institutional arrangements and policy tools for enterprise — In accordance with the principle of incentive compatibility (Akçay and Roughgarden, 2011; Stephan et al., 2019) — It can significantly improve the utility function of both parties, and thus better realize the organic collaboration of the government and enterprise. Following this logic, the government needs to move from a gradual reduction of traditional mandatory decarbonization regulations to an incentive-based collaborative guidance. More specifically, the government should shift from administrative compulsion to administrative service and market mechanism, from subject-centrism to object-centrism, and from management-centrism to service-centrism (Zhou and Qian, 2022). Admittedly, in the initial stage of net-zero emissions policy implementation, the government does need to fully rely on the top-down hierarchical organization to ensure the decarbonization of high-energy-consuming and high-emission enterprise through political mobilization, administrative decree and policy regulation. However, as the implementation process of net-zero emissions policy progresses and carbon emissions are gradually decoupled from economic development, the regulatory approach adopted in the past will have to be progressively shifted to incentive compatibility.

Many public policy practices have long shown that the consistent reliance on the government's monocentric governance will hardly achieve its established policy goals but may instead create more obstacles to policy implementation (Berardo and Lubell, 2019). Therefore, the future direction of the net-zero emissions policy implementation paradigm must be to gradually shift from policy regulation to incentive compatibility. In this shifting process, the government needs to make full use of a series of non-compulsory, market-based incentive mechanisms to promote enterprise's self-awareness in practicing the concept of green and low-carbon development, voluntarily progressing the enterprise's decarbonization agenda. In fact, this paradigm shift can be understood as a kind of incentive for the policy implementation of net-zero emissions for enterprises. As long as this shift can produce more non-coercive market instruments, then it will certainly be able to incentivize the autonomy, initiative and motivation of the enterprise to decarbonize. If the government makes such incentives more visible through written contracts, including tax design, financial subsidies, economic support and other policy tools, it brings the public and enterprise back into governance (Archon, 2015). It is clear that in the field of net-zero emissions policy implementation, these visible, incentive-compatible mechanisms will be more effective in achieving organic collaborative governance between the government and enterprises for better sustainable environment.

6. Conclusions

Both government and enterprise are important policy implementers of net-zero emissions. However, the heterogeneous interests of both parties inevitably lead to a game of interests. This study has systematically explored the strategic interactions between government and enterprise in the context of net-zero emissions policy implementation. It has uncovered the internal mechanisms of these interactions and outlined how they can evolve from competitive games to collaborative governance. The findings demonstrate that optimal outcomes are realized when government initiatives actively engage enterprises, which in turn respond positively, aligning their interests with policy goals. By adjusting game parameters and optimizing cost-benefit distributions through incentive-compatible policy arrangements, the study shows that it is possible to achieve a stable state of collaborative governance. These strategies not only promote more effective policy implementation but also foster a sustainable partnership conducive to achieving net-zero emissions.

This research substantiates the feasibility and necessity of collaborative governance within the framework of net-zero emissions policy implementation. As we advance in the global green transition, it becomes increasingly important to envision how governance models might adapt to enhance policy effectiveness. Future models should emphasize the collaborative efforts of multiple stakeholders to address the complex challenges posed by environmental and climate policies. Although this study quantifies the game of interests between the government and enterprise, revealing the ideal conditions for the realization of organic collaboration that may expand theoretical knowledge on collaborative governance and inform global net-zero emissions efforts, it has limitations. First, the evolutionary game matrix employed is a simple 2*2 model, which may not capture all complexities. Secondly, the focus on the intrinsic mechanism and conditions for collaboration meant less attention was paid to simulating evolutionary game outcomes. Future research could employ more complex evolutionary game matrices and, at the same time, simulate the results with the help of software such as MATLAB to further validate and enrich the research in this field.

CRediT authorship contribution statement

Cheng Zhou: Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Clare Richardson-Barlow:** Software, Methodology, Data curation, Conceptualization. **Linyan Fan:** Software, Investigation, Conceptualization. **Helen Cai:** Resources, Methodology, Formal analysis, Data curation, Conceptualization. **Wanhao Zhang:** Writing – original draft, Supervision, Resources, Project administration, Investigation, Conceptualization. **Zhenhua Zhang:** Validation, Supervision, Project administration, Conceptualization.

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Declaration of competing interest

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

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Data availability

Data will be made available on request.

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