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Mission relationships, employment relationships, or alliance relationships: wetland management from the perspective of carbon trading

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In recent years, wetland ecosystems have faced severe degradation, prompting governments to provide carbon compensations to enterprises engaged in wetland conservation efforts. The relationships between governments and enterprises in wetland management are primarily categorized into three models: mission relationships, employment relationships, and alliance relationships. Determining the optimal application scope for each model remains a critical challenge. To address this, this paper constructs three differential game models and conducts a comparative analysis of their equilibrium outcomes. The findings reveal distinct optimal scenarios for governments and enterprises. For governments, the employment relationships model maximizes social benefit when the per-unit benefit of wetland management is small; the mission relationships model is optimal for moderate benefits, and the alliance relationships model for large benefits. For enterprises, the employment relationships model maximizes social benefit when the per-unit benefit is small; the alliance relationships model is optimal for moderate benefits, and the mission relationships model for large benefits.

KEYWORDS

wetland ecosystems, differential games, carbon offsets, maximizing benefits, government governance

1 Introduction

1.1 Background and research significance

Wetlands are among the most vital ecosystems on Earth, boasting rich biodiversity and providing a multitude of ecological services. They serve as habitats and breeding grounds for species such as waterfowl, fish, amphibians, and aquatic plants, making them critical areas for biodiversity conservation (Wadle et al., 2024). Wetlands have the capacity to absorb and store significant amounts of floodwater, mitigating flood peaks and reducing flood risks (Bhattacharya et al., 2024). Their water storage capability is essential for regulating surface and subsurface water flows, maintaining the hydrological cycle, and supplying water to surrounding regions during dry seasons (Yuan et al., 2025b). Wetlands play a crucial role in carbon storage, positively impacting the mitigation of global climate change. Some wetlands also generate sediments, promoting land growth and even the formation of new islands (Rashid et al., 2023). Additionally, wetlands provide resources for human activities such as fisheries and agriculture, and hold recreational, tourism, and educational value.

However, wetlands are facing severe degradation. Firstly, biodiversity is being lost, as many aquatic and terrestrial species depend on wetlands for survival. The destruction of wetlands leads to habitat loss, resulting in species decline or even extinction (Londe et al., 2024). Secondly, water quality is deteriorating, with the filtering and self-purification capacities of wetlands declining, potentially increasing pollutants in surface and groundwater, affecting water safety for humans and ecosystems (Zhang W. et al., 2024). Thirdly, flood control capabilities are weakening, as damaged wetlands cannot effectively mitigate flood impacts or store floodwater, potentially increasing flood risks (Tillman and Matthews, 2023). Fourthly, carbon emissions are rising, particularly from peatlands that store large amounts of carbon. When damaged, this carbon is released into the atmosphere, exacerbating the greenhouse effect and climate change (Xie et al., 2023). Fifthly, changes in groundwater levels occur, with the drying and destruction of wetlands leading to a decline in groundwater levels, affecting groundwater recharge and the hydrological cycle (Anza et al., 2019). The destruction of wetlands is primarily caused by urban development, land-use changes, agricultural expansion, water conservancy projects, and sewage discharge (Robson and Drouillard, 2024).

To prevent further destruction and sustainably manage wetland resources, effective management measures and proactive environmental protection actions are necessary. In the process of wetland governance, three main relationships exist between governments and enterprises: mission relationships, employment relationships, and alliance relationships. Mission relationships emphasize cooperation based on shared environmental protection or carbon reduction goals, focusing on long-term visions and strategic alignment (Zhang et al., 2023b). Employment relationships refer to the clear delineation of responsibilities and benefit distribution in wetland management through hiring or contractual forms, typically characterized by clear power structures and economic incentives (Groenendaal et al., 2023). Alliance relationships are partnerships formed by multiple parties based on resource complementarity and synergistic effects, usually achieved through agreements or joint actions, offering strong flexibility and adaptability. In the context of carbon trading, these three relationships provide different cooperation frameworks and governance pathways for wetland management.

The destruction of wetlands has garnered global attention, prompting international organizations to issue numerous documents aimed at wetland conservation. The United Nations Framework Convention on Climate Change (UNFCCC) serves as the foundational document for global efforts to address climate change, aiming to stabilize greenhouse gas concentrations and prevent dangerous anthropogenic interference with the climate system. The Paris Agreement, a significant achievement under the UNFCCC framework, emphasizes the need for innovative approaches to reduce carbon emissions and enhance natural carbon sinks (Huang et al., 2024). The Kyoto Protocol was the first to establish legally binding emission reduction targets for developed countries and introduced carbon trading mechanisms, such as the Clean Development Mechanism (CDM), laying the groundwork for the development of carbon markets (Doan et al., 2024). The Ramsar Convention is the first international treaty specifically dedicated to wetland conservation, aiming to protect and sustainably utilize wetland resources through international cooperation (Bartold and Kluczek, 2024).

Many countries have recognized the importance of wetlands and have taken proactive measures to protect and restore wetland ecosystems. China, as a key participant in global wetland conservation, boasts abundant wetland resources. In recent years, China has vigorously promoted wetland protection and restoration through legislation (such as the Wetland Protection Law), the establishment of wetland parks (e.g., Xixi Wetland in Hangzhou), and participation in international conventions (e.g., the Ramsar Convention) (Bartold and Kluczek, 2024). China has also proposed a "carbon neutrality" target, integrating the carbon sequestration function of wetlands with carbon trading mechanisms. The United States has established a rigorous wetland protection system through policies such as the Clean Water Act and the Wetland Conservation Program. Its National Wetlands Inventory provides a scientific basis for wetland management. Additionally, the U.S. promotes wetland protection and restoration through carbon trading markets, such as the California Carbon Market. Canada, which possesses 20% of the world's wetland resources, has provided policy support for wetland conservation through its Wetland Conservation Policy and Canadian Wetland Strategy. Canada also actively participates in international wetland conservation cooperation and supports wetland carbon sequestration projects through carbon trading mechanisms (Robson and Drouillard, 2024).

Globally, the integration of wetland conservation and carbon trading mechanisms has emerged as a pivotal strategy for promoting ecological sustainable development. Practices in countries such as China, the United States, and Canada in the fields of wetland conservation and carbon trading have provided valuable experiences and insights for the global community. However, the challenge of more effectively integrating wetland

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ecological conservation with carbon trading mechanisms under different management models remains a critical issue that requires in-depth research.

Therefore, this paper explores wetland management from the perspective of carbon trading, focusing on mission relationships, employment relationships, and alliance relationships as distinct relational models. It analyzes how these relational models influence wetland management within the context of carbon trading, aiming to delve into the roles these models play in wetland management, the potential challenges they may face, and their inherent advantages. The study seeks to identify more effective wetland management strategies that facilitate the seamless integration and synergistic development of wetland ecological protection and carbon trading mechanisms.

The contributions of this study are primarily manifested in three aspects: firstly, it systematically compares, for the first time, the application of three management models—mission relationships, employment relationships, and alliance relationships—in wetland management, enhancing the applicability and flexibility of these models through comprehensive comparative research. Secondly, the study employs differential game theory to capture the dynamic characteristics and interactions among multiple stakeholders in wetland management, analyzing wetland management strategies at different time points by introducing time variables. Lastly, it innovatively analyzes the design and implementation of carbon offset mechanisms under different management models, providing a theoretical foundation and practical guidance for the construction of carbon offset mechanisms, and offering new perspectives and methods for the context-specific design and implementation of these mechanisms.

1.2 Literature review

As research into wetland conservation and management deepens, a wealth of academic work has emerged. Some researchers have focused on the impact of policies on wetland governance. For instance, Aung et al. (2021) analyzed how to formulate wetland management policies in Myanmar. The effect of land use practices on soil degradation was studied by Kong et al. (2023). The impact of territorial space planning on the wetlands of the Yellow River Delta was examined by Qu et al. (2023). These studies encompass the effects of land policies, land use practices, and land planning on wetlands.

Researchers have conducted studies on the mechanisms affecting the wetlands of the Yellow River Delta. For instance, conservation and restoration mechanisms can facilitate the ecological and environmental improvement of the Yellow River Delta wetlands (Duan et al., 2023). The effectiveness of restoration mechanisms in the governance of the Yellow River Delta was assessed by Zhang et al. (2023a). The impact of mechanism design on the evolution of tidal flats in the Yellow River Delta was explored by Cao et al. (2023). These studies have covered the impacts of conservation and restoration mechanisms, repair mechanisms, and compensation mechanisms on the governance of wetlands in the Yellow River Delta.

In the field of management research methodologies, the use of meta-analysis, system dynamics, econometrics, optimization techniques, and decision systems to study wetland management has produced a multitude of findings. For example, Woodward and Wui (2001) employed meta-analysis to assess the relative values of different wetland services, the sources of valuation biases in wetlands, and the scale of returns shown in wetland valuation. Jogo and Hassan (2010) utilized system dynamics to simulate the impact of various policy regimes on wetland functions and economic welfare. Ando and Getzner (2006) applied econometric analysis to explore the roles of ownership, ecology, and economics in public wetland conservation decision-making. Mirzaei and Zibaei (2021) managed water resource conflicts among different water users and usage patterns within a watershed using optimization methods. These studies draw on methodologies from management science, including time series, statistical analysis, complex systems, numerical models, and machine learning.

The aforementioned research on wetland management has achieved significant progress across multiple dimensions. Policy studies have unveiled the profound impacts of land policies, land use practices, and land planning on wetland ecosystems, emphasizing the critical role of scientific policy formulation in wetland conservation. Mechanism design research has focused on protection and restoration mechanisms, exploring their contributions to the improvement of wetland ecological environments and sustainable development, particularly in typical regions such as the Yellow River Delta. In terms of research methodology, researchers have extensively employed management science methods such as meta-analysis, system dynamics, econometrics, optimization techniques, and decision support systems, enriching the theoretical framework of wetland governance and providing a scientific basis for practical applications. Previous research has made significant progress in the areas of policy, mechanism design, and methodology for wetland management. However, there is a notable gap in the in-depth exploration of the specific roles of mission relationships, employment relationships, and alliance relationships in wetland management from the perspective of carbon trading. This gap has led to an insufficient understanding of the synergistic effects of these relationships on carbon reduction and ecological conservation goals. Moreover, the unique value of these relationships in practical applications has not been fully revealed.

Some researchers have studied carbon offset. For example, Meric and Serhat (2021) conducted an assessment of the carbon offset effects of global automobile factories, concluding that hydroelectric power plants are the most suitable option for automobile companies to reduce carbon dioxide emissions. Peng et al. (2022) analyzed whether carbon offset policies could be implemented in all regions of China. Sapkota and White (2020) examined carbon offset market approaches applicable to the restoration and protection of coastal wetlands in the United States. Hope et al. (2021) conducted a financial analysis of carbon offset accounting agreements for four representative afforestation projects. Woo et al. (2021) derived the net income of forest carbon offset projects by analyzing the application of South Korea's emissions trading system in the forestry sector.

Research on carbon offsets has extensively explored the feasibility and effectiveness of reducing carbon emissions through various mechanisms and strategies, covering multiple industries and regions. Studies generally emphasize the importance of carbon offsets in addressing climate change and analyze their potential applications in policy, market, and technological dimensions. Carbon offset research also delves into its role in promoting sustainable development, particularly in advancing clean energy transitions, ecological restoration, and low-carbon technological innovation. As a comprehensive tool, carbon offsets play an indispensable role in achieving global climate goals and sustainable development objectives. Although previous studies have extensively explored the feasibility and effectiveness of carbon offsetting, research on the specific mechanisms and synergistic effects of mission relationships, employment relationships, and alliance relationships in the context of carbon trading within wetland management remains relatively scarce. This gap has resulted in an insufficient understanding of the unique value these relationships hold in achieving carbon reduction and ecological conservation goals.

Several scholars have investigated the three types of relationships: mission relationships, employment relationships, and alliance relationships. Wang et al. (2024) analyzed the third mission of university social workers in innovative learning models, which focuses on promoting health and well-being. Zhang et al. (2023b) explored the recycling processes associated with China's carbon neutrality mission. Olsen and Buren (2024) examined the ethics of adversarial respect within employment relationships. Groenendaal et al. (2023) studied inclusive human resource management in the context of freelance employment relationships. Wechtler et al. (2023) analyzed the employment relationships of self-initiated expatriates and their impacts. Khan et al. (2024) investigated strategic alliances and lending relationships. Pratt et al. (2024) analyzed community engagement projects within mission alliances.

Although previous studies have individually explored the specific applications of mission relationships, employment relationships, and alliance relationships across various fields, there is a notable absence of integrating these relationships into the framework of wetland management within the context of carbon trading. This gap has led to a lack of systematic analysis of the synergistic effects and unique value these relationships hold in achieving carbon reduction and ecological conservation goals.

Wetland management typically involves multiple stakeholders, such as governments, environmental organizations, local communities, and businesses, whose interests may conflict. Simultaneously, wetland ecosystems are complex dynamic systems whose states evolve over time. Compared to non-game-theoretic approaches, game theory can simulate the conflicts and cooperative behaviors among these stakeholders, analyzing how their decisions at different time points influence the state of the wetland. In contrast to traditional game theory models (such as static games, dynamic games, and evolutionary games), differential games can capture this dynamic nature by establishing differential equation models to describe the temporal changes of various factors in wetland ecosystems (e.g., water levels, vegetation, species populations, etc.) (Assarzadegan et al., 2024). Differential games can aid in formulating long-term wetland management strategies rather than short-term, static solutions. They are widely applied in logistics mode selection (Bai et al., 2022a), advertising strategies (Yu et al., 2023), product competition (Ge and Li, 2024), water pollution management (Yuan et al., 2024; Bai et al., 2022b), and other fields.

Although previous studies have employed methods such as differential game theory to simulate the conflict and cooperation behaviors among multiple stakeholders in wetland management, there is a significant gap in systematically analyzing the dynamic synergistic effects of these relationships—mission relationships, employment relationships, and alliance relationships—from the perspective of carbon trading. Furthermore, the integration of these relationships into the formulation of long-term management strategies for wetland carbon reduction and ecological protection remains under-explored.

To address these issues, this paper proposes a range of innovative research methods, manifesting in several key aspects. Firstly, this paper systematically compares, for the first time, the application of three management models—mission relationships, employment relationships, and alliance relationships—in wetland management. This comprehensive comparative study provides diversified options and strategies for wetland management, enhancing the applicability and flexibility of management models.

Secondly, the method of differential games is employed to capture the dynamic characteristics and the interactions among multiple stakeholders in wetland management. At the core of differential games lies dynamic optimization, which, by incorporating time variables, enables the analysis of wetland management strategies at different temporal points. For instance, the carbon sequestration capacity of wetlands, ecological restoration outcomes, and policy implementation effectiveness can all exhibit dynamic changes over time.

Thirdly, this paper innovatively analyzes the design and implementation of carbon offset mechanisms under different management models, providing both theoretical foundations and practical guidance for the construction of carbon offset mechanisms. This approach offers new perspectives and methodologies for designing and implementing carbon offset mechanisms tailored to local conditions, thereby enhancing the specificity and effectiveness of these mechanisms.

This study holds several significant implications. Firstly, it aims to enhance the efficiency and effectiveness of carbon offset projects by comparing different management models—including mission relationships, employment relationships, and alliance relationships. The research reveals which management model or combination of models is most suitable for implementing carbon offset projects, thereby improving the overall efficiency and ecological benefits of these projects.

Secondly, it promotes the sustainability of wetland conservation and restoration. Wetlands are vital ecosystems that offer multiple functions such as carbon sequestration, biodiversity conservation, and flood prevention. Studying how different management models affect the long-term sustainable management of wetlands helps in the protection and restoration of these precious natural resources.

Thirdly, the study enhances cooperation among multiple stakeholders. By exploring cooperative models such as alliances, the research helps to build mechanisms for collaboration among various stakeholders, including governments, local communities, and non-governmental organizations. Such cooperation is crucial for effective wetland management and carbon offsets.

2 Methodology

2.1 Problem and variables

2.1.1 Problem description

In the process of wetland management based on carbon offsetting, the game between the government and enterprises involves carbon emission reduction responsibilities, cost-sharing, and the distribution of carbon credit benefits. The government promotes enterprise participation in carbon offsetting by formulating laws, policies, and standards (such as limiting carbon emissions and requiring enterprises to purchase carbon offsets). Enterprises, on the other hand, may lobby for favorable policies or more reasonable emission reduction targets and timelines, while assessing the relationship between project costs and emission reduction obligations or corporate reputation enhancement, and negotiating with the government to obtain economic incentives or subsidies. Enterprises also hope to generate tradable carbon credits through wetland carbon sequestration projects. The government needs to establish market rules to ensure transparency and fairness in the carbon market, prevent fraud and abuse, and consider environmental and social benefits within the policy framework. Enterprises must also negotiate with communities and non-governmental organizations to ensure broad social support for the projects. In international negotiations (such as the United Nations Framework Convention on Climate Change and the Paris Agreement), the government's emission reduction commitments may influence the carbon reduction obligations of domestic enterprises, while enterprises seek government support to avoid excessive economic burdens. The key challenge in this game lies in balancing economic growth with environmental protection responsibilities. Ideally, the government and enterprises can collaborate to develop sustainable wetland management and carbon offset mechanisms, ensuring effective emission reduction while promoting economic development and ecological conservation. This requires the government to provide clear policy guidance and market incentive mechanisms, and enterprises to actively participate in carbon reduction and wetland protection actions with a responsible attitude (Stephanie et al., 2022).

The reasons for the sustained and long-term participation of governments and enterprises in carbon offset-based wetland management include: 1) the persistence of climate change, which necessitates continuous control of greenhouse gas concentrations through measures such as carbon offsetting and wetland management; 2) the lengthy restoration cycle of wetland ecosystems, as ecological restoration and the establishment of carbon storage capacity require years or even decades, demanding long-term governance efforts to achieve ecological balance and maximize carbon sequestration potential; 3) the gradual improvement of carbon offset market mechanisms, whose rules, regulatory systems, and incentive mechanisms are still evolving (Woo et al., 2021), requiring governments and enterprises to continuously participate in market construction to adapt to changes and enhance carbon offset efficiency; and 4) the need for ongoing monitoring and evaluation of the sustainability of carbon offset projects to ensure that carbon sequestration effects meet expected targets, which demands sustained resource investment by governments and enterprises for project management and performance assessment. In summary, governments and enterprises must engage in long-term cooperation and actively participate in wetland management and carbon offsetting to address the enduring challenges of climate change, ensuring environmental sustainability and ecological balance. Such collaboration contributes to the establishment of more robust and sustainable carbon offset mechanisms, which are crucial for wetland conservation and the global carbon cycle.

Under carbon offset schemes, governments and corporations predominantly adopt three main models for the effective governance of wetlands.

(1) Mission relationship mode. The mission relationships model in wetland governance under carbon compensation between governments and enterprises is quite complex, involving various roles, responsibilities, and cooperation mechanisms. These mission relationships mainly manifest in several areas. Firstly, in legislation and policy formulation, the government, as the creator of laws and policies, is responsible for establishing suitable legal frameworks and incentive mechanisms such as carbon taxes, carbon trading markets, and subsidies. It also needs to set environmental standards and carbon compensation rules for wetland governance, ensuring business activities align with environmental objectives.

Secondly, in regulation and enforcement, the government, acting as a regulator, must monitor enterprises' carbon emissions and ensure their compliance with policies and regulations related to wetland protection and carbon compensation (Giri and Paul, 2022).

Thirdly, in investment and implementation, enterprises act as implementers of wetland projects, investing in and creating wetland conservation or restoration projects to generate carbon credits or meet specific emission reduction targets. Enterprises evaluate participation in carbon compensation projects based on cost-effectiveness and corporate social responsibility.

Fourthly, in monitoring and reporting, both governments and enterprises are responsible for the monitoring and evaluation of projects to ensure carbon compensation activities yield substantial carbon emission reductions. Enterprises must report their emission reduction performance and the progress of carbon compensation projects regularly, according to government standards and requirements.

Lastly, in transparency and credibility, the government needs to ensure the carbon compensation market's transparency, building confidence among market participants and the public in carbon compensation projects. Enterprises should disclose their emission reduction achievements and validate the authenticity and effectiveness of their carbon compensation projects through third-party verification agencies. This mission relationships model demands a high level of consistency in philosophy, goals, and execution between governments and enterprises and mutual support. Their interaction not only requires clear rules and cooperation mechanisms but also ongoing communication and coordination to adapt to new environmental changes and economic dynamics. Through such sustained cooperation, both parties work together to promote wetland conservation and reduce carbon emissions, aiming for the long-term goal of sustainable development.

(2) Employment relationship mode. Under carbon compensation, the employment relationships mode for government and business governance of wetlands typically involves the following work. First, government departments usually act as regulators and supervisors, setting up policy frameworks within carbon compensation schemes, overseeing their implementation, and ensuring standards are followed.

Second, enterprises might invest in wetland governance projects to meet carbon reduction targets, fulfill environmental responsibilities, or to acquire carbon credits. Enterprises may directly hire employees for project management tasks or purchase corresponding carbon credits through carbon trading markets. In this model, the roles of governments and enterprises complement each other. The government provides an appropriate policy environment and regulatory safeguards, while enterprises implement carbon compensation-related wetland governance measures through various employment and cooperation relationships within this framework. It is important to note that such employment relationships models should be based on clear contracts, transparent processes, and fair working conditions to ensure the successful implementation of projects and the protection of all parties' interests (Groenendaal et al., 2023).

(3) Alliance relationship mode. Under carbon compensation, the alliance relationships model for governance of wetlands by governments and enterprises emphasizes cooperation and partnership. In this model, various stakeholders unite to achieve a common goal: reducing atmospheric carbon emissions through wetland conservation and restoration projects. The characteristics of this alliance relationships model include the following. First, the participation of multiple stakeholders. This model involves not only governments and enterprises but also non-governmental organizations (NGOs), community groups, research institutions, and international bodies. All parties work together to maximize the carbon sequestration capabilities of wetlands.

Second, the creation of alliance platforms. Governments often create or support platforms, such as carbon markets or specific wetland management cooperative projects, to enable different stakeholders to collaborate and share resources.

Third, role and responsibility delineation. In this alliance, the roles and responsibilities of each party need to be clearly defined. For example, the government may be responsible for policy formulation and project regulation, enterprises may handle investment and execution, and NGOs may take on community mobilization and monitoring the social impacts of the project (Yan et al., 2020).

Fourth, communication and information sharing. Alliance partners regularly exchange information, maintain transparency, and share project progress, data, best practices, and challenges faced.

Fifth, common goals and performance indicators. As members of the alliance, all parties need to jointly establish the project's long-term and short-term objectives and how these objectives will be quantified, such as by reducing a certain amount of CO2 emissions or restoring a specific area of wetland.

In this model, wetland governance projects become a result driven by both social welfare and commercial value, aimed at providing sustainable environmental and economic benefits through collaborative action at local and global levels. This alliance is built on trust, mutual commitment, and transparency, often requiring complex negotiations and ongoing management. However, it offers a unified framework for collaboration among different stakeholders, achieving a win-win situation for better environmental governance and carbon emission control.

2.1.2 Hypothesis

Hypothesis 1: The mission relationships model may result in long-term unresolved issues, leading to losses.

In the context of government and enterprises' efforts to protect wetlands through carbon offsetting, the mission relationships model aims to enhance overall efficiency by understanding and leveraging the dependencies, priorities, and resource requirements among tasks. However, in certain cases, this model may lead to long-standing unresolved issues, thereby causing losses to wetland conservation and carbon offset projects. Specifically, the application of the mission relationships model in wetland management may trigger the following problems.

First, task dependencies can become overly complex. For instance, the intricate relationship between wetland restoration and carbon credit generation may make it difficult for the model to accurately predict and schedule tasks, leading to prolonged delays or postponement of wetland restoration projects.

Second, resource allocation may become imbalanced. Governments and enterprises might over-allocate resources to certain tasks (such as carbon credit trading) while neglecting the needs of other tasks (such as wetland ecological monitoring), resulting in resource wastage and task backlogs.

Third, priority management may be inadequate. If the model fails to correctly identify and adjust task priorities, critical tasks (such as wetland carbon sequestration capacity assessment) may be overlooked, leading to project delays or failures (Caldwell et al., 2020).

Fourth, the lack of a feedback mechanism may prevent the model from making timely adjustments and optimizations, causing persistent issues (such as subpar carbon offset performance) to remain unresolved. In the context of wetland conservation and carbon offsetting, these problems may hinder the effective implementation of projects, thereby undermining environmental protection and the stability of carbon markets.

Therefore, governments and enterprises need to introduce more refined dependency management, resource allocation optimization, priority adjustment mechanisms, and effective feedback systems into the mission relationships model to ensure the smooth progress of wetland management and carbon offset projects, achieving the dual goals of ecological conservation and economic development.

Hypothesis 2: The employment relationships model can increase both governance costs and the reputation of governments and corporations.

The employment relationships model not only affects employee efficiency and satisfaction but also has profound implications for the overall governance costs and reputation of wetland conservation projects. Specifically, the employment relationships model may impact governments and enterprises through the following two aspects.

First, it increases governance costs. The employment relationships model may involve complex contracts, benefit systems, and performance evaluation mechanisms, all of which require substantial resources for management and maintenance. In wetland conservation projects, governments and enterprises must comply with relevant laws and regulations to ensure the legality and fairness of employment relationships, which may lead to additional compliance costs. To enhance the capabilities and satisfaction of employees involved in wetland conservation projects, organizations may need to invest significant resources in training and development, further increasing governance costs (Lindvert et al., 2022).

Second, it enhances reputation. The positive employment relationships model can improve employee satisfaction and loyalty, thereby boosting the overall reputation of the organization. By demonstrating social responsibility through a fair and transparent employment relationships model, governments and enterprises can gain the trust and support of the public and stakeholders. In the fields of wetland conservation and carbon offsetting, a good employment relationships model can become a key component of the brand image of governments and enterprises, attracting top talent and partners and facilitating the smooth implementation of wetland conservation projects.

Many enterprises indeed face increased management and compliance costs when implementing complex employment relationships models. For example, enterprises involved in wetland conservation and carbon offsetting projects must allocate substantial resources for management and supervision to ensure the welfare and rights of their employees. Some well-known enterprises have successfully enhanced their brand image and market competitiveness by implementing fair and transparent employment relationships models. For instance, in the field of wetland conservation, certain environmental enterprises are renowned for their superior employee benefits and working environments, attracting top talent and thereby improving the efficiency and effectiveness of wetland conservation projects. According to organizational management theory, complex employment relationships models require more resources for management and maintenance, inevitably leading to increased governance costs (Sikk and Caruso, 2024). Reputation management theory suggests that organizations can gain public and stakeholder trust and support by demonstrating social responsibility and fairness, thereby enhancing their reputation.

In summary, the hypothesis that the employment relationships model increases governance costs and enhances reputation for governments and enterprises is reasonable and meaningful. This hypothesis reminds us to fully consider the cost and reputation impacts when designing and implementing employment relationships models and to adopt corresponding optimization measures. In the context of wetland conservation and carbon offsetting, governments and enterprises need to balance governance costs with reputation enhancement by optimizing the employment relationships model, attracting and retaining excellent talent, and ensuring the smooth implementation of wetland management and carbon offset projects, thereby achieving the dual goals of ecological conservation and economic development.

Hypothesis 3: The alliance relationships model can increase both the governance costs and revenues for governments and corporations.

The alliance relationships model aims to enhance the overall efficiency and competitiveness of wetland conservation projects through resource sharing, risk sharing, and synergistic effects. However, despite its potential benefits, the alliance relationships model may also increase governance costs. Specifically, the alliance relationships model may impact governments and enterprises through the following two aspects.

First, it increases governance costs. The alliance relationships model requires frequent communication and coordination among participants to ensure alignment of goals and synchronization of actions in wetland conservation projects, which may lead to higher coordination costs. This model involves collaboration among multiple organizations, increasing management complexity and requiring more resources for supervision and management. Governments and enterprises need to comply with relevant laws and regulations to ensure the legality and fairness of alliance relationships, which may result in additional compliance costs. The alliance relationships model involves risk-sharing mechanisms, potentially requiring more resources for risk management and response (Chen et al., 2024).

Second, it enhances benefits. The alliance relationships model enables resource sharing, improves resource utilization efficiency, and reduces operational costs for individual organizations. Through the alliance relationships model, participants can leverage their respective strengths to achieve synergistic effects, enhancing overall efficiency and competitiveness (Yan et al., 2020). This model can promote technological innovation and knowledge sharing, creating new development opportunities for governments and enterprises. Through the alliance relationships model, governments and enterprises can access new markets and fields, expanding their influence and market share (Geroe, 2022).

Many governments and enterprises indeed face increased coordination costs and management complexity when implementing the alliance relationships model. For example, certain multinational corporations must allocate substantial resources for coordination and management when establishing global supply chain alliances. Some governments and enterprises have successfully achieved resource sharing and synergistic effects by implementing the alliance relationships model, thereby enhancing overall efficiency and competitiveness. For instance, certain cities have improved urban management efficiency and service levels by forming smart city alliances. According to organizational management theory, complex alliance relationships models require more resources for management and coordination, inevitably leading to increased governance costs. Benefit management theory suggests that through resource sharing and synergistic effects, organizations can improve resource utilization efficiency and overall competitiveness, thereby increasing benefits.

In summary, the hypothesis that the alliance relationships model increases governance costs and enhances benefits for governments and enterprises is reasonable and meaningful. This hypothesis reminds us to fully consider the cost and benefit impacts when designing and implementing alliance relationships models and to adopt corresponding optimization measures. In the context of wetland conservation and carbon offsetting, governments and enterprises need to balance governance costs with benefit enhancement by optimizing the alliance relationships model, achieving resource sharing and synergistic effects, and ensuring the smooth implementation of wetland management and carbon offset projects, thereby realizing the dual goals of ecological conservation and economic development.

The logical structure diagram for this article is shown in Figure 1.

2.1.3 Variable definition

When constructing the differential game model in this article, many parameters and variables are designed. These parameters and variables are defined as shown in Table 1.

This paper provides explanations for the aforementioned complex variables and parameters. "Government carbon offsets to enterprises" refers to a mechanism through which the government compensates enterprises for the costs or losses incurred from participating in wetland management or reducing carbon emissions, typically via policy or economic measures. Such compensation is often realized through financial support, tax reductions, carbon quota allocations, or other incentives, aiming to encourage enterprises to actively engage in carbon trading and wetland protection, thereby promoting the sustainable development of the ecological environment. Carbon offsets not only help balance the economic burden on enterprises but also foster cooperative relationships between the government and enterprises, advancing the achievement of carbon reduction goals. In wetland management, the carbon offset mechanism is particularly crucial, as wetlands, serving as vital carbon sink ecosystems, require substantial financial and technological investments for their protection and restoration. Government compensation policies can effectively mobilize enterprise participation, ensuring the long-term and stable operation of projects.

"The cost to the government or enterprises of managing wetlands at a unit level" refers to the economic costs borne by the government or enterprises for managing and maintaining wetland ecosystems per unit area or scale. These costs include direct expenditures for wetland protection, restoration, monitoring, and the development of carbon sink functions, such as land acquisition, ecological restoration projects,

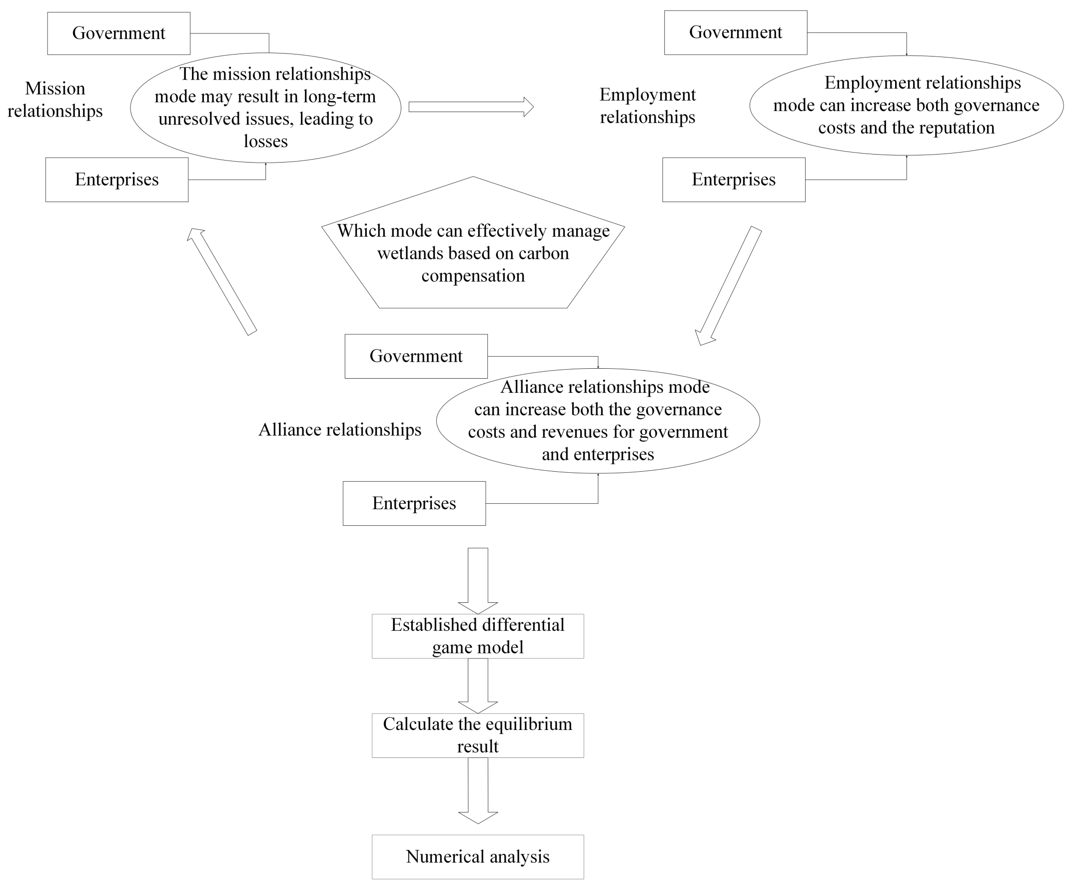

FIGURE 1
Logic structure diagram.

TABLE 1 The main definition of variables and parameters in this article.

Variables and Parameters	Specific meaning
$Y=\{T,E,A\}$	three organizational structures for effective wetland management (mission relationships, employment relationships or alliance relationships)
Independent variable	
$F_{Y1}(t)$	the extent of the government's efforts to manage wetlands under the organizational structure Y
$F_{Y2}(t)$	he extent of the enterprises' efforts to manage wetlands under the organizational structure Y
$x_{Y1}(t)$	the government's reputation in the management of wetlands under the organizational structure Y
$x_{Y2}(t)$	the enterprises' reputation in the management of wetlands under the organizational structure Y
Parameter	
ρ	the discount rate that occurs over time, $0\leq\rho\leq1$
δ	decay of reputation, $\delta>0$
b_1, b_2	the benefits that the government or enterprises gain by managing wetlands at a unit level, b_1, $b_2>0$
c_1,c_2	the cost to the government or enterprises of managing wetlands at a unit level, c_1, $c_2>0$
β_1	complexity of wetland issues, $\beta_1>0$
b_T	benefits from flexibility, $b_T>0$
b_A	increased revenue to the enterprises from market expansion, $b_A>0$
C_o	government carbon offsets to enterprises, $C_o>0$
λ_A	extent of risk sharing and benefit sharing, $\lambda_A>0$
c_E	increased cost to government of building stable relationships, $c_E>0$
l	the positive effects of reputation, $l>0$
a_E	increased reputation of the government for building stable relationships, $a_E>0$
c_A	increased cost to governments of managing complexity, $c_A>0$
a_1,a_2	the reputation gained by government or enterprises for managing wetlands at a unit level, a_1,$a_2>0$
Function	
$J_{Y1}(t)$	the social welfare function of government under the organizational structure Y
$J_{Y2}(t)$	the social welfare function of enterprises under the organizational structure Y
$V_{Y1}(t)$	the social benefits of government under the organizational structure Y
$V_{Y2}(t)$	the social benefits of enterprises under the organizational structure Y

technological equipment investments, personnel salaries, and long-term maintenance expenses. Additionally, indirect costs may also be considered, such as administrative expenses for policy formulation and implementation, as well as potential losses resulting from restrictions on surrounding economic activities (e.g., agriculture or industry) due to wetland protection. Calculating unit costs helps quantify the economic investment in wetland management, providing a critical basis for cost-benefit analysis and policy-making in carbon trading. Furthermore, it assists governments and enterprises in optimizing resource allocation, enhancing the efficiency and sustainability of wetland management.

"Complexity of wetland issues" refers to the multi-dimensional and multi-layered complexity inherent in wetland management. As a critical component of ecosystems, wetland management requires not only the protection and restoration of ecological functions (such as carbon sequestration, biodiversity, and hydrological regulation) but also the coordination of economic, social, and policy-related factors. For instance, wetland management may involve the formulation of carbon trading market rules, stakeholder coordination, disputes over land ownership, the impacts of climate change, and challenges related to long-term sustainability. This complexity is further compounded by the dynamic and uncertain nature of wetland ecosystems, such as the irreversibility of wetland degradation, the variability of carbon sequestration functions, and the lag in management outcomes. Therefore, addressing the complexity of wetland issues necessitates comprehensive, interdisciplinary management strategies to ensure the healthy development of wetland ecosystems and the effective achievement of carbon trading goals.

"Benefits from flexibility" refer to the positive outcomes derived from flexible policy design, cooperative models, or management strategies in the context of wetland management and carbon trading. Such flexibility enables governments, enterprises, and other stakeholders to better respond to the uncertainties, dynamics, and complexities of wetland management, such as the impacts of climate change, fluctuations in carbon markets, or the long-term nature of ecological restoration. Specifically, flexibility may manifest in adaptive policy adjustments (e.g., dynamic allocation of carbon quotas), diversified cooperative relationships (e.g., the establishment of alliance relationships), and innovative management approaches (e.g., ecosystem-based adaptive management). Through flexibility, stakeholders can optimize resource allocation, mitigate risks, enhance project sustainability, and maximize the ecological, economic, and social benefits of wetland management. Thus, "benefits from flexibility" underscore the critical role of flexible mechanisms in achieving wetland conservation and carbon trading objectives.

"The extent of risk sharing and benefit sharing" refers to the degree to which risks and benefits are shared among governments, enterprises, and other stakeholders in the process of wetland management and carbon trading. Wetland management projects typically involve significant economic investments, technical complexity, and ecological uncertainties, necessitating shared responsibility for potential risks, such as under-performance of carbon sequestration functions, policy changes, or market fluctuations. Simultaneously, successful wetland management projects generate substantial ecological, economic, and social benefits, including carbon credit revenues, enhanced ecosystem services, and community development opportunities. These benefits must be fairly distributed among participants. The extent of risk and benefit sharing reflects the depth and sustainability of cooperative relationships, influencing the willingness of stakeholders to participate, the efficiency of project implementation, and the achievement of long-term goals. By establishing equitable mechanisms for risk and benefit sharing, closer cooperation can be fostered, driving the successful implementation of wetland management and carbon trading initiatives.

"Increased reputation of the government for building stable relationships" refers to the enhancement of the government's credibility and reputation in the fields of wetland management and carbon trading through the establishment and maintenance of stable cooperative relationships. Governments play a pivotal role in wetland management projects, collaborating with enterprises, communities, non-governmental organizations, and other stakeholders to advance ecological conservation and carbon trading objectives. By formulating transparent and equitable policies, promoting effective risk and benefit-sharing mechanisms, and ensuring the fulfillment of long-term commitments, governments can establish a reliable and responsible image. Such stable cooperative relationships not only strengthen trust in the government but also improve the efficiency and sustainability of project implementation, thereby further elevating the government's reputation both domestically and internationally in the realms of environmental protection and climate change governance. Thus, "increased reputation of the government for building stable relationships" underscores the importance of the government's leadership and trust-building role in cooperative endeavors.

"Increased cost to governments of managing complexity" refers to the higher costs borne by governments due to the growing complexity of issues in wetland management. Wetland management involves multifaceted complexities spanning ecological, economic, social, and policy dimensions, such as the formulation and implementation of carbon trading rules, technical challenges in ecological restoration, stakeholder coordination, and the assurance of long-term sustainability. These complexities require governments to allocate more resources, including financial, human, and temporal investments, to address uncertainties, dynamic changes, and cross-sectoral coordination needs in wetland management. For instance, governments may need to establish more sophisticated monitoring systems, develop adaptive policies, promote multi-stakeholder cooperation mechanisms, and respond to potential ecological risks or market fluctuations. Therefore, "increased cost to governments of managing complexity" reflects the resource pressures and fiscal burdens faced by governments in addressing complex wetland management issues, while also highlighting the importance of optimizing management strategies to reduce costs.

"The social welfare function of government" refers to the long-term objective function of governments in wetland management and carbon trading, aimed at maximizing overall societal welfare. This function typically integrates multiple dimensions, including economic, ecological, and social factors, such as the ecological benefits (e.g., carbon sequestration, biodiversity conservation), economic benefits (e.g., carbon credit revenues, employment opportunities), and social benefits (e.g., community development, public health) achieved through long-term wetland protection and carbon trading. By formulating long-term policies, allocating resources, and coordinating stakeholders, governments strive to maximize long-term social welfare in wetland management projects. This function reflects the government's core role in the game as a representative of public interest, balancing the interests of various parties and promoting sustainable development.

"The social benefits of government" refer to the specific societal benefits realized through government actions and policies in wetland management and carbon trading. These benefits include, but are not limited to, improved environmental quality, enhanced public health, promoted community participation and development, increased climate resilience, and the advancement of green economic growth. For example, wetland conservation projects can reduce flood risks, purify water quality, while carbon trading mechanisms can incentivize enterprises to reduce carbon emissions and create new economic opportunities for communities. These social benefits not only enhance public trust and support for the government but also reinforce its leadership in environmental protection and climate change governance.

"The social welfare function of enterprises" refers to the objective function of enterprises in wetland management and carbon trading, aimed at generating positive impacts on overall societal welfare through their long-term actions and decisions. This function typically combines economic objectives (e.g., profit maximization) with social responsibilities (e.g., environmental protection, community development), such as reducing carbon emissions through long-term participation in carbon trading mechanisms, investing in wetland conservation projects to enhance ecological benefits, or promoting sustainable development through long-term green technological innovation. In this game, enterprises strive to achieve dual goals of economic efficiency and social value by balancing their own interests with societal benefits. This function highlights the potential contributions of enterprises in wetland management, where they act not only as market entities but also as key participants in social and environmental governance.

"The social benefits of enterprises" refer to the societal benefits achieved through the specific actions of enterprises in wetland management and carbon trading. These benefits include, but are not limited to, reducing carbon emissions to address climate change, protecting wetland ecosystems to maintain biodiversity, creating green employment opportunities to promote community development, and enhancing public welfare through corporate social responsibility initiatives. For example, by participating in carbon trading, enterprises can not only generate economic returns but also contribute to environmental conservation; by investing in wetland restoration projects, they can improve local ecological conditions and enhance community quality of life. These social benefits not only strengthen the social image and brand value of enterprises but also foster cooperative relationships between enterprises, governments, and communities.

2.2 Differential game of three protection modes

Mission relationships are centered around the completion of specific tasks, with participants collaborating toward clearly defined objectives. In wetland management and carbon trading, such tasks may include concrete carbon reduction projects or wetland restoration initiatives. These relationships are typically associated with specific tasks or projects and may terminate or transition to new tasks upon completion. Participants engage in explicit role assignments based on task requirements, each assuming corresponding responsibilities to ensure efficient task execution. Mission relationships allow participants to flexibly adjust strategies and methods during collaboration to address changes and challenges encountered during task implementation. Resources, knowledge, and expertise are pooled to enhance the capacity for task completion.

Enterprises may accomplish preliminary tasks in wetland restoration, such as vegetation recovery and pollution control, but subsequent maintenance and monitoring are often neglected. Wetland ecosystems are complex dynamic systems, and short-term tasks cannot resolve all issues (Asyhari et al., 2024). For instance, maintaining carbon sequestration capacity requires long-term monitoring and management; neglecting this issue may lead to the gradual degradation of wetland carbon sink functions. After mission relationships conclude, governments may lack effective mechanisms to address long-term problems, resulting in their persistence and exacerbation. These issues ultimately lead to "losses caused by unresolved long-term problems" for governments.

Simultaneously, "losses caused by unresolved long-term problems" follow a logarithmic pattern. This is primarily due to the following reasons. First, issues in wetland management, such as declining carbon sequestration capacity and ecological function degradation, tend to accumulate gradually. In the initial stages, the negative impacts of these issues may be minimal; however, as time progresses, the problems accumulate, and losses begin to manifest. For example, in the early stages, the decline in wetland carbon sequestration capacity may not be evident, and its impact on carbon trading may be negligible; in the intermediate stages, the issues gradually become apparent, and losses accelerate; in the later stages, once the problems reach a certain threshold, the rate of loss growth slows, but the overall loss has already become substantial.

Second, the nonlinear characteristics of ecosystems. Wetland ecosystems exhibit nonlinear characteristics, meaning that changes in ecological functions are not linearly related to external disturbances. For instance, minor disturbances may have limited effects on wetland ecological functions; however, when disturbances exceed a certain threshold, wetland ecological functions may rapidly degrade, leading to a sharp increase in losses; once wetland degradation reaches a certain level, further degradation of ecological functions may slow, but the overall loss has already become severe (Zhang et al., 2024).

Third, the increasing costs of governance. As wetland problems accumulate over time, the costs of governance gradually rise. For example, in the initial stages of governance, when problems are minor, the costs are relatively low; in the later stages of governance, after problems have accumulated, the difficulty and costs of governance significantly increase, but the effectiveness of governance may be limited, resulting in a slower rate of loss growth.

In the mission relationships mode, the social welfare functions of the government and the corporations are represented by Equations 1, 2 respectively:

$$J_{T1} = \int_0^{\infty} \left[(b_1 + b_T)F_{T1}(t) - \frac{c_1 + \ln(1+\beta_1)}{2} F_{T1}^2(t) - C_O + lx_{T1}(t) \right] e^{-\rho t} dt \tag{1}$$

$$J_{T2} = \int_0^{\infty} \left[b_2 F_{T2}(t) - \frac{c_2}{2} F_{T2}^2(t) + C_O + lx_{T2}(t) \right] e^{-\rho t} dt \tag{2}$$

In the above formulas, $(b_1 + b_T)F_{T1}(t)$ represents the benefits gained by the government in governing wetlands under the mission relationships model. $b_T F_{T1}(t)$ denotes the profits derived from flexibility within the same framework. $\frac{c_1+\ln(1+\beta_1)}{2} F_{T1}^2(t)$ illustrates the costs incurred by the government in wetland governance under this model. $\frac{\ln(1+\beta_1)}{2} F_{T1}^2(t)$ reflects the losses caused by long-term unresolved issues in the context of the mission relationships model. $lx_{T1}(t)$ signifies the positive impact on government reputation due to task-related actions. $b_2 F_{T2}(t)$ indicates the benefits accrued to corporations in wetland governance under this model. $\frac{c_2}{2} F_{T2}^2(t)$ describes the costs borne by enterprises in managing wetlands within the mission relationships framework. Lastly, $lx_{T2}(t)$ highlights the positive influence on corporate reputation due to task-related activities in this model.

The change in the reputation of government and enterprises under the mission relationships mode can be expressed as:

$$\dot{x}_{T1}(t) = a_1 F_{T1}(t) - \delta x_{T1}(t) \tag{3}$$

$$\dot{x}_{T2}(t) = a_2 F_{T2}(t) - \delta x_{T2}(t) \tag{4}$$

In the above formula (Equations 3, 4), $a_1 F_{T1}(t)$ represents the reputation gained by the government in managing wetlands under the mission relationships model. $a_2 F_{T2}(t)$ indicates the reputation acquired by corporations in the governance of wetlands within the same framework. $\delta x_{T1}(t)$ depicts the decline of government reputation under the mission relationships model. $\delta x_{T2}(t)$ illustrates the deterioration of corporate reputation within the context of the mission relationships model.

Employment relationships are typically defined through contracts that specify the rights and obligations of both parties, providing legal enforceability. Participants primarily collaborate for economic benefits, with employers providing compensation and employees offering labor or services. Such relationships often exhibit a clear hierarchical structure, where employers hold decision-making authority, and employees execute tasks. Employment relationships may be short-term or project-based, potentially terminating upon task completion. Employees usually possess specific professional skills, and employers hire talent according to their needs (Jungst and Verbeeck, 2025).

Under the employment relationships model, governments and enterprises must invest resources to establish and maintain stable collaborative partnerships. These costs include contract management, communication and coordination, as well as supervision and evaluation. Governments need to allocate resources to draft detailed contracts that clearly define the rights and obligations of both parties. They must also monitor whether enterprises fulfill their contractual obligations, which requires investment in human and material resources (Simms, 2024). During wetland governance, contracts may need adjustments to adapt to changing environmental conditions and requirements. Governments and enterprises must establish effective information-sharing mechanisms to ensure alignment throughout the wetland governance process. Coordination in decision-making is essential to maintain consistency in governance strategies. Governments need to implement supervision mechanisms to oversee enterprise activities, ensuring that governance outcomes meet expectations. Additionally, governments must evaluate enterprise performance to determine whether contractual objectives have been achieved.

Simultaneously, these costs exhibit a linear pattern, primarily due to the following reasons. First, the continuous management of contracts. Under employment relationships, governments must consistently invest resources in contract management, including drafting, execution, and adjustments. These costs increase at a constant rate over time. Second, ongoing communication and coordination. Governments and enterprises need to maintain continuous communication and coordination to ensure consistency in the wetland governance process. These communication and coordination costs increase at a constant rate over time. Third, continuous supervision and evaluation. Governments must persistently supervise and evaluate enterprise activities to ensure governance outcomes meet expectations (Lindvert et al., 2022). These supervision and evaluation costs increase at a constant rate over time.

In the employment relationships mode, the social welfare functions of the government and enterprises are represented by Equations 5, 6:

$$J_{E1} = \int_0^{\infty} \left[b_1 F_{E1}(t) - \frac{(c_1 + c_E)}{2} F_{E1}^2(t) - C_O + l x_{E1}(t) \right] e^{-\rho t} dt \quad (5)$$

$$J_{P2} = \int_0^{\infty} \left[b_2 F_{E2}(t) - \frac{(c_2 + c_E)}{2} F_{E2}^2(t) + C_O + l x_{E2}(t) \right] e^{-\rho t} dt \quad (6)$$

In the above formulas, $b_1 F_{E1}(t)$ represents the benefits obtained by the government in managing wetlands under the employment relationships model. $\frac{(c_1+c_E)}{2} F_{E1}^2(t)$ illustrates the costs incurred by the government in the governance of wetlands within this framework. $\frac{c_E}{2} F_{E1}^2(t)$ indicates the increased costs to the government from establishing stable relationships under the employment relationships model. $l x_{E1}(t)$ highlights the positive impact on government reputation from reputational effects within this model. $b_2 F_{E2}(t)$ denotes the benefits accrued to corporations in managing wetlands under the employment relationships model. $\frac{(c_2+c_E)}{2} F_{E2}^2(t)$ describes the costs borne by enterprises in the governance of wetlands within this context. $\frac{c_E}{2} F_{E2}^2(t)$ reflects the additional costs to corporations from establishing stable relationships under the employment relationships model. Lastly, $l x_{E2}(t)$ signifies the positive influence on corporate reputation due to reputational effects in this model.

The change in the reputation of government and enterprises under the employment relationships mode can be expressed as:

$$\dot{x}_{E1}(t) = (a_1 + a_E) F_{E1}(t) - \delta x_{E1}(t) \quad (7)$$

$$\dot{x}_{E2}(t) = (a_2 + a_E) F_{E2}(t) - \delta x_{E2}(t) \quad (8)$$

In the above formula (Equations 7, 8), $a_1 F_{E1}(t)$ signifies the reputation gained by the government in wetland management under the employment relationships model. $a_E F_{E1}(t)$ conveys the enhanced reputation of the government from establishing stable relationships within this model. $a_2 F_{E2}(t)$ denotes the reputation acquired by corporations in the governance of wetlands under the employment relationships model. $a_E F_{E2}(t)$ reflects the improved corporate reputation resulting from stable relationships in this context. $\delta x_{E1}(t)$ illustrates the decline of government reputation under the employment relationships model. $\delta x_{E2}(t)$ depicts the deterioration of corporate reputation within the employment relationships framework.

Alliance relationships represent a strategic form of collaboration, where participants pool their resources and capabilities to jointly address market or environmental challenges. All parties in the alliance expect to benefit from the cooperation, and such relationships are built on mutual benefit. Alliance relationships typically emphasize equality and mutual respect among participants, with shared decision-making and outcomes. Alliance members share resources while jointly bearing the risks that may arise during the collaboration. Alliances can take various forms, such as joint ventures or strategic partnerships, and are flexibly adjusted based on collaborative goals and environmental conditions.

Under the alliance relationships model, governments and enterprises can more effectively address uncertainties in wetland governance through risk-sharing and profit-sharing mechanisms, thereby enhancing overall profitability. The specific reasons are as follows. First, risk-sharing. Governments and enterprises jointly bear the risks during the governance process, such as technological failures, policy changes, or market fluctuations, thereby reducing the risks faced by a single entity; by integrating the resources and capabilities of both parties, the alliance can more effectively address risks, for example, through technological innovation or market diversification strategies (Righi and Moresco, 2024). Second, profit-sharing. The profit-sharing mechanism incentivizes governments and enterprises to work together to maximize the benefits of wetland governance; through profit-sharing, governments and enterprises can allocate resources more rationally, such as investing funds and technology into the most promising governance projects. Third, resource integration. Governments and enterprises integrate their respective resources (e.g., funding, technology, management expertise) to improve the efficiency of wetland governance; through collaboration, governments and enterprises can jointly drive technological and managerial innovations, thereby enhancing governance outcomes (Saner, 2019).

For enterprises, profits exhibit a linear pattern, meaning that they increase at a constant rate over time. This linear profit pattern can be explained by the following aspects. First, stable revenue sources. Under alliance relationships, enterprises typically secure stable revenue sources through contracts or agreements, such as carbon trading income or ecological service fees. These revenues usually increase at a constant rate, resulting in a linear profit pattern. Second, clear profit distribution mechanisms. Alliance relationships often have well-defined profit distribution mechanisms, where enterprises receive corresponding profits based on their contributions to the collaboration (Simms, 2024). These profit distribution mechanisms typically increase at a constant rate, leading to a linear profit pattern. Third, continuous operations and management. Enterprises usually need to consistently invest resources in the operations and management of wetland governance, and these investments typically increase at a constant rate, resulting in a linear profit pattern.

In the alliance relationships mode, the social welfare functions of the government and enterprises are represented by Equations 9, 10 respectively:

$$J_{A1} = \int_0^\infty \Big[b_1 \ln(\mathrm{e} + \lambda_A) F_{A1}(t) - \frac{(c_1 + c_A)}{2} F_{A1}^2(t) - C_O + l x_{A1}(t) \Big] e^{-\rho t} dt \tag{9}$$

$$J_{A2} = \int_0^\infty \Big[(b_2 + b_A) F_{A2}(t) - \frac{(c_2 + c_A)}{2} F_{A2}^2(t) + C_O + l x_{A2}(t) \Big] e^{-\rho t} dt \tag{10}$$

In the above formulas, $b_1 \ln(\mathrm{e} + \lambda_A) F_{A1}(t)$ signifies the benefits obtained by the government in managing wetlands under the alliance relationships model. $b_1 \ln(\mathrm{e} + \lambda_A) F_{A1}(t) - b_1 F_{A1}(t)$ denotes the increased profits from risk sharing and revenue sharing under this model. $\frac{(c_1+c_A)}{2} F_{A1}^2(t)$ illustrates the costs incurred by the government in wetland governance within the alliance framework. $\frac{c_A}{2} F_{A1}^2(t)$ reflects the increased costs to the government due to management complexities in this model. $l x_{A1}(t)$ highlights the positive impact on government reputation from reputational effects within the alliance context. $(b_2 + b_A) F_{A2}(t)$ represents the benefits accrued to corporations in managing wetlands under the alliance relationships model. $b_A F_{A2}(t)$ conveys the increased corporate profits from market expansion under this framework. $\frac{(c_2+c_A)}{2} F_{A2}^2(t)$ describes the costs borne by enterprises in the governance of wetlands within the alliance model. $\frac{c_A}{2} F_{A2}^2(t)$ indicates the additional costs to corporations due to management complexities in this context. Lastly, $l x_{A2}(t)$ signifies the positive influence on corporate reputation from reputational effects under the alliance relationships model.

The change in the reputation of government and enterprises under the alliance relationships mode can be expressed as:

$$\dot{x}_{A1}(t) = a_1 F_{A1}(t) - \delta x_{A1}(t) \tag{11}$$

$$\dot{x}_{A2}(t) = a_2 F_{A2}(t) - \delta x_{A2}(t) \tag{12}$$

In the above formula (Equations 11, 12), $a_1 F_{A1}(t)$ signifies the reputation gained by the government in wetland management under the alliance relationships model. $a_2 F_{A2}(t)$ denotes the reputation acquired by corporations in the governance of wetlands under the same model. $\delta x_{A1}(t)$ illustrates the decline in government reputation within the alliance framework. Lastly, $\delta x_{A2}(t)$ reflects the deterioration of corporate reputation under the alliance relationships model.

3 Results

In the differential game, the decisions of government and enterprises in the process of wetland management are not only affected by control variables and parameters, but also change over time. In order to better calculate the control benefits and social benefits, the HJB formula is used. The HJB formula is a partial differential equation, which is the core of optimal control.

3.1 HJB formula

Under the mission relationships mode, the HJB equation of the social welfare function of the government and enterprises are as Equations 13, 14:

$$\rho V_{T1} = \max_{F_{T1}(t)} \Big\{ \Big[(b_1 + b_T) F_{T1}(t) - \frac{c_1 + \ln(1 + \beta_1)}{2} F_{T1}^2(t) - C_O + l x_{T1}(t) \Big] + \frac{\partial V_{T1}}{\partial x_{T1}} [a_1 F_{T1}(t) - \delta x_{T1}(t)] \Big\} \tag{13}$$

$$\rho V_{T2} = \max_{F_{T2}(t)} \Big\{ \Big[b_2 F_{T2}(t) - \frac{c_2}{2} F_{T2}^2(t) + C_O + l x_{T2}(t) \Big] + \frac{\partial V_{T2}}{\partial x_{T2}} [a_2 F_{T2}(t) - \delta x_{T2}(t)] \Big\} \tag{14}$$

Under the employment relationships mode, the HJB equation of the social welfare function of the government and enterprises are as Equations 15, 16:

$$\rho V_{E1} = \max_{F_{E1}(t)} \Big\{ \Big[b_1 F_{E1}(t) - \frac{(c_1 + c_E)}{2} F_{E1}^2(t) - C_O + l x_{E1}(t) \Big] + \frac{\partial V_{E1}}{\partial x_{E1}} [(a_1 + a_E) F_{E1}(t) - \delta x_{E1}(t)] \Big\} \tag{15}$$

$$\rho V_{E2} = \max_{F_{E2}(t)} \Big\{ \Big[b_2 F_{E2}(t) - \frac{(c_2 + c_E)}{2} F_{E2}^2(t) + C_O + l x_{E2}(t) \Big] + \frac{\partial V_{E2}}{\partial x_{E2}} [(a_2 + a_E) F_{E2}(t) - \delta x_{E2}(t)] \Big\} \tag{16}$$

Under the alliance relationships mode, the HJB equation of the social welfare function of the government and enterprises are as Equations 17, 18:

$$\rho V_{A1} = \max_{F_{A1}(t)} \Big\{ \Big[b_1 \ln(\mathrm{e} + \lambda_A) F_{A1}(t) - \frac{(c_1 + c_A)}{2} F_{A1}^2(t) - C_O + l x_{A1}(t) \Big] + \frac{\partial V_{A1}}{\partial x_{A1}} [a_1 F_{A1}(t) - \delta x_{A1}(t)] \Big\} \tag{17}$$

$$\rho V_{A2} = \max_{F_{A2}(t)} \left\{ \left[(b_2 + b_A) F_{A2}(t) - \frac{(c_2 + c_A)}{2} F_{A2}^2(t) + C_O + l x_{A2}(t) \right] + \frac{\partial V_{A2}}{\partial x_{A2}} [a_2 F_{A2}(t) - \delta x_{A2}(t)] \right\} \tag{18}$$

3.2 Result of equilibrium

Proposition 1: Under the mission relationships mode, the balanced extent of efforts to manage wetlands, and balanced social benefits of government and enterprises are respectively Equations 19–22 (the specific solving procedure is shown in Appendix 1):

$$F_{T1}^*(t) = \frac{b_1 + b_T}{c_1 + \ln(1+\beta_1)} + \frac{a_1}{c_1 + \ln(1+\beta_1)} \frac{l}{\rho + \delta} \tag{19}$$

$$F_{T2}^*(t) = \frac{b_2}{c_2} + \frac{a_2}{c_2} \frac{l}{\rho + \delta} \tag{20}$$

$$V_{T1}^* = \frac{l}{\rho+\delta} x_{T1} + \frac{1}{\rho}(b_1 + b_T)\left[\frac{b_1+b_T}{c_1+\ln(1+\beta_1)} + \frac{a_1}{c_1+\ln(1+\beta_1)}\frac{l}{\rho+\delta}\right] - \frac{1}{\rho}\frac{c_1+\ln(1+\beta_1)}{2} \left[\frac{b_1+b_T}{c_1+\ln(1+\beta_1)} + \frac{a_1}{c_1+\ln(1+\beta_1)}\frac{l}{\rho+\delta}\right]^2 - \frac{1}{\rho} C_O + \frac{1}{\rho}\frac{l}{\rho+\delta} a_1 \left[\frac{b_1+b_T}{c_1+\ln(1+\beta_1)} + \frac{a_1}{c_1+\ln(1+\beta_1)}\frac{l}{\rho+\delta}\right] \tag{21}$$

$$V_{T2}^* = \frac{l}{\rho+\delta} x_{T2} + \frac{1}{\rho} b_2 \left(\frac{b_2}{c_2} + \frac{a_2}{c_2}\frac{l}{\rho+\delta}\right) - \frac{c_2}{2}\frac{1}{\rho}\left(\frac{b_2}{c_2} + \frac{a_2}{c_2}\frac{l}{\rho+\delta}\right)^2 + \frac{1}{\rho} C_O + \frac{l}{\rho+\delta}\frac{1}{\rho} a_2 \left(\frac{b_2}{c_2} + \frac{a_2}{c_2}\frac{l}{\rho+\delta}\right) \tag{22}$$

Conclusion 1: The greater the complexity of the wetland problem, the less government governance of wetlands. The greater the benefits of flexibility, the greater the degree of government governance of wetlands.

Proposition 2: Under the employment relationships mode, the balanced extent of efforts to manage wetlands, and balanced social benefits of government and enterprises are respectively equation Equations 23–26 (the specific solving procedure is shown in Appendix 2):

$$F_{E1}^*(t) = \frac{b_1}{c_1 + c_E} + \frac{a_1 + a_E}{c_1 + c_E} \frac{l}{\rho + \delta} \tag{23}$$

$$F_{E2}^*(t) = \frac{b_2}{c_2 + c_E} + \frac{a_2 + a_E}{c_2 + c_E} \frac{l}{\rho + \delta} \tag{24}$$

$$V_{E1}^* = \frac{l}{\rho+\delta} x_{E1} + \frac{1}{\rho} b_1 \left(\frac{b_1}{c_1+c_E} + \frac{a_1+a_E}{c_1+c_E}\frac{l}{\rho+\delta}\right) - \frac{(c_1+c_E)}{2}\frac{1}{\rho} \left(\frac{b_1}{c_1+c_E} + \frac{a_1+a_E}{c_1+c_E}\frac{l}{\rho+\delta}\right)^2 - \frac{1}{\rho} C_O + \frac{1}{\rho}\frac{l}{\rho+\delta}(a_1 + a_E)\left(\frac{b_1}{c_1+c_E} + \frac{a_1+a_E}{c_1+c_E}\frac{l}{\rho+\delta}\right) \tag{25}$$

$$V_{E2}^* = \frac{l}{\rho+\delta} x_{E2} + \frac{1}{\rho} b_2 \left(\frac{b_2}{c_2+c_E} + \frac{a_2+a_E}{c_2+c_E}\frac{l}{\rho+\delta}\right) - \frac{1}{\rho}\frac{(c_2+c_E)}{2} \left(\frac{b_2}{c_2+c_E} + \frac{a_2+a_E}{c_2+c_E}\frac{l}{\rho+\delta}\right)^2 + \frac{1}{\rho} C_O + \frac{1}{\rho}\frac{l}{\rho+\delta}(a_2 + a_E)\left(\frac{b_2}{c_2+c_E} + \frac{a_2+a_E}{c_2+c_E}\frac{l}{\rho+\delta}\right) \tag{26}$$

Conclusion 2: The greater the reputation enhanced by the government's establishment of a stable relationship, the greater the degree of government or corporate governance of wetlands.

Proposition 3: Under the alliance relationships mode, the balanced extent of efforts to manage wetlands, and balanced social benefits of government and enterprises are respectively Equations 27–30 (the specific solving procedure is shown in Appendix 3):

$$F_{A1}^*(t) = \frac{b_1 \ln(\mathrm{e} + \lambda_A)}{c_1 + c_A} + \frac{a_1}{c_1 + c_A} \frac{l}{\rho + \delta} \tag{27}$$

$$F_{A2}^*(t) = \frac{b_2 + b_A}{c_2 + c_A} + \frac{a_2}{c_2 + c_A} \frac{l}{\rho + \delta} \tag{28}$$

$$V_{A1}^* = \frac{l}{\rho+\delta} x_{A1} + \frac{1}{\rho} b_1 \ln(\mathrm{e} + \lambda_A)\left[\frac{b_1 \ln(\mathrm{e}+\lambda_A)}{c_1+c_A} + \frac{a_1}{c_1+c_A}\frac{l}{\rho+\delta}\right] - \left[\frac{b_1 \ln(\mathrm{e}+\lambda_A)}{c_1+c_A} + \frac{a_1}{c_1+c_A}\frac{l}{\rho+\delta}\right]^2 \frac{1}{\rho}\frac{(c_1+c_A)}{2} - \frac{1}{\rho} C_O + \frac{1}{\rho}\frac{l}{\rho+\delta} a_1 \left[\frac{b_1 \ln(\mathrm{e}+\lambda_A)}{c_1+c_A} + \frac{a_1}{c_1+c_A}\frac{l}{\rho+\delta}\right] \tag{29}$$

$$V_{A2}^* = \frac{l}{\rho+\delta} x_{A2} + \frac{1}{\rho}(b_2 + b_A)\left(\frac{b_2+b_A}{c_2+c_A} + \frac{a_2}{c_2+c_A}\frac{l}{\rho+\delta}\right) - \frac{1}{\rho}\frac{(c_2+c_A)}{2}\left(\frac{b_2+b_A}{c_2+c_A} + \frac{a_2}{c_2+c_A}\frac{l}{\rho+\delta}\right)^2 + \frac{1}{\rho} C_O + \frac{1}{\rho}\frac{l}{\rho+\delta} a_2 \left(\frac{b_2+b_A}{c_2+c_A} + \frac{a_2}{c_2+c_A}\frac{l}{\rho+\delta}\right) \tag{30}$$

Conclusion 3: The greater the degree of risk sharing and benefit sharing, the greater the degree of government governance of wetlands.

3.3 Case analysis

Indonesia possesses the world's largest tropical peatlands, which serve as significant carbon sinks. However, due to agricultural development (such as palm oil cultivation) and deforestation, these peatlands have experienced severe degradation, leading to substantial carbon dioxide emissions. To address this issue, the Indonesian government has collaborated with international organizations to initiate peatland restoration projects and has raised funds through carbon trading mechanisms (Putra and Lee, 2024).

Peatlands are wetlands formed by the accumulation of partially decomposed plant residues, characterized by exceptionally high carbon density. Indonesia's peatlands, among the largest tropical peatlands globally, are particularly rich in carbon storage, with each hectare capable of storing thousands of tons of carbon, far exceeding that of other ecosystems such as forests or grasslands. In Indonesia, peatland degradation is primarily driven by agricultural development (e.g., palm oil cultivation) and deforestation, activities that lead to peatland drainage and burning, resulting in substantial carbon dioxide emissions. Degraded peatlands represent significant sources of carbon emissions (Asyhari et al., 2024). Restored peatlands can reabsorb and store large amounts of carbon dioxide, with each hectare of restored peatland potentially reducing emissions by tens of tons annually and accumulating carbon stocks over the long term. The carbon sequestration effect of peatland restoration is enduring, as restored peatlands continue to absorb and store carbon dioxide over time, further enhancing their carbon offset value. Given that these activities typically require substantial time and resource investments, relatively generous carbon offset mechanisms can help mitigate these costs, making such investments more attractive and economically viable for businesses (Peng et al., 2022). These factors collectively underscore the significant environmental and economic value of peatland restoration projects within carbon trading systems. Therefore, this paper hypothesizes that government carbon offsets C_o to enterprises is 8.

In the process of peatland restoration in Indonesia, establishing stable relationships is a long-term endeavor that requires continuous resource investment, whereas the costs associated with increased management complexity are typically short-term or phased, and once resolved, subsequent costs are significantly reduced (Duan et al., 2023). In government-enterprise collaborations, the interests of various parties may diverge, necessitating substantial government resources to coordinate conflicts and reach consensus. In contrast, the costs of increased management complexity usually do not involve conflicting interests and are more easily addressed through technical means. Building trust and cooperation requires unique resources and capabilities (e.g., diplomacy, negotiation, communication skills), which are often scarce and thus more costly. On the other hand, the costs of increased management complexity rely more on technical and managerial capabilities, resources that are relatively easier to obtain. Therefore, the "cost of establishing stable relationships by the government" is higher than the "cost incurred by the government due to increased management complexity." For convenience, this article hypothesizes that the increased cost c_E to government of building stable relationships is 2, and the increased cost c_A to governments of managing complexity is 1.5.

The benefits derived from flexibility are typically short-term and limited, whereas the gains from market expansion are long-term and substantial. For instance, the cost savings achieved through flexibility may be significantly lower than the increase in sales or profits generated by market expansion. The benefits of market expansion exhibit a cumulative effect, growing progressively over time, whereas the advantages of flexibility generally lack this cumulative nature. Market expansion can provide strategic value to enterprises, such as enhancing brand image or entering new market domains, while flexibility primarily offers tactical value, such as cost optimization or risk reduction (Peng et al., 2022). Consequently, the long-term benefits and strategic value obtained by enterprises through market expansion far exceed the short-term gains derived from flexibility. For convenience, this paper hypothesizes that the benefits b_T from flexibility is 1.5, and the increased revenue b_A to the enterprises from market expansion is 2.

In the governance of peatlands, the establishment of stable relationships often involves cooperation at global or regional levels, with outcomes and impacts that are broad in scope. In contrast, the management of peatlands at the unit level typically pertains to local or specific regions, with limited influence. Establishing stable relationships requires the coordination of multiple interests and the resolution of complex issues, a capability regarded as a high-level governance achievement that can significantly enhance the reputation of governments or enterprises (Stephanie et al., 2022). The establishment of stable relationships usually signifies a long-term commitment and sustainability to projects, which can strengthen the reputation of governments or enterprises. By successfully advancing peatland restoration projects through the establishment of stable relationships, governments or enterprises can gain recognition from the international community and provide exemplary models for other countries or regions, further elevating their reputation. Therefore, "the reputation gained by governments through the establishment of stable relationships" exceeds "the reputation obtained by governments or enterprises through unit-level wetland management." For convenience, this paper hypothesizes that the increased reputation a_E of the government for building stable relationships is 2.5, and the reputation a_1,a_2 gained by government or enterprises for managing wetlands at a unit level is 2.

The tropical peatland ecosystems in Indonesia exhibit long-term stability, with their carbon sequestration benefits persisting over extended periods. Consequently, a lower discount rate can more accurately reflect the sustained future value of carbon sequestration (Tan et al., 2023). Additionally, driven by policy support and global climate governance objectives, the carbon trading market faces relatively low uncertainty in future returns. Therefore, this study assumes a discount rate of 0.9 to better capture the stability of the market, i.e., ρ=0.9.

The decline in the reputation of local governments and enterprises in Indonesia's tropical peatlands is typically a relatively slow process, particularly in long-term cooperative projects such as carbon trading and wetland management (Asyhari et al., 2024). The maintenance and enhancement of reputation are key objectives for both parties, resulting in a lower decay rate. A lower decay rate (e.g., 0.1) reflects the positive impact of policy stability and corporate social responsibility practices on reputation, indicating that reputational loss does not occur rapidly but accumulates gradually over time. Therefore, this study hypothesizes that decay δ of reputation is 0.1.

Reputation plays a critical role in carbon trading and wetland management, as strong government and enterprise reputations can significantly enhance cooperative trust, reduce transaction costs, and improve project sustainability. If the positive influence is set to 1, it indicates that reputation maximizes its impact on project success, aligning with its role as a core driver in practice. Carbon trading projects typically require long-term cooperation and policy support, where the positive influence of reputation can markedly enhance project stability and attractiveness. Therefore, setting it to 1 better reflects the direct contribution of reputation to project performance, i.e., l =1.

The tropical peatland ecosystems in Indonesia exhibit moderate complexity, with their multifunctional roles in carbon sequestration, biodiversity conservation, and hydrological regulation requiring comprehensive consideration of various factors, though not reaching a highly complex level (Adinugroho et al., 2024). Wetland management within the context of carbon trading typically involves the coordination of multiple dimensions, including policy, economy, ecology, and society. Assuming a complexity level of 2 adequately reflects this intermediate level of integrated challenges, i.e., $\beta_1 = 2$.

Wetland management in the context of carbon trading involves multiple stakeholders (e.g., governments, enterprises, communities) and requires the establishment of effective cooperative mechanisms to balance risks and benefits. In this scenario, the degree of risk-sharing and benefit-sharing is slightly above average, reflecting the tendency of all parties in wetland management projects to optimize resource allocation and enhance project sustainability through strengthened cooperation. The long-term nature and complexity of Indonesia's tropical peatland ecosystems demand a higher level of risk-sharing and benefit-sharing. Assuming this degree to be 1.2 better captures the depth and breadth of such cooperation, i.e., λ_A=1.2.

At the same time, this paper assumes that the game is in the unit state, i.e., the state variable is 1.

Based on this, the expression of (31)-(36) can be obtained by inserting the values of the above parameters and the following values of c_1, c_2 into (21), (25) and (29); the values of the above parameters and the following values of c_1, c_2 are put into (22), (26) and (30) to obtain the expression (37)-(42).

In order to simplify the consideration of cost factors, this study eliminates the need to meticulously distinguish between the differences in unit wetland management costs between the government and enterprises, thereby reducing the complexity of the model and decreasing the number of variables, which allows for a more focused analysis on factors related to social benefits. By excluding the interference of cost differences during the comparative analysis of social benefits, it becomes clearer to demonstrate the impacts of other aspects (such as management methods, resource allocation, policy implementation, etc.) of wetland management by the government and enterprises on social benefits. This approach aids in a more precise evaluation of the contributions of both parties to social benefits in wetland management, providing more direct and effective reference for the formulation and optimization of wetland management policies. Therefore, this paper assumes that c_1=c_2.

When the cost c_1, c_2 to the government or enterprises of managing wetlands at a unit level is 1, this article can calculate the social benefits of government as Equations 31–33:

$$V^*_{T1} = -7.888 + 0.26(b_1 + 3.5)^2 \tag{31}$$

$$V^*_{E1} = -7.888 + 0.185(b_1 + 4.5)^2 \tag{32}$$

$$V^*_{A1} = -7.888 + 0.222(1.37b_1 + 2)^2 \tag{33}$$

The following graphs (named Figure 2) can also be produced:

When the cost c_1, c_2 to the government or enterprises of managing wetlands at a unit level is 2, this article can calculate the social benefits of government as equation Equations 34–36:

$$V^*_{T1} = -7.888 + 0.18(b_1 + 3.5)^2 \tag{34}$$

$$V^*_{E1} = -7.888 + 0.139(b_1 + 4.5)^2 \tag{35}$$

$$V^*_{A1} = -7.888 + 0.159(1.37b_1 + 2)^2 \tag{36}$$

The following graphs (named Figure 3) can also be produced:

Conclusion 4: When the benefits derived from wetlands under the degree of government governance are relatively small, the employment relationships model can yield the maximum social benefit for the government. As the benefits reach a moderate level, the mission relationships model becomes the one that enables the government to obtain the greatest social benefit. When the benefits derived from wetlands under government governance are substantial, the alliance relationships model is the most effective in maximizing social benefits for the government.

When the cost c_1, c_2 to the government or enterprises of managing wetlands at a unit level is 1, this article can calculate the social benefits of enterprises as Equations 37–39:

$$V^*_{T2} = 9.888 + 0.556(b_2 + 2)^2 \tag{37}$$

$$V^*_{E2} = 9.888 + 0.185(b_2 + 4.5)^2 \tag{38}$$

$$V^*_{A2} = 9.888 + 0.222(b_2 + 4)^2 \tag{39}$$

The following graph (named Figure 4) can also be produced:

When the cost c_1, c_2 to the government or enterprises of managing wetlands at a unit level is 2, this article can calculate the social benefits of enterprises as Equations 40–42:

$$V^*_{T2} = 9.888 + 0.278(b_2 + 2)^2 \tag{40}$$

$$V^*_{E2} = 9.888 + 0.139(b_2 + 4.5)^2 \tag{41}$$

$$V^*_{A2} = 9.888 + 0.159(b_2 + 4)^2 \tag{42}$$

The following graph (named Figure 5) can also be produced:

Conclusion 5: When the benefits derived from wetlands under the degree of corporate governance are relatively small, the employment relationships model can yield the maximum social benefit for corporations. As the benefits reach a moderate level, the alliance relationships model becomes the most effective in enabling corporations to secure the greatest social benefit. When the benefits derived from wetlands under corporate governance are substantial, the mission relationships model is the one that ensures the highest social benefit for corporations.

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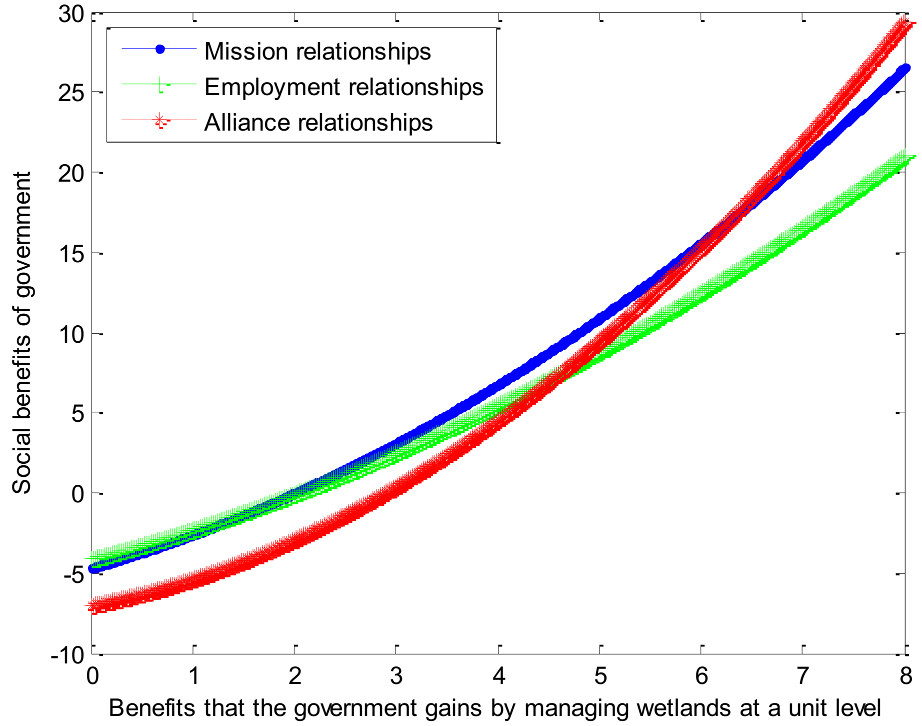

FIGURE 2
Impact of benefits of government on social welfare.

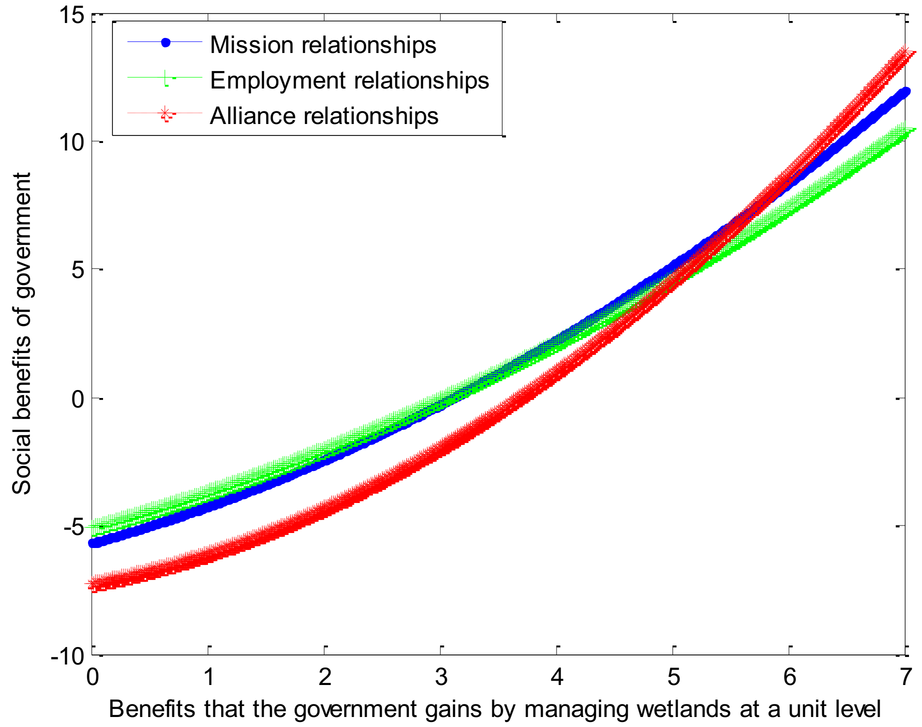

FIGURE 3
Impact of benefits of government on social welfare.

4 Discussion

Conclusion 1 mainly involves the relationship between the complexity of wetland issues and the degree of governmental governance, as well as the impact of flexibility on governance. Conclusion 1 can be understood from the perspective of environmental management and policy formation. First, an increase in complexity leads to a decrease in the degree of governance. Although both address issues related to complexity, this study differs from the research conducted by Zhang H. et al. (2024). Zhang H. et al. (2024) argue that optimized nodes increase the complexity of river networks. Their research primarily focuses on how governance leads to increased complexity, whereas this study examines the impact of complexity on wetland governance.

The complexity of wetland ecosystems often includes multiple aspects such as biodiversity, hydrological cycles, and interactions with human activities. When the complexity of wetland issues increases, challenges faced by the government include difficulties in obtaining accurate scientific data, predicting ecosystem responses, and devising effective management measures. In this context, governments may tend to take fewer intervention measures, partly because of higher uncertainties making it difficult for policymakers to develop policies with extensive social support.

Moreover, high complexity can also lead to a significant increase in management costs, further hindering proactive governance by the government. Second, an increase in the benefits brought by flexibility leads to an increase in the degree of governance. Flexibility in environmental management often refers to the adaptability and adjustment capabilities in the policy-making and implementation process. When governments recognize that a flexible governance strategy can more effectively address uncertainties and changes in wetland conservation and utilization, the benefits of flexibility increase. For example, by adopting adaptive management approaches, governments can adjust their strategies based on environmental monitoring data and socio-economic feedback to respond to changing environmental conditions and human demands. An increase in flexibility can enhance the effectiveness of policies and acceptability in society, thereby motivating governments to increase the level of wetland governance, achieving a better balance between environmental protection and resource utilization.

Therefore, when the complexity of wetland management issues increases, governments may decrease the degree of governance due to high uncertainties and decision-making difficulties. Conversely, when the benefits of flexibility increase, governments are more likely to increase the degree of governance, utilizing flexible management strategies to effectively cope with changes in environmental and socio-economic conditions. This suggests that enhancing the flexibility of policy-making and implementation may be key to improving governance outcomes in the face of complex environmental issues.

Conclusion 1 can be further validated both theoretically and practically. At the theoretical level, the Complex Adaptive Systems (CAS) theory can support Conclusion 1. Wetland ecosystems are complex adaptive systems characterized by nonlinearity, dynamism, and multi-scale features. According to this theory, complexity issues

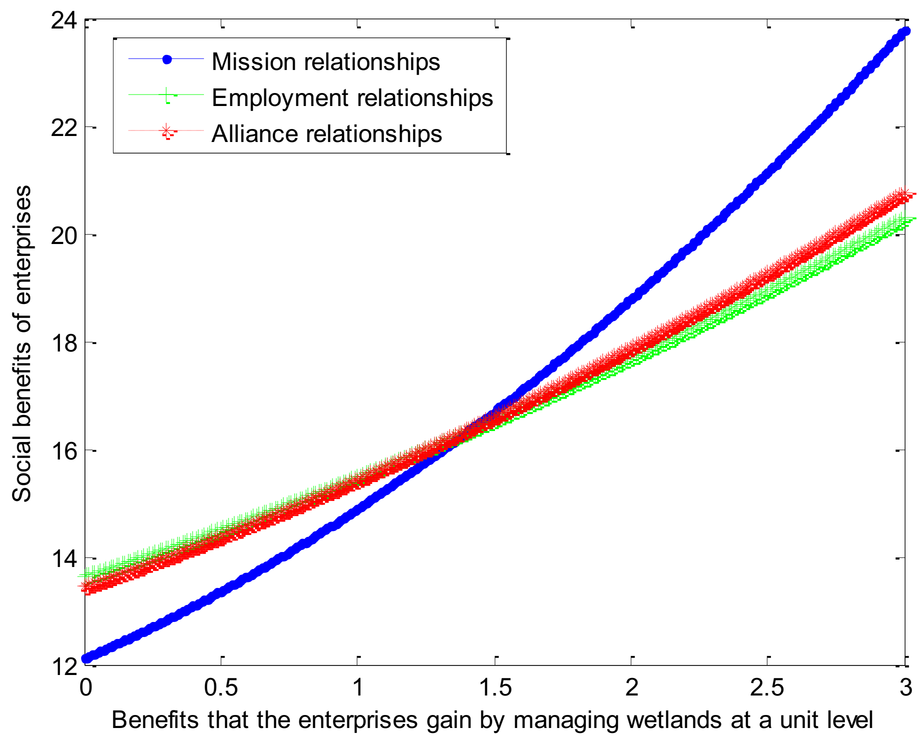

FIGURE 4
Impact of benefits of enterprises on social welfare.

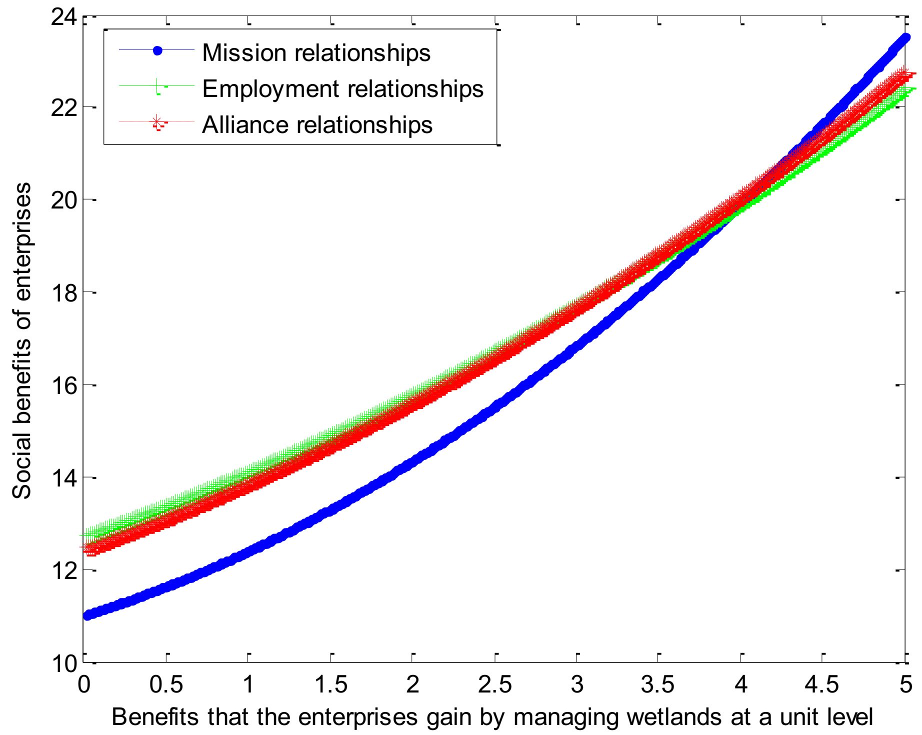

FIGURE 5
Impact of benefits of enterprises on social welfare.

may lead to difficulties in defining governance objectives, thereby reducing governance inputs (Sikk and Caruso, 2024).

At the practical level, the Florida Everglades, the largest subtropical wetland in the United States, faces challenges such as water resource management and urbanization (Giarikos et al., 2023). Wetland issues involve multiple states, federal governments, environmental organizations, and private stakeholders, making governance coordination highly challenging. Despite the complexity, the U.S. government has implemented long-term governance through the "Comprehensive Everglades Restoration Plan" (CERP), emphasizing flexibility and multi-party collaboration.

According to Conclusion 1, to achieve maximum benefits, governments will establish flexible policy frameworks that allow local adjustments based on actual conditions. In addressing complexity issues, governments will concentrate resources on key areas rather than implementing comprehensive interventions. In scenarios where the benefits of flexibility are high, governments will strengthen oversight while providing technical, financial, or policy support to ensure the effectiveness of flexible measures.

According to Conclusion 2, the stable relationships and enhanced reputation that governments or corporations establish in dealing with environmental issues, such as wetland governance, have a significant impact on their level of governance for several reasons. This finding shares similarities with the results of Sampet (2023), but it is not entirely identical. Sampet (2023) argues that if a company demonstrates the impact of sustainable development performance, consumers are more likely to perceive higher satisfaction, trust, and reputation for the company. Sampet (2023) primarily explains the positive impact of sustainable development performance on reputation. In contrast, Conclusion 2 focuses on the positive impact of stable relationships during environmental governance on reputation.

Conclusion 2 can be explained from the following aspects. First, by establishing stable relationships and improving their reputation in environmental management, governments or corporations can significantly increase public trust in their decision-making and actions. This trust is based on the public's belief that the government or corporation can manage and protect environmental resources responsibly, especially in complex and sensitive areas like wetland conservation. When public trust increases, the actions of the government or corporation receive wider social support, thus increasing the social capital for taking more active governance measures.

Second, stable relationships foster cooperation between the government or corporation and various stakeholders, including non-governmental organizations, communities, scientific research institutions, and the private sector. This cooperation is key to achieving effective wetland governance because it can bring together diverse resources, knowledge, and expertise to address complex issues. Stable relationships built on trust and consensus among partners can accelerate the decision-making process, share responsibilities, and enhance enforcement.

Third, in order to maintain and enhance their reputation in environmental protection, governments or corporations might adopt more proactive and forward-looking governance measures. This behavior reflects their commitment to sustainable development and environmental responsibility. In some cases, an exemplary environmental governance record can become part of the brand and identity of the government or corporation, attracting more investors and partners, while also meeting the demands of increasingly environmentally conscious consumers (He et al., 2021).

Fourth, governments or corporations with a good reputation in environmental policy and governance typically value long-term interests over short-term gains. Stable relationships and a good reputation encourage them to adopt a more comprehensive and long-term perspective on environmental issues such as wetland governance, identifying and implementing sustainable solutions that not only address current issues but also prevent future problems.

In sum, the stable relationships and enhanced reputation that governments or corporations establish in environmental governance, especially in wetland governance, can increase public trust, facilitate multi-party cooperation, and improve the effectiveness and enforcement of policies, leading to a greater degree of governance. This illustrates that a good reputation and stable relationships are valuable assets in the field of environmental protection, capable of motivating and supporting stronger environmental governance measures.

Conclusion 2 can also be further validated both theoretically and practically. At the theoretical level, Reputation Theory can support Conclusion 2. Reputation is a critical asset for governments or companies, influencing their decision-making behaviors. Governments or companies with high reputations are more inclined to take proactive governance actions to maintain and enhance their reputations (Guo and Rochat, 2024). Reputation Theory can be used to analyze whether the behaviors of governments or companies in wetland governance are driven by reputation. For instance, governments with high reputations may be more willing to invest resources in wetland governance to demonstrate their environmental responsibility and governance capabilities.

At the practical level, the Chinese government has placed significant emphasis on wetland protection in recent years, integrating it as a crucial component of ecological civilization construction. Stable collaborative relationships have been established among the government, the public, environmental organizations, and enterprises. Through wetland governance, the Chinese government has built an image of environmental responsibility both domestically and internationally. The implementation of China's wetland protection policies has been robust, with a high level of governance effectiveness.

According to Conclusion 2, to achieve maximum benefits, governments will strive to establish long-term and stable cooperative relationships with relevant stakeholders (e.g., enterprises, communities, environmental organizations). Such relationships contribute to enhancing the government's credibility and reputation. As reputation improves, governments will intensify efforts in wetland governance, formulating stricter policies and regulations to ensure the achievement of wetland protection goals. Governments will encourage enterprises and non-governmental organizations to participate in wetland governance through cooperative governance models, sharing responsibilities and further enhancing reputation and governance effectiveness. Governments will increase transparency in the governance process and establish accountability mechanisms to strengthen public trust and reputation.

To achieve maximum benefits, enterprises will actively participate in cooperative governance with governments, enhancing their reputation by fulfilling social responsibilities and environmental commitments. Enterprises may invest in wetland protection projects, demonstrating their commitment o environmental conservation through concrete actions, thereby improving their corporate image. Enterprises will strictly comply with government regulations on wetland protection, avoiding reputational damage caused by violations. Through communication and outreach, enterprises will showcase their efforts and achievements in wetland protection to the public, further strengthening public trust and recognition.

According to Conclusion 3, the principles of risk sharing and benefit sharing play a pivotal role in wetland governance, significantly influencing the extent of governance taken by the government. Although both studies focus on risk-sharing, this research differs from that of Tice (2024). Tice (2024) argues that when there is high common risk exposure and the selected peers significantly mitigate common risks, companies employing relative performance evaluation outperform similar companies that do not use such evaluation. Tice (2024) primarily examines the impact of risks and relative performance evaluation on companies. In contrast, this study mainly investigates the influence of risk-sharing on the extent of governance.

Conclusion 3 can be explained through several reasons. First, when risks are effectively shared, the cost of failure borne by any single party is reduced, encouraging more participants, including governments, the private sector, and non-governmental organizations, to invest in wetland conservation and restoration projects. Benefit-sharing mechanisms ensure that all participants obtain a certain return on their investments, whether in terms of economic, social, or environmental benefits. This anticipation of positive returns increases funding and resources dedicated to wetland governance activities.

Second, the principles of risk sharing and benefit sharing prompt different stakeholders to collaborate in developing and implementing wetland governance plans. This cooperation, based on principles of equality and reciprocity, helps to pool expertise, skills, and resources from multiple parties, enhancing the efficiency and effectiveness of governance measures. Through joint efforts, stakeholders can collectively address the challenges encountered in the governance process, improving the success rate of projects.

Third, when parties perceive the distribution of risks and benefits in the governance process as fair, they are more likely to support and participate in wetland conservation activities. This enhances the social legitimacy and public acceptance of the project, laying the foundation for the long-term success of wetland governance. Benefit sharing can also motivate community involvement in the conservation and restoration of wetlands, as they directly benefit from these activities.

Fourth, in an environment of shared risks, governments and other stakeholders are more likely to experiment with innovative governance approaches, as the risk of failure is collectively borne

(Yuan et al., 2025a). This spirit of innovation is key to finding effective methods for wetland governance, especially when facing complex environmental challenges. Benefit sharing also encourages parties to seek solutions that meet environmental protection goals while also providing economic or social benefits.

Fifth, under mechanisms of risk sharing and benefit sharing, governments are more motivated to formulate and implement proactive wetland governance policies. This is because such mechanisms can reduce the government's financial burden while enhancing the effectiveness and sustainability of governance measures through partnerships.

Additionally, governments can use these mechanisms to balance the relationship between environmental protection and economic development, thereby gaining broader policy support. In summary, the greater the extent of risk sharing and benefit sharing, the more it motivates resource investment, promotes collaboration among partners, increases innovation and sustainability in governance measures, thereby encouraging governments to take a more active stance in wetland governance. This not only improves governance outcomes but also promotes a harmonious coexistence between environmental protection and socio-economic development.

Conclusion 3 can also be further validated both theoretically and practically. At the theoretical level, Collaborative Governance Theory can support the verification of Conclusion 3. Collaborative governance emphasizes the joint participation of multiple stakeholders in decision-making and actions, enhancing governance efficiency through risk-sharing and benefit-sharing (Chen et al., 2024). This theory can be used to analyze the extent of collaboration among stakeholders such as governments, enterprises, and the public in wetland governance, as well as how such collaboration drives governance through risk-sharing and benefit-sharing.

At the practical level, wetland governance in the Netherlands can validate Conclusion 3. The Netherlands serves as a global model for wetland governance, with its governance model emphasizing multi-party collaboration (Hein et al., 2006). Governments, enterprises, and research institutions jointly share governance risks. The outcomes of governance, such as flood control benefits and ecotourism revenues, are shared among multiple stakeholders. The Netherlands demonstrates a high level of wetland governance, achieving significant governance effectiveness.

According to Conclusion 3, to achieve maximum benefits, governments will take measures to encourage relevant stakeholders (e.g., enterprises, communities, non-governmental organizations) to share the risks associated with wetland governance. This can be accomplished through the formulation of policies, provision of financial support, or the establishment of cooperative mechanisms. Governments will ensure that the benefits derived from wetland governance are equitably distributed among all participating parties. These benefits include economic gains (e.g., ecotourism, resource utilization) and ecological advantages (e.g., biodiversity conservation, climate regulation). As the degree of risk-sharing and benefit-sharing increases, governments will intensify their efforts in wetland governance, enacting stricter policies and regulations to ensure the achievement of wetland protection goals. Governments will establish multi-stakeholder cooperative mechanisms to ensure effective communication and collaboration among all parties, enabling them to jointly assume the responsibilities and risks of wetland governance. Governments will enhance the transparency of the governance process and implement accountability mechanisms to ensure the fairness and effectiveness of risk-sharing and benefit-sharing.

Conclusion 4 pertains to the strategic choice of organizational relationship models (employment relationships, mission relationships, and alliance relationships) adopted by governments in wetland governance to maximize social benefits. These choices reflect the variation in optimal governance models and modes of cooperation under different levels of benefits. Although both studies employ differential game theory to address environmental issues, the conclusions drawn in this paper differ from those of Yuan et al. (2024). Yuan et al. (2024) suggest strengthening cross-boundary watershed pollution control cooperation through collaborative strategies, incentive and penalty mechanisms, and the application of advanced technological equipment. In contrast, this paper analyzes the strengths and weaknesses of different wetland governance models to determine which governance model is more conducive to effective wetland management.

Conclusion 4 is caused by the following reasons. Firstly, when the direct economic benefits of wetland governance are minimal and may not suffice to attract multi-party active investments or in-depth cooperation, the employment relationships mode can be used by the government to effectively control costs and swiftly implement governance measures. In this model, as the government directly pays for specific tasks, it becomes easier to maximize social benefits in projects with lower costs and benefits (Giri and Paul, 2022).

Secondly, when wetland governance can yield moderate economic or social benefits, the mission relationships model can facilitate more efficient resource utilization and specialization. Cooperation based on clearly defined common goals allows for a better balance of inputs and benefits, leading to the efficient execution of projects and the maximization of social benefits in projects with moderate returns.

Thirdly, when the potential economic, environmental, and social benefits of wetland governance are substantial, the alliance relationships model can motivate all parties to jointly invest resources and efforts and share risks. Such in-depth cooperation can bring about economies of scale and foster innovation, ultimately maximizing returns (Saner, 2019). In high-benefit projects, the alliance relationships ensures that all participants benefit from successful governance activities, thereby maximizing overall social benefits.

In summary, as the potential benefits of wetland governance projects increase, the governance model employed by the government should also transition from simple employment relationships to more complex and cooperative alliance relationships, ensuring the maximization of social benefits at different levels of profit. The selection of such a strategy reflects a comprehensive consideration of effective resource utilization, risk management, and benefit maximization.

Conclusion 4 can also be further validated both theoretically and practically. At the theoretical level, Transaction Cost Economics (TCE) can support the verification of Conclusion 4. The core premise of this theory is that the choice of governance model depends on transaction costs (e.g., coordination costs, monitoring costs) and governance benefits (Halaburda et al., 2024). It can analyze how employment relationships, mission relationships, and alliance relationships reduce transaction costs and maximize social benefits under different benefit levels. For instance, employment relationships may be more efficient when benefits are modest, whereas alliance relationships may prove more effective when benefits are substantial.

At the practical level, wetland governance in the Netherlands can validate Conclusion 4. Dutch wetland governance yields high benefits and involves multiple stakeholders (Hein et al., 2006). Governments, research institutions, enterprises, and the public form alliances to collectively advance wetland governance. Through alliance relationships, the Netherlands has achieved efficient and sustainable wetland governance. The success of Dutch wetland governance serves as a practical validation of the conclusion that "alliance relationships models are most effective under high benefit levels."

According to Conclusion 5, when enterprises participate in wetland governance, they choose the most appropriate organizational relationship model (employment relationships, alliance relationships, or mission relationships) based on expected benefits to maximize social returns. This study shares similarities with the research conducted by Peng et al. (2024), yet it is not entirely identical. Peng et al. (2024) developed a quantitative-quality-benefit model and employed the Coupling Coordination Degree Model (CCDM) to further analyze the impact of the coupling coordination relationship among water quantity, water quality, and water benefits on water sustainability evaluation. In contrast, this paper constructs a differential game model to derive the benefits of different governance models, thereby providing a reference for selecting the most appropriate governance approach. Distinct from government entities, corporate decision-making typically places greater emphasis on economic returns and risk management.

Here are the governance models enterprises may adopt under different profit scenarios and the reasons for such choices. Firstly, for wetland governance projects with small returns, enterprises may be unwilling or find it unnecessary to invest substantial resources in establishing complex cooperative relationships. In such instances, the employment relationships model enables the simplification of management processes, reduction of communication costs, and quick achievement of project goals at lower costs, thus maximizing social benefits within the defined profit scope (Lindvert et al., 2022).

Secondly, when potential benefits from wetland governance are moderate, enterprises can gather more resources and expertise through establishing an alliance relationships model to develop more effective governance solutions collectively. This kind of cooperation can expand the project's scale and impact while distributing risks, making the project more viable and sustainable, thereby achieving the greatest social returns under moderate benefit conditions.

Thirdly, in scenarios where returns are substantial, enterprises may face increased competition and high uncertainty. By adopting a mission relationships model, enterprises can flexibly assemble experts and resources in specific areas to focus on challenging large-scale projects. This model helps enterprises concentrate their resources on overcoming technical obstacles or achieving strategically significant objectives, thus maximizing social and environmental benefits in high-return projects.

Overall, in selecting governance models, enterprises need to consider potential project benefits, the allocation of resources and capabilities, as well as the trustworthiness and depth of cooperation with partners. As potential project benefits increase, enterprises typically shift from an employment relationship with direct control towards models relying more on cooperation and specialization to realize larger social benefits.

At the theoretical level, Resource Dependence Theory (RDT) can validate Conclusion 5. The core premise of this theory is that organizations choose governance models to manage their dependence on external resources (Wang and Liu, 2021). This theory can analyze how enterprises optimize resource utilization and social benefits by adjusting their relationship models (e.g., employment, alliance, task) with stakeholders under different benefit levels.

The research presented in this paper makes several significant contributions. First, it is the first to systematically analyze three relationship models (mission relationships, employment relationships, and alliance relationships) in wetland management from the perspective of carbon trading, providing a new theoretical framework for wetland management research. Second, by integrating the context of carbon trading, it proposes policy recommendations for optimizing wetland management, emphasizing the flexible application of different relationship models to balance environmental and economic benefits, thereby offering scientific support for relevant policy formulation. Third, it combines carbon trading mechanisms with wetland management, expanding the interdisciplinary field of environmental management and economic tools, and providing direction for future research.

5 Conclusion

Wetland ecosystems have suffered significant damage, necessitating effective protection by both governments and corporations. Under carbon offset schemes, governments need to grant certain carbon emission rights to enterprises that participate in wetland governance. Considering the three primary modes of governance cooperation between governments and enterprises—mission relationships, employment relationships, and alliance relationships—this paper constructs differential game models for these modes, derives equilibrium results, and conducts comparative analyses. The research concludes that when the benefits derived from a unit area of wetland governance by the government are minimal, the employment relationships model yields the maximum social benefit for the government; when the benefits are moderate, the mission relationships model secures the maximum social benefit for the government; and when the benefits are substantial, the alliance relationships model ensures the maximum social benefit for the government. Similarly, for enterprises, when the benefits from a unit area of wetland governance are minimal, the employment relationships model provides the maximum social benefit for the business; when the benefits are moderate, the alliance relationships model procures the maximum social benefit for the business; and when the benefits are substantial, the mission relationships model facilitates the maximum social benefit for the business.

This study reveals that, in the context of carbon trading, governments and enterprises should adopt employment relationships, mission relationships, or alliance relationships models based on the varying levels of wetland management benefits per unit area, to maximize social benefits. In practical applications, the findings of this study provide significant guidance for governments and enterprises in formulating wetland management strategies. For example, in regions with relatively scarce wetland resources or low carbon trading benefits, governments and enterprises can adopt the employment relationships model to achieve wetland conservation goals through stable human resource investments. In regions with moderate benefits, governments can employ the task relationship model, while enterprises may opt for the alliance relationships model, enhancing governance efficiency through flexible task allocation or resource sharing. In regions with abundant wetland resources or high carbon trading benefits, governments should prioritize the alliance relationships model, while enterprises can utilize the task relationship model to maximize social benefits through efficient resource allocation and synergistic effects. These research findings not only contribute to optimizing wetland management strategies but also promote the healthy development of the carbon trading market, achieving a win-win scenario for ecological conservation and economic benefits.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material. Further inquiries can be directed to the corresponding author.

Author contributions

SW: Conceptualization, Data curation, Investigation, Writing – original draft. YB: Conceptualization, Investigation, Methodology, Project administration, Writing – original draft. JL: Methodology, Validation, Writing – original draft. YY: Writing – original draft.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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The author(s) declare that no Generative AI was used in the creation of this manuscript.

Publisher's note

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Appendix 1

Taking the derivative of the right-hand side of (13) with respect to the variable F_{T1}, and taking the derivative of the right-hand side of (14) with respect to the variable F_{T2}, and setting them equal to zero, we can get Equations 43, 44:

$$F_{T1}^{\star}(t)=\frac{b_1+b_T}{c_1+\ln(1+\beta_1)}+\frac{a_1}{c_1+\ln(1+\beta_1)}\frac{\partial V_{T1}}{\partial x_{T1}} \tag{43}$$

$$F_{T2}^{\star}(t)=\frac{b_2}{c_2}+\frac{a_2}{c_2}\frac{\partial V_{T2}}{\partial x_{T2}} \tag{44}$$

Substituting (43) into (13) and substituting (44) into (14), we can get Equations 45, 46:

$$\begin{aligned}\rho V_{T1}=&(b_1+b_T)\left[\frac{b_1+b_T}{c_1+\ln(1+\beta_1)}+\frac{a_1}{c_1+\ln(1+\beta_1)}\frac{\partial V_{T1}}{\partial x_{T1}}\right]-\frac{c_1+\ln(1+\beta_1)}{2}\\&\left[\frac{b_1+b_T}{c_1+\ln(1+\beta_1)}+\frac{a_1}{c_1+\ln(1+\beta_1)}\frac{\partial V_{T1}}{\partial x_{T1}}\right]^2-C_O+lx_{T1}(t)+\\&\frac{\partial V_{T1}}{\partial x_{T1}}a_1\left[\frac{b_1+b_T}{c_1+\ln(1+\beta_1)}+\frac{a_1}{c_1+\ln(1+\beta_1)}\frac{\partial V_{T1}}{\partial x_{T1}}\right]-\frac{\partial V_{T1}}{\partial x_{T1}}\delta x_{T1}(t)\end{aligned} \tag{45}$$

$$\begin{aligned}\rho V_{T2}=&b_2\left(\frac{b_2}{c_2}+\frac{a_2}{c_2}\frac{\partial V_{T2}}{\partial x_{T2}}\right)-\frac{c_2}{2}\left(\frac{b_2}{c_2}+\frac{a_2}{c_2}\frac{\partial V_{T2}}{\partial x_{T2}}\right)^2+C_O\\&+lx_{T2}(t)+\frac{\partial V_{T2}}{\partial x_{T2}}\left[a_2\left(\frac{b_2}{c_2}+\frac{a_2}{c_2}\frac{\partial V_{T2}}{\partial x_{T2}}\right)-\delta x_{T2}(t)\right]\end{aligned} \tag{46}$$

Letting $V_{T1}^{\star}=k_1x_{T1}+k_2$, $V_{T2}^{\star}=k_3x_{T2}+k_4$, wherein, k_1, k_2, k_3 and k_4 are all constants. The parameters of the optimal social welfare function can be obtained by calculation as follows (Equations 47, 48):

$$\begin{cases}k_1=\frac{l}{\rho+\delta}\\ k_2=\frac{1}{\rho}(b_1+b_T)\left[\frac{b_1+b_T}{c_1+\ln(1+\beta_1)}+\frac{a_1}{c_1+\ln(1+\beta_1)}\frac{l}{\rho+\delta}\right]-\frac{1}{\rho}\frac{c_1+\ln(1+\beta_1)}{2}\\ \qquad\left[\frac{b_1+b_T}{c_1+\ln(1+\beta_1)}+\frac{a_1}{c_1+\ln(1+\beta_1)}\frac{l}{\rho+\delta}\right]^2-\frac{1}{\rho}C_O+\\ \qquad\frac{1}{\rho}\frac{l}{\rho+\delta}a_1\left[\frac{b_1+b_T}{c_1+\ln(1+\beta_1)}+\frac{a_1}{c_1+\ln(1+\beta_1)}\frac{l}{\rho+\delta}\right]\end{cases} \tag{47}$$

$$\begin{cases}k_3=\frac{l}{\rho+\delta}\\ k_4=\frac{1}{\rho}b_2\left(\frac{b_2}{c_2}+\frac{a_2}{c_2}\frac{l}{\rho+\delta}\right)-\frac{c_2}{2}\frac{1}{\rho}\left(\frac{b_2}{c_2}+\frac{a_2}{c_2}\frac{l}{\rho+\delta}\right)^2\\ \qquad+\frac{1}{\rho}C_O+\frac{l}{\rho+\delta}\frac{1}{\rho}a_2\left(\frac{b_2}{c_2}+\frac{a_2}{c_2}\frac{l}{\rho+\delta}\right)\end{cases} \tag{48}$$

Therefore, it can be concluded that (Equations 49, 50):

$$\begin{aligned}V_{T1}^{\star}=&\frac{l}{\rho+\delta}x_{T1}+\frac{1}{\rho}(b_1+b_T)\left[\frac{b_1+b_T}{c_1+\ln(1+\beta_1)}+\frac{a_1}{c_1+\ln(1+\beta_1)}\frac{l}{\rho+\delta}\right]-\frac{1}{\rho}\frac{c_1+\ln(1+\beta_1)}{2}\\&\left[\frac{b_1+b_T}{c_1+\ln(1+\beta_1)}+\frac{a_1}{c_1+\ln(1+\beta_1)}\frac{l}{\rho+\delta}\right]^2-\frac{1}{\rho}C_O+\\&\frac{1}{\rho}\frac{l}{\rho+\delta}a_1\left[\frac{b_1+b_T}{c_1+\ln(1+\beta_1)}+\frac{a_1}{c_1+\ln(1+\beta_1)}\frac{l}{\rho+\delta}\right]\end{aligned} \tag{49}$$

$$\begin{aligned}V_{T2}^{\star}=&\frac{l}{\rho+\delta}x_{T2}+\frac{1}{\rho}b_2\left(\frac{b_2}{c_2}+\frac{a_2}{c_2}\frac{l}{\rho+\delta}\right)\\&-\frac{c_2}{2}\frac{1}{\rho}\left(\frac{b_2}{c_2}+\frac{a_2}{c_2}\frac{l}{\rho+\delta}\right)^2+\frac{1}{\rho}C_O\\&+\frac{l}{\rho+\delta}\frac{1}{\rho}a_2\left(\frac{b_2}{c_2}+\frac{a_2}{c_2}\frac{l}{\rho+\delta}\right)\end{aligned} \tag{50}$$

In this case, Equations 51, 52 can be concluded that:

$$F_{T1}^{\star}(t)=\frac{b_1+b_T}{c_1+\ln(1+\beta_1)}+\frac{a_1}{c_1+\ln(1+\beta_1)}\frac{l}{\rho+\delta} \tag{51}$$

$$F_{T2}^{\star}(t)=\frac{b_2}{c_2}+\frac{a_2}{c_2}\frac{l}{\rho+\delta} \tag{52}$$

Appendix 2

Taking the derivative of the right-hand side of (15) with respect to the variable F_{E1}, and taking the derivative of the right-hand side of (16) with respect to the variable F_{E2}, and setting them equal to zero, we can get Equations 53, 54:

$$F_{E1}^{\star}(t)=\frac{b_1}{c_1+c_E}+\frac{a_1+a_E}{c_1+c_E}\frac{\partial V_{E1}}{\partial x_{E1}} \tag{53}$$

$$F_{E2}^{\star}(t)=\frac{b_2}{c_2+c_E}+\frac{a_2+a_E}{c_2+c_E}\frac{\partial V_{E2}}{\partial x_{E2}} \tag{54}$$

Substituting (53) into (15) and substituting (54) into (16), we can get Equations 56, 55:

$$\begin{aligned}\rho V_{E1}=&b_1\left(\frac{b_1}{c_1+c_E}+\frac{a_1+a_E}{c_1+c_E}\frac{\partial V_{E1}}{\partial x_{E1}}\right)-\frac{(c_1+c_E)}{2}\left(\frac{b_1}{c_1+c_E}+\frac{a_1+a_E}{c_1+c_E}\frac{\partial V_{E1}}{\partial x_{E1}}\right)^2\\&-C_O+lx_{E1}(t)\\&+\frac{\partial V_{E1}}{\partial x_{E1}}\left[(a_1+a_E)\left(\frac{b_1}{c_1+c_E}+\frac{a_1+a_E}{c_1+c_E}\frac{\partial V_{E1}}{\partial x_{E1}}\right)-\delta x_{E1}(t)\right]\end{aligned} \tag{55}$$

$$\begin{aligned}\rho V_{E2}=&b_2\left(\frac{b_2}{c_2+c_E}+\frac{a_2+a_E}{c_2+c_E}\frac{\partial V_{E2}}{\partial x_{E2}}\right)-\frac{(c_2+c_E)}{2}\left(\frac{b_2}{c_2+c_E}+\frac{a_2+a_E}{c_2+c_E}\frac{\partial V_{E2}}{\partial x_{E2}}\right)^2\\&+C_O+lx_{E2}(t)\\&+\frac{\partial V_{E2}}{\partial x_{E2}}\left[(a_2+a_E)\left(\frac{b_2}{c_2+c_E}+\frac{a_2+a_E}{c_2+c_E}\frac{\partial V_{E2}}{\partial x_{E2}}\right)-\delta x_{E2}(t)\right]\end{aligned} \tag{56}$$

Letting $V_{E1}^{\star}=k_5x_{E1}+k_6$, $V_{E2}^{\star}=k_7x_{E2}+k_8$, wherein, k_5, k_6, k_7 and k_8 are all constants. The parameters of the optimal social welfare function can be obtained by calculation as follows (Equations 57, 58):

$$\begin{cases}k_5=\frac{l}{\rho+\delta}\\ k_6=\frac{1}{\rho}b_1\left(\frac{b_1}{c_1+c_E}+\frac{a_1+a_E}{c_1+c_E}\frac{l}{\rho+\delta}\right)-\frac{(c_1+c_E)}{2}\frac{1}{\rho}\left(\frac{b_1}{c_1+c_E}+\frac{a_1+a_E}{c_1+c_E}\frac{l}{\rho+\delta}\right)^2-\frac{1}{\rho}C_O\\ \qquad+\frac{1}{\rho}\frac{l}{\rho+\delta}(a_1+a_E)\left(\frac{b_1}{c_1+c_E}+\frac{a_1+a_E}{c_1+c_E}\frac{l}{\rho+\delta}\right)\end{cases} \tag{57}$$

$$\begin{cases} k_7 = \frac{l}{\rho+\delta} \\ k_8 = \frac{1}{\rho} b_2 \left(\frac{b_2}{c_2+c_E} + \frac{a_2+a_E}{c_2+c_E} \frac{l}{\rho+\delta} \right) - \frac{1}{\rho} \frac{(c_2+c_E)}{2} \left(\frac{b_2}{c_2+c_E} + \frac{a_2+a_E}{c_2+c_E} \frac{l}{\rho+\delta} \right)^2 + \frac{1}{\rho} C_O \\ \qquad + \frac{1}{\rho} \frac{l}{\rho+\delta} (a_2 + a_E) \left(\frac{b_2}{c_2+c_E} + \frac{a_2+a_E}{c_2+c_E} \frac{l}{\rho+\delta} \right) \end{cases} \tag{58}$$

Therefore, it can be concluded that (Equations 59, 60):

$$V_{E1}^{*} = \frac{l}{\rho+\delta} x_{E1} + \frac{1}{\rho} b_1 \left(\frac{b_1}{c_1+c_E} + \frac{a_1+a_E}{c_1+c_E} \frac{l}{\rho+\delta} \right) - \frac{(c_1+c_E)}{2} \frac{1}{\rho} \left(\frac{b_1}{c_1+c_E} + \frac{a_1+a_E}{c_1+c_E} \frac{l}{\rho+\delta} \right)^2 - \frac{1}{\rho} C_O + \frac{1}{\rho} \frac{l}{\rho+\delta} (a_1 + a_E) \left(\frac{b_1}{c_1+c_E} + \frac{a_1+a_E}{c_1+c_E} \frac{l}{\rho+\delta} \right) \tag{59}$$

$$V_{E2}^{*} = \frac{l}{\rho+\delta} x_{E2} + \frac{1}{\rho} b_2 \left(\frac{b_2}{c_2+c_E} + \frac{a_2+a_E}{c_2+c_E} \frac{l}{\rho+\delta} \right) - \frac{1}{\rho} \frac{(c_2+c_E)}{2} \left(\frac{b_2}{c_2+c_E} + \frac{a_2+a_E}{c_2+c_E} \frac{l}{\rho+\delta} \right)^2 + \frac{1}{\rho} C_O + \frac{1}{\rho} \frac{l}{\rho+\delta} (a_2 + a_E) \left(\frac{b_2}{c_2+c_E} + \frac{a_2+a_E}{c_2+c_E} \frac{l}{\rho+\delta} \right) \tag{60}$$

In this case, Equations 61, 62 can be concluded that:

$$F_{E1}^{*}(t) = \frac{b_1}{c_1 + c_E} + \frac{a_1 + a_E}{c_1 + c_E} \frac{l}{\rho + \delta} \tag{61}$$

$$F_{E2}^{*}(t) = \frac{b_2}{c_2 + c_E} + \frac{a_2 + a_E}{c_2 + c_E} \frac{l}{\rho + \delta} \tag{62}$$

Appendix 3

Taking the derivative of the right-hand side of (17) with respect to the variable F_{A1}, and taking the derivative of the right-hand side of (18) with respect to the variable F_{A2}, and setting them equal to zero, we can get Equations 63, 64:

$$F_{A1}^{*}(t) = \frac{b_1 \ln(\mathrm{e} + \lambda_A)}{c_1 + c_A} + \frac{a_1}{c_1 + c_A} \frac{\partial V_{A1}}{\partial x_{A1}} \tag{63}$$

$$F_{A2}^{*}(t) = \frac{b_2 + b_A}{c_2 + c_A} + \frac{a_2}{c_2 + c_A} \frac{\partial V_{A2}}{\partial x_{A2}} \tag{64}$$

Substituting (63) into (17) and substituting (64) into (18), we can get Equations 65, 66:

$$\rho V_{A1} = b_1 \ln(\mathrm{e} + \lambda_A) \left[\frac{b_1 \ln(\mathrm{e}+\lambda_A)}{c_1+c_A} + \frac{a_1}{c_1+c_A} \frac{\partial V_{A1}}{\partial x_{A1}} \right] - \frac{(c_1+c_A)}{2} \left[\frac{b_1 \ln(\mathrm{e}+\lambda_A)}{c_1+c_A} + \frac{a_1}{c_1+c_A} \frac{\partial V_{A1}}{\partial x_{A1}} \right]^2 - C_O + l x_{A1}(t) + \frac{\partial V_{A1}}{\partial x_{A1}} a_1 \left[\frac{b_1 \ln(\mathrm{e}+\lambda_A)}{c_1+c_A} + \frac{a_1}{c_1+c_A} \frac{\partial V_{A1}}{\partial x_{A1}} \right] - \frac{\partial V_{A1}}{\partial x_{A1}} \delta x_{A1}(t) \tag{65}$$

$$\rho V_{A2} = (b_2 + b_A) \left(\frac{b_2+b_A}{c_2+c_A} + \frac{a_2}{c_2+c_A} \frac{\partial V_{A2}}{\partial x_{A2}} \right) - \frac{(c_2+c_A)}{2} \left(\frac{b_2+b_A}{c_2+c_A} + \frac{a_2}{c_2+c_A} \frac{\partial V_{A2}}{\partial x_{A2}} \right)^2 + C_O + l x_{A2}(t) + \frac{\partial V_{A2}}{\partial x_{A2}} \left[a_2 \left(\frac{b_2+b_A}{c_2+c_A} + \frac{a_2}{c_2+c_A} \frac{\partial V_{A2}}{\partial x_{A2}} \right) - \delta x_{A2}(t) \right] \tag{66}$$

Letting $V_{A1}^{*} = k_9 x_{A1} + k_{10}$, $V_{A2}^{*} = k_{11} x_{A2} + k_{12}$, wherein, k_9, k_{10}, k_{11} and k_{12} are all constants. The parameters of the optimal social welfare function can be obtained by calculation as follows (Equations 67, 68):

$$\begin{cases} k_9 = \frac{l}{\rho+\delta} \\ k_{10} = \frac{1}{\rho} b_1 \ln(\mathrm{e} + \lambda_A) \left[\frac{b_1 \ln(\mathrm{e}+\lambda_A)}{c_1+c_A} + \frac{a_1}{c_1+c_A} \frac{l}{\rho+\delta} \right] - \frac{1}{\rho} \frac{(c_1+c_A)}{2} \left[\frac{b_1 \ln(\mathrm{e}+\lambda_A)}{c_1+c_A} + \frac{a_1}{c_1+c_A} \frac{l}{\rho+\delta} \right]^2 \\ \qquad - \frac{1}{\rho} C_O + \frac{1}{\rho} \frac{l}{\rho+\delta} a_1 \left[\frac{b_1 \ln(\mathrm{e}+\lambda_A)}{c_1+c_A} + \frac{a_1}{c_1+c_A} \frac{l}{\rho+\delta} \right] \end{cases} \tag{67}$$

$$\begin{cases} k_{11} = \frac{l}{\rho+\delta} \\ k_{12} = \frac{1}{\rho} (b_2 + b_A) \left(\frac{b_2+b_A}{c_2+c_A} + \frac{a_2}{c_2+c_A} \frac{l}{\rho+\delta} \right) - \frac{1}{\rho} \frac{(c_2+c_A)}{2} \left(\frac{b_2+b_A}{c_2+c_A} + \frac{a_2}{c_2+c_A} \frac{l}{\rho+\delta} \right)^2 \\ \qquad + \frac{1}{\rho} C_O + \frac{1}{\rho} \frac{l}{\rho+\delta} a_2 \left(\frac{b_2+b_A}{c_2+c_A} + \frac{a_2}{c_2+c_A} \frac{l}{\rho+\delta} \right) \end{cases} \tag{68}$$

Therefore, it can be concluded that (Equations 69, 70):

$$V_{A1}^{*} = \frac{l}{\rho+\delta} x_{A1} + \frac{1}{\rho} b_1 \ln(\mathrm{e} + \lambda_A) \left[\frac{b_1 \ln(\mathrm{e}+\lambda_A)}{c_1+c_A} + \frac{a_1}{c_1+c_A} \frac{l}{\rho+\delta} \right] - \left[\frac{b_1 \ln(\mathrm{e}+\lambda_A)}{c_1+c_A} + \frac{a_1}{c_1+c_A} \frac{l}{\rho+\delta} \right]^2 \frac{1}{\rho} \frac{(c_1+c_A)}{2} - \frac{1}{\rho} C_O + \frac{1}{\rho} \frac{l}{\rho+\delta} a_1 \left[\frac{b_1 \ln(\mathrm{e}+\lambda_A)}{c_1+c_A} + \frac{a_1}{c_1+c_A} \frac{l}{\rho+\delta} \right] \tag{69}$$

$$V_{A2}^{*} = \frac{l}{\rho+\delta} x_{A2} + \frac{1}{\rho} (b_2 + b_A) \left(\frac{b_2+b_A}{c_2+c_A} + \frac{a_2}{c_2+c_A} \frac{l}{\rho+\delta} \right) - \frac{1}{\rho} \frac{(c_2+c_A)}{2} \left(\frac{b_2+b_A}{c_2+c_A} + \frac{a_2}{c_2+c_A} \frac{l}{\rho+\delta} \right)^2 + \frac{1}{\rho} C_O + \frac{1}{\rho} \frac{l}{\rho+\delta} a_2 \left(\frac{b_2+b_A}{c_2+c_A} + \frac{a_2}{c_2+c_A} \frac{l}{\rho+\delta} \right) \tag{70}$$

In this case, Equations 71, 72 can be concluded that:

$$F_{A1}^{*}(t) = \frac{b_1 \ln(\mathrm{e} + \lambda_A)}{c_1 + c_A} + \frac{a_1}{c_1 + c_A} \frac{l}{\rho + \delta} \tag{71}$$

$$F_{A2}^{*}(t) = \frac{b_2 + b_A}{c_2 + c_A} + \frac{a_2}{c_2 + c_A} \frac{l}{\rho + \delta} \tag{72}$$