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Dog mastiff effect, domino effect, fish tank theory: how to improve wetland resilience through risk management measures

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In the restoration of wetlands, the dog mastiff effect emphasizes the importance of strong management measures and strict enforcement to protect wetland ecosystems and prevent human destruction. The domino effect highlights the need to consider various factors comprehensively and manage risks holistically within the wetland ecosystem. The fish tank theory stresses the importance of transparent management and public participation, using open information platforms and engagement mechanisms to enhance awareness and support for wetland protection from all sectors of society. The application of these risk management measures provides crucial guidance for improving the capacity of wetland restoration. Not only can they effectively restore and protect wetland ecosystems, but they can also promote multiple environmental benefits, such as enhancing biodiversity, improving water quality, and regulating climate. Research indicates that when the benefits from establishing effective monitoring and regulatory mechanisms are substantial, and the benefits from enhancing wetland resilience are relatively small, the management of wetlands by the government and enterprises is more in line with the dog mastiff effect. Conversely, when the benefits from enhancing wetland resilience are significant, the government's wetland governance is more in line with the domino effect. When the benefits from establishing effective monitoring and regulatory mechanisms are small, and the benefits from enhancing wetland resilience are also small, the wetland governance by enterprises is more in line with the fish tank theory. When the benefits from enhancing wetland resilience are substantial, the wetland governance by enterprises is more in line with the domino effect.

KEYWORDS

differential game, dog mastiff effect, domino effect, fish tank theory, wetland resilience

1 Introduction

1.1 Background and research significance

Wetlands are among Earth's most vital ecosystems, playing a pivotal role in flood regulation, water purification, climate modulation, and biodiversity conservation. They provide essential habitats for diverse species and support key socio-economic activities (Akhtar and Tsuyuzaki, 2024). However, rapid industrialization, urbanization, and population growth are posing unprecedented threats, including intensified pollution,

wetland loss due to land development, and disrupted hydrological cycles. These pressures severely impair wetland ecological functions and reduce their natural resilience to disasters (Petry et al., 2025).

Effective risk management is therefore critical to enhancing wetland resilience. It mitigates direct human impacts through measures such as stricter environmental regulations, conservation initiatives, and sustainable practices (Xiong et al., 2023). Furthermore, it strengthens adaptive capacity to environmental changes; by restoring natural hydrology, soils, and vegetation, wetlands can more effectively deliver services like water purification, habitat provision, and flood mitigation (Zhou et al., 2024). Ultimately, these efforts sustain a balance between socio-economic development and ecological integrity, ensuring wetland benefits for future generations (Zhuang et al., 2024). This complex, multi-stakeholder endeavor not only safeguards the wetlands themselves but is also fundamental to ecological security and sustainable human-nature relations (Liu et al., 2024c), underscoring the need for interdisciplinary collaboration.

In this context, the dog mastiff effect, domino effect, and fish tank theory offer useful conceptual tools for understanding interactions within wetland ecosystems and their influence on resilience.

The dog mastiff effect metaphorically describes how certain keystone species or critical ecological functions—akin to guardian mastiffs—exert a disproportionate influence on ecosystem stability. In wetlands, specific aquatic plants or microbial communities play such a role by driving nutrient cycling and water purification (Fang et al., 2025). Protecting these functionally pivotal components can significantly enhance the wetland's ability to withstand and recover from disturbances.

The domino effect illustrates how a single disturbance may trigger cascading failures across trophic levels and ecological processes (Siqueira et al., 2024). For instance, the loss of a keystone predator can release herbivore populations, leading to overgrazing of aquatic vegetation, sediment destabilization, and degraded water quality—ultimately undermining resilience (Arlinghaus et al., 2023). Risk management should thus identify and mitigate such cascade triggers to prevent localized issues from escalating into systemic collapse.

The fish tank theory emphasizes the importance of maintaining a sound environmental “container”—including hydrology, soil quality, and pollution control—as a foundation for ecosystem health (Chuma et al., 2024). Importantly, organisms within this container can actively reshape their environment. Keystone species such as beavers or sediment-stabilizing vegetation may alter hydrology and substrate, creating positive feedback loops. For example, improved water quality promotes plant growth, which further enhances water purification—a reinforcing cycle that strengthens structural stability and overall resilience (Cooke and Zack, 2008). Effective management must therefore integrate both abiotic conditioning and biological facilitation.

1.2 Literature review

With the continuous in-depth research on improving the restoration capacity of wetlands through risk management

measures, a large number of research results have emerged. Some scholars have studied risk analysis. For instance, Han et al. (2023) investigated residents' attitudes toward nature-based solutions to flood risk using a land-based risk assessment model. Greiner et al. (2022) examined the uncertainties in risk analysis from the perspectives of connecting science, management, and communication. Kim and Kwon (2023) analyzed the indirect impacts of wildfire disasters on regional economies. Greenberg (2023) explored ways to reduce the risk of disasters. Liu et al. (2024) employed a novel spatial econometric model to study risk communication in multi-stakeholder engagement. These scholars have conducted risk analysis from various aspects, including risk uncertainty, risk communication, risk mitigation, and the impacts of risk.

The integration of risk analysis into wetland management is a well-established approach, as evidenced by a growing body of literature. Existing studies have successfully demonstrated methods for spatially and temporally refined ecological risk assessment (Xiong et al., 2023), evaluated regional wetland degradation characteristics (Zhuang et al., 2024), and quantified risks from specific pollutants like polycyclic aromatic hydrocarbons and metals (Anjana et al., 2025). However, these valuable contributions often focus on identifying and quantifying risks without providing a cohesive conceptual framework that elucidates the underlying mechanisms through which risks propagate and impact overall ecosystem resilience. Specifically, they seldom articulate how risks target keystone elements (relating to the dog mastiff effect), how they trigger cascading failures across the ecosystem (reflecting the domino effect), or how the environmental context constrains or facilitates these processes (echoing the fish tank theory). Therefore, this study aims to bridge this gap by proposing a unified framework based on these three metaphors. This framework is designed to not only systematize risk identification but also to enhance the understanding of risk interactions, thereby offering more strategic insights for improving wetland resilience.

Specific practices and strategies for wetland restoration and management play a crucial role in the recovery of wetlands, and some scholars have conducted research in this area. For example, Beheshti et al. (2023) informed adaptive management for California wetland restoration through large-scale field studies. Bell-James (2023) drew lessons from Australia's blue carbon approach to overcome legal barriers in coastal wetland restoration. Hagger et al. (2022) explored opportunities for blue carbon in coastal wetland restoration, which can bring synergistic benefits to biodiversity, coastal fisheries, and water quality. Adam et al. (2024) analyzed whether short-term success criteria can predict long-term outcomes in wetland restoration. Liu et al. (2024) conducted a meta-analysis of the effectiveness of ecological restoration in China's coastal wetlands. Houde et al. (2024) investigated the influence of seed mixture performance, environmental stressors, and invasions on wetland restoration.

Some scholars have focused on analyzing the mechanisms of wetland restoration, resilience, and land-use changes. For instance, Lin et al. (2022) studied the impact of restoration strategies on wetlands, using the Xinjiang River National Wetland Park as a case

study. Stevens et al. (2023) evaluated the resilience of tidal wetlands and proposed a scalable framework to support strategic management. Zhou et al. (2024) suggested that the distinct molecular responses of mangrove plants to hypoxia and reoxygenation stress contribute to their resilience in coastal wetlands. Jiang et al. (2024) summarized the experiences and future research trends in wetland conservation and restoration in China. Gimbo et al. (2024) investigated the dynamics of land-use and land-cover changes in inland valley wetlands in East Africa.

However, the aforementioned studies exhibit certain limitations that hinder the development of a predictive and holistic risk management strategy. Firstly, a predominant focus persists on analyzing individual risk factors—such as isolated ecological, pollution, or socio-economic risks—without systematically integrating them. For instance, Han et al. (2023) and Greiner et al. (2022) provided valuable insights into resident attitudes and risk uncertainty, respectively, yet their approaches remain fragmented and do not converge into a comprehensive framework. This compartmentalization obscures the synergistic or cascading effects of multiple, interacting stressors, leading to an incomplete understanding of wetland resilience. Secondly, and critically, there is a notable scarcity of quantitative modeling approaches capable of simulating the non-linear interactions and feedback loops between these diverse risk factors. The absence of such predictive tools makes it challenging to move from retrospective risk assessment to proactive risk management, thereby limiting the ability to forecast systemic vulnerabilities and prioritize interventions effectively within complex wetland ecosystems.

Secondly, there is a neglect of risk propagation and chain reactions. Existing studies have paid insufficient attention to the propagation and cascading effects of risks. For instance, Kim and Kwon (2023) explored the indirect impacts of wildfire disasters on regional economies but did not delve into how these effects could further influence the resilience of wetland ecosystems through domino effects. Risk management measures need to consider the pathways of risk propagation and potential chain reactions to prevent localized risks from escalating into systemic crises.

Thirdly, there is a lack of multi-scale perspectives. The aforementioned studies are mostly confined to a single scale (e.g., local or regional), lacking a multi-scale viewpoint. For example, Xiong et al. (2023) and Zhuang et al. (2024) investigated the ecological risks of freshwater wetlands and the Bashang area of Zhangjiakou, respectively, but did not link these localized risks to broader-scale ecosystem dynamics. The management of wetland resilience requires a comprehensive consideration of risk factors at both micro and macro scales to formulate more effective management strategies.

To address the limitations of fragmented and predominantly qualitative risk assessments identified in previous studies, this research makes a primary contribution by proposing a novel, integrated risk management framework. The innovation lies not only in systematically incorporating ecological, economic, and social risk factors into a unified system but also in providing a structured pathway for its operationalization. Specifically, the framework translates the conceptual metaphors—the dog mastiff effect (identifying keystone vulnerabilities), the domino effect

(mapping risk propagation pathways), and the fish tank theory (defining systemic boundaries and capacities)—into a basis for defining measurable Key Performance Indicators (KPIs) and critical pressure thresholds (Zhao et al., 2016). For instance, rather than merely acknowledging pollution as a risk, the framework guides managers to establish quantitative thresholds for key water quality parameters (e.g., nutrient loads) that, if exceeded, would trigger a cascading degradation (domino effect) impacting keystone species (dog mastiff effect) within the wetland's carrying capacity (fish tank theory). This approach moves beyond abstract integration towards a actionable system that enables proactive, metrics-based monitoring and intervention, thereby significantly enhancing the strategic integrity and coordination of wetland restoration efforts.

Secondly, the domino effect theory is introduced to analyze the propagation pathways and chain reactions of risks within wetland ecosystems, proposing management strategies to prevent and mitigate risk transmission. By investigating the mechanisms of risk propagation, it becomes possible to more effectively predict and address the potential escalation of localized risks into systemic crises, thereby enhancing the risk resilience of wetland restoration efforts.

Thirdly, based on the fish tank theory, this study proposes a multi-scale risk management approach that integrates risk factors at local, regional, and global scales to develop adaptive management strategies. Through a multi-scale perspective, it is possible to better understand the dynamic changes in wetland resilience and formulate more targeted and actionable management measures.

2 Methodology

2.1 Problem description and variable definition

2.1.1 Problem description

In the process of improving wetland resilience through risk management measures, the reasons for selecting the government and enterprises as the key players in the game are multifaceted.

First, policy and regulation formulation. The government is the primary entity responsible for crafting policies and regulations. During wetland protection and restoration, the government can establish laws, regulations, and policies that favor wetland conservation, thereby providing a regulatory framework and support. For instance, the government can designate protected wetland areas, restrict economic activities that may negatively impact the wetland environment, or offer financial support and incentives to encourage projects for wetland protection and restoration.

Second, resource allocation and financial support. The government has the ability to allocate resources and provide financial support. Wetland restoration often requires significant financial investment, including but not limited to environmental management, ecological restoration, and scientific research

(Jiang et al., 2024). The government can provide necessary financial support for these projects or attract private capital through policies such as tax incentives and subsidies.

Third, the economic activities and environmental impact of enterprises. Enterprises are vital drivers of economic development, but their operations often have adverse effects on the natural environment, including wetlands. This is particularly evident in industries such as heavy industry, agriculture, and real estate development, where improper development activities can directly damage wetland ecosystems. By collaborating with enterprises, it is possible to guide them towards more environmentally friendly production methods, reduce their negative impact on wetlands, and encourage their participation in wetland restoration projects, thus achieving a win-win situation for economic development and environmental protection (Greenberg, 2023).

While wetland resilience is undoubtedly influenced by a multitude of stakeholders, including local communities, non-governmental organizations, and academic institutions, this study deliberately focuses its differential game model on the strategic interaction between two primary actors: governmental regulators and profit-driven enterprises. This deliberate scoping is justified on three grounds. First, from a modeling tractability perspective, the objective functions of governments (prioritizing societal welfare and ecological integrity) and enterprises (prioritizing economic returns) are relatively well-defined and can be parameterized, whereas the utilities of a broader set of stakeholders are highly heterogeneous and difficult to quantify consistently. Introducing a third or fourth player with incommensurate goals would render the derivation of time-consistent equilibria analytically intractable. Second, from a policy-relevance standpoint, the government-enterprise dyad represents the most fundamental and potent lever of change in environmental governance; understanding this core dynamic is a prerequisite for designing effective policies that subsequently engage broader communities. Finally, the influence of other stakeholders is not entirely absent but is implicitly incorporated: community welfare is a key component of the government's objective function, and social pressure acts as an external constraint on enterprise behavior. Therefore, this focused approach allows for a parsimonious yet powerful examination of the core strategic conflict, providing a solid foundation upon which more complex, multi-stakeholder models can be built in future research.

In summary, the government and enterprises play crucial roles in enhancing the capability of wetland restoration. Selecting them as key players in the game is aimed at better integrating resources, leveraging their respective strengths, and promoting effective protection and sustainable restoration of wetlands through collaboration (Hagger et al., 2022).

In the process of improving wetland resilience through risk management measures, the dynamic, continuous, and ongoing characteristics of the game between the government and enterprises are primarily due to the multifaceted economic, social, and environmental factors involved in wetland protection and restoration. The government and enterprises often hold different positions and objectives in these areas. This can be further understood from the following points.

First, differences in interests. The government typically bears the responsibility of protecting natural resources, the environment, and public health, and tends to adopt stricter protection measures to ensure the long-term ecological value and public welfare of wetlands (Han et al., 2023). In contrast, enterprises aim to maximize economic benefits and may focus more on current commercial interests, such as developing areas around or within wetlands to increase production capacity or expand business operations. This difference in interests is the fundamental cause of the game between the two parties.

Second, adjustments in policies and regulations. As ecological awareness increases and scientific and technological advancements are made, the government continuously updates relevant policies and laws based on the latest research findings and societal needs, guiding wetland protection and restoration efforts in a more scientific and rational manner. Enterprises, in turn, need to adjust their operational strategies and development directions to adapt to the new policy environment and market demands. This adjustment process is ongoing, leading to continuous changes and adaptations in the game between the two parties.

Third, information asymmetry. During the process of wetland protection and restoration, there is a certain degree of information asymmetry between the government and enterprises. The government may possess more specialized knowledge and data on environmental protection, while enterprises may have better insights into market dynamics and their operational specifics. In the process of information exchange, each party tries to influence the other's information reception and processing to protect their own rights and interests. This interaction is a dynamic and continuous process.

In summary, the game relationship between the government and enterprises, within the context of multiple goals and constraints in wetland protection and restoration, is an interactive process where both parties strive to achieve their own interests (Liu et al., 2024a). This process is influenced by changes in the external environment, including policy and regulations, public opinion, economic conditions, and technological advancements, thus exhibiting dynamic, continuous, and ongoing characteristics. To achieve the best outcomes in wetland protection, both parties need to maintain communication and cooperation, working together to find solutions that benefit both environmental protection and economic development.

In the process of improving wetland resilience through risk management measures, the interactions between the government and enterprises can be explained using the concepts of the dog mastiff effect, domino effect, and fish tank theory. These concepts reveal important characteristics and potential impacts from different perspectives in the game between the two parties.

2.1.1.1 Dog mastiff effect

The dog mastiff effect metaphorically describes the tightly interwoven and mutually constraining relationship among key stakeholders, such as governments and enterprises, wherein any action by one party triggers a direct reaction from the other, shaping

a dynamic equilibrium. A concrete example can be illustrated through the setting of wastewater discharge standards in a wetland watershed. Suppose the government, aiming to enhance wetland resilience, considers imposing a stringent new standard that drastically reduces the permissible levels of key pollutants (e.g., nitrogen and phosphorus). This regulatory action (the government's move) directly increases compliance costs for upstream enterprises, such as fertilizer plants (the impact on the enterprise). Faced with potential reduced profitability or operational viability, these enterprises may respond by threatening relocation, scaling down production, or lobbying against the policy (the enterprise's counter-move). Anticipating or experiencing this pushback, the government must then recalibrate its approach. It might choose to phase in the standards gradually, offer subsidies for green technology upgrades, or strengthen enforcement on non-compliant actors (the government's adapted strategy). This iterative process demonstrates the dog mastiff effect: the initial policy stance is not static but is dynamically refined through the anticipated and actual reactions of the regulated entities, ultimately leading to a more pragmatic and sustainable outcome for the wetland ecosystem.

2.1.1.2 Domino effect

In the context of wetland governance, the domino effect serves as a metaphor for the potential chain reactions where a single management decision or ecological event can trigger a series of secondary consequences, amplifying the initial impact. For instance, a government policy that expands protected wetland areas might not only displace certain enterprise operations but also indirectly affect supply chains and regional economic structures, illustrating the interconnected nature of socio-ecological systems.

However, within our formal differential game model, this metaphor is operationalized not by explicitly simulating a cascade of ecological failures, but by incorporating its core strategic implication: the management of systemic, nonlinear risk. This is achieved by designing utility functions where the benefits of risk mitigation are subject to a logarithmic transformation or include a risk-propagation discount factor. These mathematical forms capture the essence of the domino effect by reflecting the escalating costs and reputational damages associated with failing to interrupt a chain of risks. Thus, the model translates the governance concept of preventing a "domino cascade" into a quantifiable incentive for proactive management, focusing on the strategic decisions that can break the chain before it begins.

2.1.1.3 Fish tank theory

The fish tank theory emphasizes that transparency fundamentally alters strategic decision-making by making actions observable to all stakeholders. In wetland management, this theory elucidates how public disclosure of ecological information directly shapes the high-stakes decisions regarding land use and resource allocation. A pivotal application lies in the process of delineating wetland ecological protection redlines or permitting development

projects in buffer zones. When the government commits to fully disclosing the scientific rationale for redline boundaries, the environmental impact assessments (EIAs) for proposed projects, and the compliance records of enterprises (creating the transparent "fish tank"), it introduces powerful accountability mechanisms. For instance, a company seeking to develop land near a wetland must weigh the cost of compliance against the risk of public backlash and reputational damage should its EIA reveal significant negative impacts. This transparency forces a more rigorous internal assessment, often leading to the voluntary adoption of stricter environmental safeguards than minimally required by law (impact on enterprise decision-making). Conversely, the government's own decision to approve or reject a project is subjected to public scrutiny. Approving a project with a poorly conducted EIA or known high ecological risks could lead to a loss of public trust and political credibility (impact on government decision-making). Thus, transparency, as conceptualized by the fish tank theory, is not merely about observation but about actively reshaping the incentive structures for both parties, leading to outcomes that prioritize long-term wetland resilience over short-term, opaque gains.

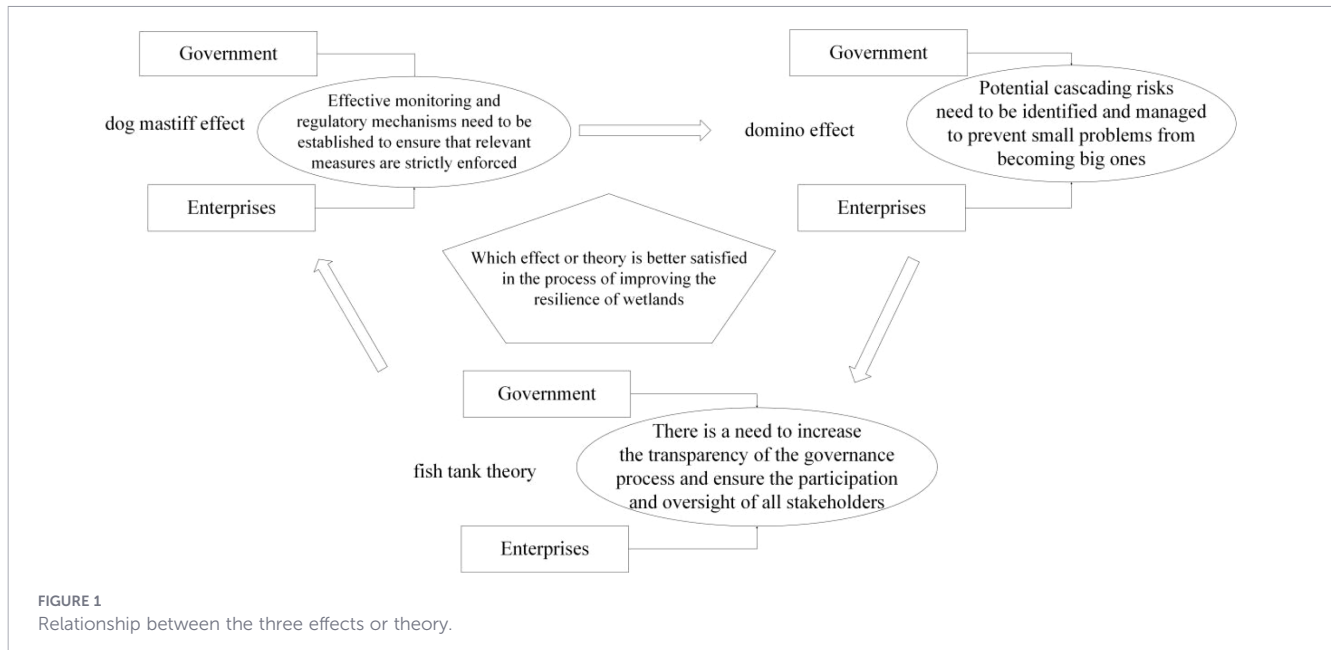
The relationship between the three effects or theory in the process of improving the resilience of wetlands is shown in [Figure 1](#).

2.1.2 Hypothesis

2.1.2.1 Hypothesis 1: government and enterprises make continuous decisions to maximize their utility based on available information

Hypothesis 1 establishes the fundamental decision-making principle within the model, positing that the government and enterprises are rational agents seeking to maximize their own utility. Here, "utility" is a comprehensive concept that encompasses not only direct economic benefits (e.g., corporate profits, government tax revenue) but also ecological gains (e.g., environmental value derived from wetland restoration) and intangible returns such as reputation (e.g., government credibility, corporate social image) (Cadier et al., 2020). Simultaneously, the qualifier "based on available information" acknowledges that decision-makers are not omniscient; rather, they render judgments under the realistic constraints of incomplete information. This incorporation of "bounded rationality" renders the model more congruent with the complex decision-making environments of the real world.

Within the model, Hypothesis 1 serves as the cornerstone for constructing objective functions. It implies that the strategies of the government and enterprises (e.g., regulatory stringency, environmental investment) are neither one-off nor static choices, but rather a continuous process of adjustment over time. This continuity is pivotal for the application of differential game theory, enabling the analysis of dynamic phenomena such as the sustained regulatory pressure observed in the dog mastiff effect or the chain reactions of policy incentives characteristic of the domino effect. Consequently, this assumption translates static interest calculations



into a dynamic strategic interaction, providing a theoretical starting point for investigating how agents optimize their behavioral trajectories over time.

2.1.2.2 Hypothesis 2: wetland resilience changes dynamically under the joint influence of enterprise efforts and government supervision

Hypothesis 2 defines wetland resilience as a dynamic state variable, the evolution of which constitutes the systemic environment of the entire game. It explicitly posits that the health status of an ecosystem is neither static nor autogenous, but is directly driven by the external behaviors of the two core agents within the model. Restoration efforts by enterprises (e.g., investments in clean technology, vegetation restoration) typically exert a positive influence on resilience, whereas government regulation (e.g., setting standards, enforcing penalties) affects resilience indirectly by constraining corporate behavior or stimulating proactive engagement (Timpone-Padgham et al., 2017). This perfectly aligns with the metaphor of the fish tank theory, wherein the interventions of the manager directly determine the health status of the ecosystem—"the fishbowl."

Mathematically, Hypothesis 2 corresponds directly to the state equation of the differential game. This equation, describing the rate of change in resilience, serves as the bridge linking micro-level decisions (the actions of the government and enterprises) to macro-level outcomes (the level of wetland resilience). Through this equation, we can quantitatively analyze how distinct management strategies—such as the dog mastiff effect, which emphasizes immediate regulation, or the domino effect, which prioritizes long-term cultivation—result in divergent evolutionary trajectories of resilience. Consequently, Hypothesis 2 is fundamental to the model’s capacity to simulate how risk control measures impact ecological outcomes.

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.

The decline δ in the reputation of both the government and enterprises is formalized as a critical dynamic mechanism that captures the erosion of trust and credibility due to inadequate actions. For the government, reputation decay occurs when it is perceived as failing in its role as a credible regulator—for instance, by inconsistently enforcing environmental policies, succumbing to lobbying pressures that weaken standards, or lacking transparency in decision-making (Aziz et al., 2024). This decline diminishes its political capital and public legitimacy, weakening its ability to secure compliance and implement long-term conservation strategies effectively. Conversely, for enterprises, reputation decay stems from non-compliance with regulations, involvement in ecological damage, or a failure to meet publicly stated environmental commitments. This erosion directly translates into tangible economic risks, including reduced consumer trust, difficulties in securing licenses to operate, and heightened scrutiny from investors and financial institutions.

The interplay of these dual reputation decays is central to the model’s dynamics. A decline δ in corporate reputation often triggers public pressure on the government to act, potentially accelerating the government’s own reputation loss if its response is deemed insufficient. Similarly, a government with a declining reputation may create a permissive environment where non-compliance is tacitly expected, thereby reducing the immediate reputational risks for enterprises but ultimately jeopardizing systemic resilience. Thus, modeling these co-evolving reputational states allows the analysis to reflect how the dog mastiff effect (strategic interdependence) and the fish tank theory (transparency and accountability) jointly shape the long-term path toward wetland resilience, ensuring that both

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

Variables and parameters	Specific meaning
$Y=\{W,B,L\}$	effect or theory in the process of improving the resilience of wetlands (dog mastiff effect, domino effect, fish tank theory)
Independent variable	
$G_{Y1}(t)$	the government's efforts to improve the resilience of wetlands under the effect or theory Y
$G_{Y2}(t)$	the enterprises' efforts to improve the resilience of wetlands under the effect or theory Y
$x_{Y1}(t)$	reputation of the government to improve the resilience of wetlands under the effect or theory Y
$x_{Y2}(t)$	reputation of the enterprises to improve the resilience of wetlands under the effect or theory Y
Parameter	
ρ	the discount rate that occurs over time, $0 \leq \rho \leq 1$
δ	decay of reputation, $\delta > 0$
l	the positive effects of reputation, $l > 0$
b_1, b_2	income earned by the government or enterprises from improving the resilience of wetlands, and where 1 represents government, 2 represents enterprises, the same as below, $b_1, b_2 > 0$
c_1, c_2	the costs to the government or enterprises from the improving the resilience of wetlands, $c_1, c_2 > 0$
b_{D1}, b_{D2}	the benefits obtained by the government or enterprises from establishing effective supervision and regulatory mechanisms, $b_{D1}, b_{D2} > 0$
c_{D1}, c_{D2}	the cost incurred by the government or enterprises in establishing effective supervision and regulatory mechanisms, $c_{D1}, c_{D2} > 0$
λ_1	the degree of reputation improvement brought to the government by identifying and managing potential chain risks, $\lambda_1 > 0$
λ_2	the degree of reputation improvement brought to the enterprises by identifying and managing potential chain risks, $\lambda_2 > 0$
f_1, f_2	the reputation gained by the government or enterprises from improving the resilience of wetlands, $f_1, f_2 > 0$
r_1	the ratio of increased government's reputation due to increased transparency in governance processes, $r_1 > 0$
r_2	the ratio of increased enterprises' reputation due to increased transparency in governance processes, $r_2 > 0$
Function	
$J_{Y1}(t)$	the social welfare function of government under the effect or theory Y
$J_{Y2}(t)$	the social welfare function of enterprises under the effect or theory Y
$V_{Y1}(t)$	the social benefits of government under the effect or theory Y
$V_{Y2}(t)$	the social benefits of enterprises under the effect or theory Y

parties' strategies are evaluated against the backdrop of their evolving social license to operate.

The benefits b_{D1}, b_{D2} obtained by the government or enterprises from establishing effective supervision and regulatory mechanisms are multifaceted and integral to their long-term strategic objectives.

For the government, the primary benefit is a reduction in the long-term cost of environmental governance (Brunella et al., 2025). An effective mechanism, underpinned by the principles of the fish tank theory (transparency) and informed by the dog mastiff effect (strategic anticipation), allows for earlier detection of non-compliance and more efficient resource allocation. This proactive approach minimizes the need for costly emergency remediation projects that arise from unchecked degradation—a manifestation of the domino effect. Consequently, this directly enhances the government's objective function, which typically seeks to maximize social welfare (a composite of ecological health and economic stability) while minimizing public expenditure on enforcement and cleanup.

For enterprises, the benefits are strategically distinct but equally compelling. A clear, consistent, and transparent regulatory framework reduces uncertainty and operational risk. When rules are well-defined and monitoring is credible, firms can make confident long-term investments in green technologies and sustainable practices without fear of arbitrary policy shifts. This stability lowers the risk of reputational damage, legal penalties, and project delays. In the model's terms, this translates to a more predictable cost structure and safeguards their long-term profitability, which is a central component of their objective function. Thus, while compliance entails upfront costs, the strategic benefit lies in securing a social license to operate and ensuring market access in an increasingly eco-conscious landscape, thereby turning effective regulation from a mere constraint into a condition for sustained viability.

The cost c_{D1}, c_{D2} incurred by the government or enterprises in establishing effective supervision and regulatory mechanisms represents a critical strategic investment that directly shapes their decision-making calculus. For the government, these costs are predominantly upfront and operational, encompassing the financial outlays required to develop sophisticated monitoring systems (e.g., remote sensing, continuous water quality sensors), hire and train enforcement personnel, administer permitting processes, and maintain transparency platforms as advocated by the fish tank theory. This expenditure is a direct deduction from the government's objective function, which must be weighed against the anticipated long-term benefits of a more resilient wetland ecosystem, such as avoided disaster remediation costs and enhanced public welfare.

For enterprises, the costs are twofold. First, they face direct compliance costs, including investments in cleaner technologies, process modifications, and ongoing expenses for emissions monitoring and reporting. These are tangible impacts on their bottom line. Second, and more subtly, they incur agency costs associated with adapting to and navigating the regulatory landscape, such as dedicating managerial resources to engagement and compliance tasks. In the context of the dog mastiff effect, these costs are the immediate strategic burden that enterprises seek to minimize. However, the model posits that incurring these costs is essential to avoid the far greater penalties, reputational damage, and operational disruptions that would result from non-compliance—a dynamic that ultimately pushes the strategic equilibrium toward a more sustainable outcome. Thus, the allocation and burden of these

costs are central to the negotiation of roles and responsibilities implicit in enhancing systemic resilience.

2.2 Three differential game models of effect or theory

Integrating the three metaphors reveals a dynamic and reinforcing framework for enhancing wetland resilience, where each concept addresses a critical link in a continuous management cycle. The domino effect provides the foundational diagnostic lens, emphasizing the need for proactive monitoring to identify key nodes within the ecosystem where a localized disturbance could trigger cascading failures. This risk identification then dictates targeted intervention. The dog mastiff effect informs the strategic intervention itself, guiding managers on how to design policies and incentives that account for the strategic interactions between major stakeholders (e.g., governments and enterprises) to effectively secure or stabilize the critical nodes identified by the domino effect analysis. Finally, the fish tank theory establishes the essential systemic condition for sustained success. By ensuring transparency and public accountability throughout the governance process, it compels adherence to the agreed-upon strategies and enables the timely detection of new risks, thereby reinforcing the monitoring function of the domino effect and ensuring the strategic game modelled by the dog mastiff effect is played in a manner that prioritizes long-term resilience over short-term gains. Thus, it is the synergistic interaction—where diagnosis directs intervention, and transparency secures compliance and adaptivity—that creates a robust causal pathway to improved wetland governance outcomes.

Differential game theory provides a robust framework for analyzing the dynamic strategic interactions between governments and enterprises in wetland resilience management. It excels at modeling the continuous, feedback-driven processes that characterize gradual ecosystem stressors, such as cumulative pollution or slow habitat fragmentation, which can be effectively captured as the evolution of state variables over time (Ji et al., 2024). In this framework, governments dynamically adjust policy stringency and enterprises make ongoing decisions about pollution control investments, with both actors responding to the continuously changing state of the wetland ecosystem, consistent with the feedback strategy structure of differential games.

The model constructed herein focuses on quantifying the long-term strategic interplay arising from these gradual pressures. It formalizes the dog mastiff effect (how policy compels corporate action), the latent domino effect (how incremental degradation increases systemic vulnerability), and the fish tank theory (how transparency influences strategic choices) through state equations (e.g., the rate of change in wetland health) and respective objective functions.

Crucially, this foundational model of continuous dynamics provides the necessary baseline against which the impact of sudden exogenous shocks, such as storm surges or extreme flooding, can be rigorously evaluated in future work. These discrete events can be incorporated as stochastic impulses or parameter shifts that abruptly alter the ecosystem state variable,

allowing researchers to investigate how the strategic equilibrium between regulators and firms adjusts pre-shock and post-shock. Thus, the current model does not ignore such events but establishes the core dynamic structure required to analyze their disruptive effects on management strategies and resilience outcomes.

Furthermore, differential game theory can reveal optimal equilibrium paths under different risk mechanisms (Wei and Wang, 2021). For instance, governments must balance short-term economic pressures against long-term ecological collapse risks (domino effect), while enterprises dynamically adjust between compliance costs and reputational losses (fish tank theory). By solving for optimal strategies using the Hamilton-Jacobi-Bellman equation, it is possible to simulate how policy thresholds (e.g., subsidy levels or penalty intensities) trigger a “mastiff-like” response from enterprises (immediate corrective actions), thereby interrupting chain reactions of risks and enhancing the overall resilience of wetland systems. This dynamic framework avoids the short-sighted limitations of static game theory and is more suitable for simulating collaborative governance paradigms under multi-stage risk superposition.

This study aims to establish an analytical framework to investigate how risk management measures can be leveraged to enhance wetland restoration capabilities. We begin by elucidating the multi-dimensional connotations of wetland resilience from an ecological perspective—encompassing factors such as biodiversity and water quality regulation. These ecological objectives serve as the ultimate value orientation guiding the behaviors of both the government and enterprises. However, the core contribution of this study does not lie in directly simulating these specific ecological processes, but rather in proposing a differential game model focused on governance and reputation. Within this model, wetland resilience is abstracted as a comprehensive state variable, the dynamics of which are jointly driven by the intensity of government regulation and the governance efforts of enterprises. The model's core variables encompass reputation effects, economic costs, and strategic interactions. We formalize distinct risk control logics through governance metaphors such as the dog mastiff effect, the domino effect, and the fish tank theory.

Consequently, the formal model presented herein essentially reveals the specific governance structures characterized by incentive compatibility that are required as strategic prerequisites to achieve the ecological goal of enhancing wetland restoration capabilities. By meticulously designing reputation mechanisms and regulatory rules (i.e., the utility functions within the model), the strategic calculus of the players in the game can be altered, such that their self-interested behaviors ultimately yield outcomes beneficial to the ecosystem. The conclusions of this study should be interpreted as an exploration of effective governance pathways rather than as predictions of specific ecological dynamics. The establishment of this governance model provides a robust theoretical bridge for interdisciplinary dialogue between ecological objectives and management tools.

The dog mastiff effect enhances the effectiveness of organizations or systems through external supervision and internal self-regulation. In the context of wetland restoration and risk management, this implies the need to establish effective

oversight and regulatory mechanisms to ensure the rigorous implementation of relevant measures.

This paper referred to (Chang et al., 2015; Xiao et al., 2024) when designing the model. If government and enterprises comply with the dog mastiff effect in the process of improving the resilience of wetlands, then their social welfare function can be expressed as Equations 1, 2:

$$J_{D1} = \int_0^\infty \left[(b_1 + b_{D1})G_{D1}(t) - \frac{c_1 + c_{D1}}{2}G_{D1}^2(t) + lx_{D1}(t) \right] e^{-\rho t} dt \quad (1)$$

$$J_{D2} = \int_0^\infty \left[(b_2 + b_{D2})G_{D2}(t) - \frac{c_2 + c_{D2}}{2}G_{D2}^2(t) + lx_{D2}(t) \right] e^{-\rho t} dt \quad (2)$$

In the above formula, $b_1G_{D1}(t)$ represents the gains the government makes by improving the resilience of wetlands. $b_{D1}G_{D1}(t)$ represents the gains that the government gains by establishing effective oversight and regulation mechanisms. $\frac{c_1}{2}G_{D1}^2(t)$ represents the cost to governments of improving the resilience of wetlands. $\frac{c_{D1}}{2}G_{D1}^2(t)$ represents the cost to the government of establishing effective oversight and regulation mechanisms. $lx_{D1}(t)$ represents the positive impact of reputation on the government’s social effectiveness. $b_2G_{D2}(t)$ represents the benefits gained by companies from improving the resilience of wetlands. $b_{D2}G_{D2}(t)$ represents the benefits gained by the establishment of effective supervision and regulation mechanisms. $\frac{c_2}{2}G_{D2}^2(t)$ represents the cost to enterprises of improving the resilience of wetlands. $\frac{c_{D2}}{2}G_{D2}^2(t)$ represents the cost of establishing effective monitoring and regulation mechanisms. $lx_{D2}(t)$ represents the positive impact of reputation on enterprises’ social performance.

In the differential game model of the dog mastiff effect, the government’s utility function operates essentially as a social welfare function requiring complex trade-offs. Its objective is to maximize a discounted sum of multiple factors over an infinite time horizon. This function primarily balances three components: first, the positive ecological and social benefits resulting from enhanced wetland resilience (e.g., biodiversity, flood control value, and public health), which represent the core public interest pursued by the government; second, the direct costs incurred by the government in implementing regulations (such as the establishment of monitoring systems and administrative law enforcement expenses), which constitute a negative utility; and third, the indirect economic impacts of regulatory policies (e.g., the potential transmission of increased corporate costs to the regional economy). The government’s strategy lies in investing regulatory costs (initiating the dog mastiff effect) to deter corporate behavior, with the ultimate goal of ensuring that the long-term social welfare generated by the net growth in wetland resilience exceeds the short-term regulatory expenditures and potential economic suppression, thereby achieving the maximization of total social welfare.

The enterprise’s utility function embodies the pursuit of long-term profit maximization, clearly reflecting the shift in strategic incentives driven by regulation. This function comprises several key components: the core element is the profit derived from normal production and operations; in contrast, there are the direct costs invested by the enterprise to comply with environmental

regulations and actively enhance wetland resilience (such as technical retrofits and pollution treatment expenses). Crucially, the dog mastiff effect reshapes the enterprise’s cost structure by introducing a substantial penalty term for non-compliance (encompassing fines and reputational damage). When the expected penalty far exceeds compliance costs, the rational choice for the enterprise is to shift from “risk-taking non-compliance” to “active investment in governance.” Consequently, the enterprise’s objective function drives it to incur certain compliance costs under strict regulatory deterrence to avoid greater punitive losses and potentially secure long-term gains from a green reputation, with its strategic efforts ultimately contributing indirectly to the enhancement of wetland resilience.

Under the dog mastiff effect, the government’s primary effort $G_{D1}(t)$ is to establish and credibly enforce a stringent regulatory framework aimed at altering the strategic incentives for enterprises. This involves setting clear and ambitious wetland restoration standards, implementing a system of monitoring and verification, and imposing significant financial or reputational penalties for non-compliance. The government’s strategic “effort” is not direct ecological restoration per se, but the consistent application of supervisory pressure. By making the cost of environmental damage prohibitively high, the government’s goal is to shift the enterprise’s cost-benefit calculation, compelling them to internalize the ecological externalities of their operations. In the model, this is often represented by a high penalty parameter in the government’s strategy set, which creates a powerful deterrent, thereby indirectly driving improvements in wetland resilience by aligning corporate behavior with public environmental goals (Holling, 1973).

For enterprises, their efforts $G_{D2}(t)$ under the dog mastiff effect are a strategic response to the heightened regulatory risks imposed by the government. Faced with the credible threat of substantial penalties, enterprises are incentivized to proactively invest in measures that enhance wetland resilience, such as adopting cleaner technologies, implementing sustainable resource management practices, and funding direct restoration projects. Their “effort” is fundamentally driven by economic rationality—the desire to avoid the higher costs of punishment and potential reputational damage. Thus, the enterprise’s investment in ecological improvement becomes a calculated cost-minimization strategy. In the model, this is captured by an effort variable that increases as the government’s penalty parameter intensifies, demonstrating how the dog mastiff effect channelizes corporate self-interest toward environmentally beneficial outcomes.

The change in the reputation of government and enterprises under the situation of dog mastiff effect can be expressed as:

$$\dot{x}_{D1}(t) = f_1G_{D1}(t) - \delta_1x_{D1}(t) \quad (3)$$

$$\dot{x}_{D2}(t) = f_2G_{D2}(t) - \delta_2x_{D2}(t) \quad (4)$$

In the above formula (Equations 3, 4), $f_1G_{D1}(t)$ represents the reputation gained by the government for improving the resilience of wetlands. $\delta_1x_{D1}(t)$ represents a decline in the reputation of the government. $f_2G_{D2}(t)$ represents the reputation gained by enterprises for improving the resilience of wetlands. $\delta_2x_{D2}(t)$ represents a decline in the reputation of the enterprises.

Under the dog mastiff effect, the government's reputation serves as its most strategic asset, hinging fundamentally on the credibility of its regulatory commitments. Governmental effort is not merely a one-off action but is aimed at establishing and maintaining a reputation as a "steadfast regulator"—a powerful expectation that ensures firms believe violations will inevitably be penalized. This reputation acts as a potent deterrent: if the government possesses a reputation for strict adherence to word and rigorous enforcement, enterprises will anticipate the prohibitively high costs of evading environmental responsibilities, thereby favoring proactive compliance. Conversely, if the government appears weak or inconsistent, its regulatory threats may be perceived as evadable, rendering the dog mastiff effect ineffective. Consequently, the government's utility function within the model incorporates a critical "reputation" variable; the long-term benefits derived from maintaining and enhancing this deterrent reputation—such as higher compliance rates and reduced monitoring costs—incite the government to continuously invest in regulatory efforts, thereby indirectly yet powerfully propelling the enhancement of wetland restoration capabilities.

Regarding corporate reputation under the dog mastiff effect, it primarily functions to mitigate compliance costs and secure a competitive advantage. In a stringent regulatory environment, proactive corporate investment in wetland restoration and efforts to surpass compliance standards cultivate a positive reputation as an "environmentally responsible entity." This reputation yields tangible economic benefits, including facilitated access to operational permits, favor among environmentally conscious consumers, attraction of green investment, and eligibility for government rewards or more lenient inspection regimes (Costanza et al., 1997). Thus, even though adhering to higher standards may incur short-term costs, the pursuit of the long-term benefits associated with a strong reputation serves as a powerful intrinsic incentive that complements external regulatory pressure. Within the model, the enterprise's utility function includes a "reputation return" term, translating efforts to improve wetland restoration capabilities into future economic returns; this mechanism aligns the self-interested behaviors of enterprises more closely with the public goal of wetland conservation within the framework of the dog mastiff effect.

The adoption of a linear specification for reputation decline is a deliberate methodological choice to establish an analytically tractable baseline model that prioritizes clarity in capturing the core strategic interactions. While real-world reputation loss can exhibit non-linear characteristics—such as tipping points triggered by media scandals—the primary objective of this study is to isolate and elucidate the fundamental feedback mechanism between strategic actions and reputational capital. A linear assumption posits a consistent and proportional erosion of trust over time in the absence of sustaining efforts, which effectively captures the essential idea that reputation is a depreciating asset requiring continuous investment. This simplification allows us to derive interpretable equilibrium strategies and clearly trace how the dog mastiff effect (the interplay of actions) and the fish tank theory (the condition of transparency) dynamically influence long-term outcomes. Introducing complex non-linearities at this

foundational stage would obscure these first-order insights. Therefore, the linear model serves as a necessary and powerful conceptual scaffold; its findings provide the benchmark against which the impacts of more complex, non-linear reputation dynamics can be rigorously assessed in future research.

The domino effect refers to the fact that the occurrence of one event may trigger a series of chain reactions. In wetland restoration and risk management, this means identifying and managing potential chain risks to prevent small problems from evolving into major ones.

If government and enterprises comply with the domino effect in the process of improving the resilience of wetlands, then their social welfare function can be expressed as Equations 5, 6:

$$J_{B1} = \int_0^{\infty} \left[b_1 G_{B1}(t) - \frac{c_1}{2} G_{B1}^2(t) + l x_{B1}(t) \right] e^{-\rho t} dt \quad (5)$$

$$J_{B2} = \int_0^{\infty} \left[b_2 \ln(e + \lambda_2) G_{B2}(t) - \frac{c_2}{2} G_{B2}^2(t) + l x_{B2}(t) \right] e^{-\rho t} dt \quad (6)$$

In the above formula, $b_1 G_{B1}(t)$ represents the benefits obtained by the government from enhancing wetland resilience. $\frac{c_1}{2} G_{B1}^2(t)$ represents the costs incurred by the government for enhancing wetland resilience. $l x_{B1}(t)$ represents the positive impact of reputation on the social benefits of the government. $\ln(e + \lambda_2)$ represents $\log e^{(e + \lambda_2)}$, e denotes the base of the natural logarithm, an irrational number approximately equal to 2.718281828459 (the same applies hereinafter). $b_2 \ln(e + \lambda_2) G_{B2}(t)$ represents the benefits obtained by enterprises from enhancing wetland resilience. $\ln(e + \lambda_2)$ represents the degree to which identifying and managing potential chain risks improves the benefits for enterprises. $\frac{c_2}{2} G_{B2}^2(t)$ represents the costs incurred by enterprises for enhancing wetland resilience. $l x_{B2}(t)$ represents the positive impact of reputation on the social benefits of enterprises.

In Equation 6, the benefits obtained by enterprises from enhancing wetland resilience follow a logarithmic form is adopted to capture the fundamental economic principle of diminishing marginal returns. This functional form posits that while initial investments in restoration—such as adopting basic best practices or mitigating core pollution sources—yield substantial and rapid gains in terms of reputational capital, regulatory goodwill, and ecosystem service security, each additional unit of investment generates a progressively smaller incremental benefit. For instance, the positive impact on brand image from achieving regulatory compliance is significant; however, the marginal benefit of moving from "industry leader" to "exceptional performer" is less pronounced. The logarithmic function elegantly models this saturation effect, reflecting the reality that there is an upper limit to the tangible economic value that a firm can extract from environmental stewardship. This specification prevents the model from producing unrealistic outcomes where infinite investment in restoration is optimal, thereby ensuring that the enterprise's cost-benefit analysis and the resulting strategic equilibrium with the government are both economically plausible and behaviorally credible.

Within the framework of the domino effect, the core characteristic of the government's utility function (social welfare

function) is an extreme aversion to “systemic collapse risk”, with the functional form typically exhibiting strong nonlinear aversion to losses in wetland restoration capabilities. The government’s objective shifts from simply balancing static benefits and costs to maximizing an intertemporal welfare function that reflects long-term system stability. This is embodied in the function’s design: the marginal social benefit derived from wetland restoration capabilities escalates sharply as the system becomes more fragile (i.e., as resilience levels decline), signifying that preventing the system from crossing a critical “tipping point” is accorded the highest priority. Consequently, the government’s utility function may adopt forms such as a logarithmic function or incorporate a substantial risk multiplier to quantify the immense value of “preventing the first domino from falling.” Governmental efforts (e.g., investing in ecosystem monitoring, establishing regional coordination mechanisms) are dedicated to reducing the probability of chain reactions, with decisions aimed at forestalling potential catastrophic social welfare losses in the future through forward-looking investment.

For enterprises, the core of the utility function under the domino effect is the pursuit of “long-term expected profit maximization,” achieved through the mitigation of “cascading reputation-market collapse” risks. The corporate function encompasses not only traditional production and compliance costs but, more critically, introduces a “reputation discount factor” or a “potential catastrophic loss term” associated with chain reaction risks. This factor implies that if corporate actions act as a catalyst for an ecological-social-economic chain reaction, the consequences would extend beyond fines to include the decimation of critical assets such as market share, brand equity, and financing capacity. Therefore, the enterprise’s utility function provides strong incentives for precautionary investments (e.g., adopting safer technologies, enhancing ecological transparency); these efforts are viewed as paying an “insurance premium” to avoid future, low-probability yet high-loss chain disasters. The strategic choice involves a trade-off between “higher current compliance costs” and “potential future catastrophic losses,” thereby aligning self-interested behavior with the overall resilience of the system.

From the perspective of the domino effect, the government’s core effort lies in prospective systemic risk governance, aimed at preventing initial risks from evolving into uncontrollable cascading ecological-socio-economic crises. The strategic focus of the government shifts from post-violation punishment, as characterized by the dog mastiff effect, to the construction of pre-risk early warning and incentive systems. This entails investing in comprehensive wetland ecosystem monitoring networks to identify the most vulnerable “first domino” that could trigger a chain reaction; formulating regionally coordinated development plans to mitigate the negative spillovers of isolated decision-making; and establishing dedicated funds or insurance mechanisms to share risks for enterprises pioneering high-standard protection measures. These efforts are reflected in the government’s utility function, which ascribes extremely high social value to preventing systemic collapse. This is typically modeled using a concave benefit function (such as a logarithmic form), implying that the marginal social benefit of averting an initial minor loss far exceeds that of

subsequent remediation. Consequently, the government acts as the architect and steward of system stability.

For enterprises, efforts within the domino effect framework constitute a strategic investment based on considerations of long-term survival and reputation capital. Firms recognize that triggering ecological degradation through their activities (e.g., pollution of critical water sources) may not only incur direct government penalties but also precipitate a cascade of reactions—including supply chain disruptions, community boycotts, consumer trust collapse, and financing constraints—where the cumulative impact far exceeds that of the initial event. Therefore, corporate efforts manifest as proactive risk management that surpasses minimum compliance requirements. Examples include investing in closed-loop water systems to eliminate pollution risks entirely rather than relying solely on end-of-pipe treatment; co-constructing conservation projects with local communities to secure social license; and regularly publishing detailed ecological impact reports to establish a transparent and trustworthy reputation. In the model, this is represented by the inclusion of a “reputation discount factor” or an aversion to chain-reaction losses in the enterprise’s utility function, incentivizing them to make early investments to avoid entrapment in a vicious cycle of cascading collapse, thereby jointly maintaining overall system resilience with the government.

The change in the reputation of government and enterprises under the situation of domino effect can be expressed as:

$$\dot{x}_{B1}(t) = f_1 \ln(e + \lambda_1)G_{B1}(t) - \delta_1 x_{B1}(t) \quad (7)$$

$$\dot{x}_{B2}(t) = f_2 G_{B2}(t) - \delta_2 x_{B2}(t) \quad (8)$$

In the above formula (Equations 7, 8), $f_1 \ln(e + \lambda_1)G_{B1}(t)$ represents the reputation gained by the government from enhancing wetland resilience. $\ln(e + \lambda_1)$ represents the extent to which identifying and managing potential chain risks improve the government’s reputation. $\delta_1 x_{B1}(t)$ represents the decline in the government’s reputation. $f_2 G_{B2}(t)$ represents the reputation gained by enterprises from enhancing wetland resilience. $\delta_2 x_{B2}(t)$ represents the decline in the enterprises’ reputation.

Under the governance paradigm of the domino effect, the core of the government’s reputation lies in its credibility as a “systemic risk forecaster” and a “crisis interceptor.” This reputation pertains not only to rigorous enforcement but, more crucially, to the ability to effectively identify the fragile “first domino” within the ecosystem and to prevent local risks from escalating into regional or systemic crises through prospective policies and investments. A government with a strong reputation transmits a powerful signal of “controllable circumstances and secure long-term investment” to society and market entities, thereby stabilizing expectations and encouraging stakeholders to engage in long-term, sustainable investment rather than short-term opportunistic extraction. Conversely, if the government is perceived as myopic and passively reactive, it amplifies uncertainty, prompting firms to adopt opportunistic strategies that exacerbate systemic vulnerability. Consequently, the government’s utility function assigns significant value to the long-term social stability benefits and risk-avoidance value derived

from maintaining this “reliable steward” reputation, thereby incentivizing the adoption of precautionary governance measures.

In the context of the domino effect, corporate reputation transcends the mere image of a “compliant entity” and evolves into a “resilience asset” that safeguards against cascading risks and ensures business continuity. Firms recognize that a reputation as a “responsible environmental steward” serves as a “firewall” and “insurance policy” against potential chain-reaction crises. In the event of an ecological risk incident, enterprises possessing an exemplary reputation are more likely to garner trust and support from the government, communities, and investors, thereby effectively isolating the crisis and averting secondary disasters triggered by public panic, supply chain disruptions, or financing freezes. Therefore, corporate investment in reputation—such as adopting standards that exceed compliance requirements and achieving full transparency throughout the production process—constitutes a strategic form of risk management. In the model, this is characterized by the inclusion of a robust “reputation resilience factor” in the firm’s utility function, which translates a strong reputation into the capacity to mitigate potentially catastrophic losses within an uncertain environment, incentivizing enterprises to proactively act as stabilizing nodes that prevent the domino effect from cascading.

The fish tank theory emphasizes that in a transparent and open environment, behaviors and decisions are more likely to be supervised and corrected. In wetland restoration and risk management, this means enhancing the transparency of the governance process and ensuring the participation and supervision of all stakeholders.

If government and enterprises comply with the fish tank theory in the process of improving the resilience of wetlands, then their social welfare function can be expressed as Equations 9, 10:

$$J_{F1} = \int_0^{\infty} \left[b_1 G_{F1}(t) - \frac{c_1}{2} G_{F1}^2(t) + l x_{F1}(t) \right] e^{-\rho t} dt \quad (9)$$

$$J_{F2} = \int_0^{\infty} \left[b_2 G_{F2}(t) - \frac{c_2}{2} G_{F2}^2(t) + l x_{F2}(t) \right] e^{-\rho t} dt \quad (10)$$

In the above formula, $b_1 G_{F1}(t)$ represents the benefits obtained by the government from enhancing wetland resilience. $\frac{c_1}{2} G_{F1}^2(t)$ represents the costs incurred by the government for enhancing wetland resilience. $l x_{F1}(t)$ represents the positive impact of reputation on the social benefits of the government. $b_2 G_{F2}(t)$ represents the benefits obtained by enterprises from enhancing wetland resilience. $\frac{c_2}{2} G_{F2}^2(t)$ represents the costs incurred by enterprises for enhancing wetland resilience. $l x_{F2}(t)$ represents the positive impact of reputation on the social benefits of enterprises.

The core of the government’s utility function (social welfare function) is to maximize the benefits of collaborative societal governance catalyzed by “information transparency.” The government recognizes that its most critical role is not that of a micromanager but rather the architect of a public information platform and the custodian of credible rules. Consequently, its objective function assigns significant value to the immense social gains derived from “information symmetry”: this drastically reduces

direct regulatory costs, stimulates the monitoring enthusiasm of third-party actors such as the public and the media, and utilizes market mechanisms—including consumer choice and green investment—to automatically reward or Punish corporate behavior, thereby more efficiently channeling resources toward environmental protection. The government’s utility is realized in that by investing in the maintenance of a transparent information ecosystem (i.e., a fish tank), it can mobilize broader societal forces to enhance wetland restoration capabilities with a lower administrative burden, ultimately maximizing social welfare (comprising ecological benefits, market efficiency, and social justice).

For enterprises, the key to the utility function (pursuing long-term profits) under the fish tank theory lies in internalizing “reputation capital” as a core economic variable. In a fully transparent “fish tank” environment, a firm’s environmental performance directly and immediately influences its brand image and market competitiveness. As a result, the structure of its utility function undergoes a fundamental transformation: the traditional “revenue” term is now tightly coupled with a potent “reputation multiplier”. A strong reputation amplifies revenue (e.g., through brand premiums and preferred procurement rights), whereas a poor reputation precipitates a sharp contraction in revenue. Furthermore, efforts expended by the firm to enhance wetland restoration capabilities—such as compliance costs and investments in green technology—are no longer viewed merely as disutility but as necessary investments for accumulating valuable “reputation assets.” Corporate strategic decision-making thus involves optimizing the trade-off between immediate expenditure and long-term returns derived from reputation, ensuring that self-interested behavior aligns spontaneously with societal environmental objectives under the constraint of transparency.

Within the framework of the fish tank theory, the government’s core effort lies in constructing a comprehensive, high-transparency ecosystem for supervision and information disclosure, effectively creating a “glass fish tank” for wetland management. The strategic focus of the government shifts from direct intervention to the creation and maintenance of “visibility”. This entails legislating mandatory corporate disclosure of detailed operational impacts on wetlands, establishing publicly accessible platforms for real-time environmental monitoring data, encouraging media and public engagement in oversight, and directly linking corporate environmental performance to market reputation and administrative licensing. These governmental efforts aim to eliminate information asymmetry and place enterprises under the spotlight of public opinion and market choice. In the model, this implies that the government’s utility function assigns high value to the social benefits derived from “information transparency” as a public good; regulatory costs are primarily allocated to establishing and maintaining this transparent mechanism. By rendering all actions “visible”, the government leverages the power of societal monitoring to incentivize and constrain corporate behavior.

For enterprises, the essence of effort under the fish tank theory is the proactive investment in “impression management” and “reputation capital” within a highly transparent environment to secure the trust of key stakeholders (e.g., consumers, investors, communities). Since all actions are exposed within the “fish tank”,

enterprises cannot conceal negative environmental behaviors; any myopic or destructive practices will rapidly result in reputational damage and market penalties. Consequently, the rational choice for firms is to surpass minimum compliance standards by proactively adopting eco-friendly production processes, regularly publishing detailed social responsibility reports, inviting third-party environmental audits, and actively participating in wetland conservation initiatives. In the model, this is represented by the incorporation of “social reputation” and “brand image” as core variables in the enterprise’s utility function, with market returns being highly positively correlated with reputation. Efforts to enhance wetland restoration capabilities are thus directly transformed into strategic necessities for demonstrating a positive image and gaining competitive advantage within the transparent “fish tank”.

The change in the reputation of government and enterprises under the situation of fish tank theory can be expressed as:

$$\dot{x}_{F1}(t) = f_1(1 + r_1)G_{F1}(t) - \delta_1 x_{F1}(t) \quad (11)$$

$$\dot{x}_{F2}(t) = f_2(1 + r_2)G_{F2}(t) - \delta_2 x_{F2}(t) \quad (12)$$

In the above formula (Equations 11, 12), $f_1 G_{F1}(t)$ represents the reputation gained by the government from enhancing wetland resilience. $f_1 r_1 G_{F1}(t)$ represents the increase in the government’s reputation from improving the transparency of governance processes. $\delta_1 x_{F1}(t)$ represents the decline in the government’s reputation. $f_2 G_{F2}(t)$ represents the reputation gained by enterprises from enhancing wetland resilience. $f_2 r_2 G_{F2}(t)$ represents the increase in the enterprises’ reputation from improving the transparency of governance processes. $\delta_2 x_{F2}(t)$ represents the decline in the enterprises’ reputation.

Under the framework of the fish tank theory, government reputation is intrinsically linked to its “transparency” and “credibility as the steward of an impartial information platform”. The government’s core role is to establish and maintain a “transparent fish tank” in which all environmental behaviors are rendered fully visible. Consequently, its reputation depends not on the severity of direct punishments, but rather on the comprehensiveness, accuracy, and timeliness of the information provided, as well as the fairness and consistency of regulatory rules. A government with a strong reputation signals to the public and enterprises that the environmental data published are authentic and reliable, and that the oversight platform constructed is just and effective. This reputation of a “credible guardian of transparency” serves as a prerequisite for public willingness to engage in monitoring and corporate compliance with rules, thereby significantly enhancing the efficacy of the entire governance system. Conversely, if the government publishes inaccurate data or engages in selective disclosure, its reputation will be compromised. This obscures the “fish tank”, erodes public credibility, dampens enthusiasm for public engagement, and ultimately leads to the collapse of the transparency-based governance mechanism.

For enterprises, reputation within the context of the fish tank theory represents the most direct form of market competitiveness and a vital asset for survival. In the “fish tank”,

corporate environmental performance is rendered conspicuous, transforming reputation from a subjective impression into a “robust metric” shaped in real-time by verifiable data and actions. A strong reputation—manifested through high environmental ratings, transparent supply chains, and proactive community engagement—translates into consumer preference, investor confidence, and greater flexibility in social operating license, directly generating economic benefits. Therefore, investment in reputation constitutes a core strategic endeavor for firms. Any myopic behavior detrimental to wetland restoration capabilities is instantly amplified within the “fish tank”, causing rapid depreciation of reputation. This precipitates a cascade of consequences, including market share loss and increased financing costs. Under this theory, reputation acts as the “passport” for enterprises in a transparent market; maintaining it becomes an imperative choice for firms pursuing long-term development.

3 Results

In the differential game, the government and enterprises in the process of improving the resilience of wetlands 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.

This dynamic programming approach aims to determine the optimal action for each participant (i.e., the government and the enterprise) at any given point in time, based on the current system state (such as wetland health status and the reputation levels of both parties). The derivation process begins by defining a “value function” for each participant, representing the discounted sum of future total returns attainable from the current moment onward, given the state. The core principle of the HJB equation lies in the fact that, under an optimal strategy, the product of each participant’s discount rate and their value function must equal the instantaneous payoff derived from the objective function, plus the expected rate of change of their own value function driven by changes in all state variables (León et al., 2025). Therefore, such a balance equation must be constructed for every participant. During the solution process, maximization is first performed internally within the equation with respect to each participant’s control variables (e.g., government regulation intensity or corporate restoration investment), yielding a set of strategy functions expressed in terms of state variables and the derivatives of the value functions. Typically, we conjecture that the value function takes a specific mathematical form and substitute it into the equation. By equating the coefficients of all like terms on both sides of the equation, the specific coefficients within the value function can be solved. Finally, by plugging these coefficients back into the strategy functions, we obtain clear, interpretable optimal strategy rules. These rules demonstrate that each participant’s optimal action constitutes a distinct feedback law, dynamically adjusted according to the current wetland health status and the

reputation standing of both parties, thereby revealing the nature of strategic interactions such as the dog mastiff effect.

3.1 HJB formula

Under the condition that the dog mastiff effect is satisfied, the HJB equation of the social welfare function of the government and enterprises can be shown as Equations 13, 14:

$$\rho V_{D1} = \max_{G_{D1}(t)} \left\{ \left[(b_1 + b_{D1})G_{D1}(t) - \frac{c_1 + c_{D1}}{2} G_{D1}^2(t) + l x_{D1}(t) \right] + \frac{\partial V_{D1}}{\partial x_{D1}} [f_1 G_{D1}(t) - \delta_1 x_{D1}(t)] \right\} \quad (13)$$

$$\rho V_{D2} = \max_{G_{D2}(t)} \left\{ \left[(b_2 + b_{D2})G_{D2}(t) - \frac{c_2 + c_{D2}}{2} G_{D2}^2(t) + l x_{D2}(t) \right] + \frac{\partial V_{D2}}{\partial x_{D2}} [f_2 G_{D2}(t) - \delta_2 x_{D2}(t)] \right\} \quad (14)$$

Under the condition that the domino effect is satisfied, the HJB equation of the social welfare function of the government and enterprises can be shown as Equations 15, 16:

$$\rho V_{B1} = \max_{G_{B1}(t)} \left\{ \left[b_1 G_{B1}(t) - \frac{c_1}{2} G_{B1}^2(t) + l x_{B1}(t) \right] + \frac{\partial V_{B1}}{\partial x_{B1}} [f_1 \ln(e + \lambda_1) G_{B1}(t) - \delta_1 x_{B1}(t)] \right\} \quad (15)$$

$$\rho V_{B2} = \max_{G_{B2}(t)} \left\{ \left[b_2 \ln(e + \lambda_2) G_{B2}(t) - \frac{c_2}{2} G_{B2}^2(t) + l x_{B2}(t) \right] + \frac{\partial V_{B2}}{\partial x_{B2}} [f_2 G_{B2}(t) - \delta_2 x_{B2}(t)] \right\} \quad (16)$$

Under the condition that the fish tank theory is satisfied, the HJB equation of the social welfare function of the government and enterprises can be shown as Equations 17, 18:

$$\rho V_{F1} = \max_{G_{F1}(t)} \left\{ \left[b_1 G_{F1}(t) - \frac{c_1}{2} G_{F1}^2(t) + l x_{F1}(t) \right] + \frac{\partial V_{F1}}{\partial x_{F1}} [f_1(1 + r_1) G_{F1}(t) - \delta_1 x_{F1}(t)] \right\} \quad (17)$$

$$\rho V_{F2} = \max_{G_{F2}(t)} \left\{ \left[b_2 G_{F2}(t) - \frac{c_2}{2} G_{F2}^2(t) + l x_{F2}(t) \right] + \frac{\partial V_{F2}}{\partial x_{F2}} [f_2(1 + r_2) G_{F2}(t) - \delta_2 x_{F2}(t)] \right\} \quad (18)$$

3.2 Result of equilibrium

3.2.1 Proposition 1

Under the condition that the dog mastiff effect is satisfied, the efforts to improve the resilience of wetlands, and social benefits of

government and enterprises are Equations 19–22 (the specific solving procedure is shown in Appendix 1):

$$G_{D1}^*(t) = \frac{b_1 + b_{D1}}{c_1 + c_{D1}} + \frac{f_1}{c_1 + c_{D1}} \frac{l}{\rho + \delta} \quad (19)$$

$$G_{D2}^*(t) = \frac{b_2 + b_{D2}}{c_2 + c_{D2}} + \frac{f_2}{c_2 + c_{D2}} \frac{l}{\rho + \delta} \quad (20)$$

$$V_{D1}^* = \frac{l}{\rho + \delta} x_{D1} + \frac{1}{\rho} (b_1 + b_{D1}) \left(\frac{b_1 + b_{D1}}{c_1 + c_{D1}} + \frac{f_1}{c_1 + c_{D1}} \frac{l}{\rho + \delta} \right) - \frac{c_1 + c_{D1}}{2} \frac{1}{\rho} \left(\frac{b_1 + b_{D1}}{c_1 + c_{D1}} + \frac{f_1}{c_1 + c_{D1}} \frac{l}{\rho + \delta} \right)^2 + \frac{l}{\rho + \delta} \frac{1}{\rho} f_1 \left(\frac{b_1 + b_{D1}}{c_1 + c_{D1}} + \frac{f_1}{c_1 + c_{D1}} \frac{l}{\rho + \delta} \right) \quad (21)$$

$$V_{D2}^* = \frac{l}{\rho + \delta} x_{D2} + \frac{1}{\rho} (b_2 + b_{D2}) \left(\frac{b_2 + b_{D2}}{c_2 + c_{D2}} + \frac{f_2}{c_2 + c_{D2}} \frac{l}{\rho + \delta} \right) - \left(\frac{b_2 + b_{D2}}{c_2 + c_{D2}} + \frac{f_2}{c_2 + c_{D2}} \frac{l}{\rho + \delta} \right)^2 \frac{c_2 + c_{D2}}{2} \frac{1}{\rho} + \frac{l}{\rho + \delta} \frac{1}{\rho} f_2 \left(\frac{b_2 + b_{D2}}{c_2 + c_{D2}} + \frac{f_2}{c_2 + c_{D2}} \frac{l}{\rho + \delta} \right) \quad (22)$$

3.2.1.1 Conclusion 1

Under the conditions of the dog mastiff effect, the greater the benefits derived from establishing effective supervision and regulatory mechanisms, the more effort the government and enterprises will exert to enhance wetland resilience.

Although the conclusions derived from the dog mastiff effect scenario indicate that regulatory returns can incentivize government and corporate investment, the underlying implications reveal critical trade-offs and boundary conditions. First, there exists a counterintuitive threshold effect: when regulatory returns fall below implementation costs, the system becomes trapped in a “weak regulation–low investment” lock-in equilibrium. This implies that policies must surpass a minimum effective scale to trigger cooperation. Second, the efficacy of policy levers is constrained by institutional tipping points; for instance, if the profits from non-compliance are excessively high, reliance solely on return incentives may prove ineffective. In such cases, it becomes necessary to integrate robust penalty functions—such as reputation mechanisms or market access restrictions—to alter the payoff structure of the game. Consequently, optimized policy levers should not focus exclusively on returns but rather dynamically calibrate regulatory intensity and cost-sharing mechanisms. For example, phased subsidies could be employed to reduce initial corporate compliance costs, followed by a gradual transition toward performance-based rewards and penalties once ecological benefits materialize, thereby preventing system failure resulting from insufficient initial investment.

3.2.2 Proposition 2

Under the condition that the domino effect is satisfied, the efforts to improve the resilience of wetlands, and social benefits of government and enterprises are Equations 23–26 (the specific solving procedure is shown in Appendix 2):

$$G_{B1}^*(t) = \frac{b_1}{c_1} + \frac{f_1 \ln(e + \lambda_1)}{c_1} \frac{l}{\rho + \delta} \tag{23}$$

$$G_{B2}^*(t) = \frac{b_2 \ln(e + \lambda_2)}{c_2} + \frac{f_2}{c_2} \frac{l}{\rho + \delta} \tag{24}$$

$$V_{B1}^* = \frac{l}{\rho + \delta} x_{B1} + \frac{1}{\rho} b_1 \left[\frac{b_1}{c_1} + \frac{f_1 \ln(e + \lambda_1)}{c_1} \frac{l}{\rho + \delta} \right] - \frac{c_1}{2} \frac{1}{\rho} \left[\frac{b_1}{c_1} + \frac{f_1 \ln(e + \lambda_1)}{c_1} \frac{l}{\rho + \delta} \right]^2 + \frac{1}{\rho} \frac{l}{\rho + \delta} f_1 \ln(e + \lambda_1) \left[\frac{b_1}{c_1} + \frac{f_1 \ln(e + \lambda_1)}{c_1} \frac{l}{\rho + \delta} \right] \tag{25}$$

$$V_{B2}^* = \frac{l}{\rho + \delta} x_{B2} + \frac{1}{\rho} b_2 \ln(e + \lambda_2) \left[\frac{b_2 \ln(e + \lambda_2)}{c_2} + \frac{f_2}{c_2} \frac{l}{\rho + \delta} \right] - \frac{c_2}{2} \frac{1}{\rho} \left[\frac{b_2 \ln(e + \lambda_2)}{c_2} + \frac{f_2}{c_2} \frac{l}{\rho + \delta} \right]^2 + \frac{1}{\rho} \frac{l}{\rho + \delta} f_2 \left[\frac{b_2 \ln(e + \lambda_2)}{c_2} + \frac{f_2}{c_2} \frac{l}{\rho + \delta} \right] \tag{26}$$

3.2.2.1 Conclusion 2

Under the conditions of the domino effect, the greater the improvement in reputation gained from identifying and managing potential cascading risks, the more effort the government and enterprises will exert to enhance wetland resilience.

In the domino effect scenario, the facilitative effect of reputation incentives on government and corporate investment implies a critical boundary condition and a counterintuitive trade-off. Its effectiveness is strictly contingent upon the observability and transparency of risk information; if potential cascading risks cannot be accurately identified and traced by external observers (e.g., the public, the market), the reputation mechanism fails, resulting in a lack of motivation for proactive intervention among stakeholders. Even more counterintuitively, the system may exhibit a critical point of risk accumulation. During the early stages of accumulation, the lack of tangible reputation returns may lead to underinvestment by governments and enterprises. Once the chain reaction is triggered and made public, although reputational penalties are severe, the costs of recovery are already prohibitively high, resulting in an inefficient equilibrium characterized by “ex ante neglect and ex post remediation.” Therefore, the core policy lever lies in constructing a mechanism for dynamic risk visualization and reputation binding—for instance, by establishing an early warning platform for wetland health and publicly ranking performance in risk management, thereby converting covert ecological cascading risks into quantifiable reputation assets. Concurrently, governments could establish a “joint risk prevention fund” to provide dual incentives in terms of reputation and finance to enterprises that voluntarily disclose and collaboratively resolve potential chains, thereby altering the payoff structure of the game and guiding stakeholders to adopt cooperative preventive strategies before reaching the critical tipping point.

3.2.3 Proposition 3

Under the condition that the fish tank theory is satisfied, the efforts to improve the resilience of wetlands, and social benefits of

government and enterprises are [Equations 27–30](#) (the specific solving procedure is shown in [Appendix 3](#)):

$$G_{F1}^*(t) = \frac{b_1}{c_1} + \frac{f_1(1 + r_1)}{c_1} \frac{l}{\rho + \delta} \tag{27}$$

$$G_{F2}^*(t) = \frac{b_2}{c_2} + \frac{f_2(1 + r_2)}{c_2} \frac{l}{\rho + \delta} \tag{28}$$

$$V_{F1}^* = \frac{l}{\rho + \delta} x_{F1} + \frac{1}{\rho} b_1 \left[\frac{b_1}{c_1} + \frac{f_1(1+r_1)}{c_1} \frac{l}{\rho + \delta} \right] - \frac{c_1}{2} \frac{1}{\rho} \left[\frac{b_1}{c_1} + \frac{f_1(1+r_1)}{c_1} \frac{l}{\rho + \delta} \right]^2 + \frac{1}{\rho} \frac{l}{\rho + \delta} f_1(1 + r_1) \left[\frac{b_1}{c_1} + \frac{f_1(1+r_1)}{c_1} \frac{l}{\rho + \delta} \right] \tag{29}$$

$$V_{F2}^* = \frac{l}{\rho + \delta} x_{F2} + \frac{1}{\rho} b_2 \left[\frac{b_2}{c_2} + \frac{f_2(1+r_2)}{c_2} \frac{l}{\rho + \delta} \right] - \frac{c_2}{2} \frac{1}{\rho} \left[\frac{b_2}{c_2} + \frac{f_2(1+r_2)}{c_2} \frac{l}{\rho + \delta} \right]^2 + \frac{1}{\rho} \frac{l}{\rho + \delta} f_2(1 + r_2) \left[\frac{b_2}{c_2} + \frac{f_2(1+r_2)}{c_2} \frac{l}{\rho + \delta} \right] \tag{30}$$

3.2.3.1 Conclusion 3

Under the conditions of the fish tank theory, the greater the increase in reputation gained from enhancing the transparency of the governance process, the more effort the government and enterprises will exert to enhance wetland resilience.

Under the fish tank theory scenario, the incentive effect of transparency on reputation and investment reveals a critical counterintuitive trade-off and an institutional tipping point. Although higher transparency theoretically enhances reputation, its actual efficacy is heavily contingent upon the public’s monitoring capability and level of engagement. If information is overly technical or complex—resulting in public inability to comprehend or lack of interest—investment in transparency falls into a predicament of high costs and low returns. A more profound trade-off lies in the fact that an excessive pursuit of formal transparency (e.g., the mechanical disclosure of massive datasets) may expose decision-making divergences or short-term failures, triggering public distrust and engendering a “transparency paradox.” Consequently, effective policy levers should not focus solely on the quantity of information but rather promote “intelligent transparency” and collaborative interpretation. Governments can establish visualized governance dashboards that translate technical data into easily understood ecological health indices for the public. Simultaneously, the introduction of third-party experts or community representatives to jointly interpret information can transform one-way disclosure into two-way communication. This approach not only lowers the barriers to public oversight but also converts transparency into social capital that fosters long-term trust, ultimately guiding governments and enterprises to shift from passive compliance to proactive demonstration of their ecological contributions.

4 Numerical analysis

4.1 Parameter basis

In order to describe in more detail the changes in social utility of government and enterprises in the process of improving the resilience

of wetlands, this paper adopts the method of numerical analysis. The following assumptions are made for relevant parameters:

Enhancing wetland resilience typically involves specific ecological restoration measures, such as vegetation restoration, hydrological condition improvement, and pollution control (Beheshti et al., 2023). Although these measures require certain financial investments, the costs are relatively clear and controllable, and they directly contribute to the restoration of wetland ecosystems, yielding significant and immediate effects (Hagger et al., 2024). In contrast, establishing an effective regulatory mechanism necessitates long-term institutional design, personnel training, technical equipment investment, and continuous supervision and enforcement (Luo et al., 2025). These costs not only include direct economic expenditures but also involve the consumption of time and resources, with effects that may not be immediately apparent. Crucially, regulatory costs are inherently recurrent and subject to escalation (Lah and Kotnik, 2025). They encompass ongoing expenses such as salaries for enforcement personnel, maintenance of monitoring systems, and legal costs associated with non-compliance litigation. Furthermore, unlike a one-time restoration project with a defined budget, a regulatory regime represents a permanent institutional commitment that must adapt to evolving pressures and circumvent attempts at evasion, making its long-term financial burden both substantial and uncertain. After wetland restoration, the recovery of ecosystem services—such as water purification, climate regulation, and biodiversity conservation—can generate long-term economic and environmental benefits, which may partially or fully offset the initial investments (Costanza et al., 1997). However, the establishment and maintenance of regulatory mechanisms are long-term processes. While they help prevent future ecological damage, their benefits are often indirect and require sustained resource inputs. Therefore, the cost of enhancing wetland resilience for governments or enterprises is generally lower than the cost of establishing and maintaining effective regulatory mechanisms. Based on the above analysis, this paper assumes that the costs c_1 , c_2 to the government or enterprises from the improving the resilience of wetlands is 0.5; the cost c_{D1}, c_{D2} incurred by the government or enterprises in establishing effective supervision and regulatory mechanisms is 1.5.

The public generally expects governments to be responsible for protecting the environment and public resources, and thus, government actions in wetland restoration are often viewed as “part of their duty”. Even if a government successfully identifies and manages potential chain risks, the public may perceive this as an obligation, with limited impact on enhancing the government’s reputation. In contrast, corporate efforts in environmental protection are often regarded as “additional contributions” or “social responsibility”. It is important to note, however, that this perception is not universal and is shaped by cultural and institutional contexts. In societies with strong traditions of corporate social responsibility or where large corporations are viewed as de facto social stewards, public expectations of corporate environmental conduct can be significantly higher, thereby attenuating the reputational gains for merely meeting baseline expectations. If enterprises proactively identify and manage potential chain risks, they are likely to receive higher

recognition and praise from the public and stakeholders, significantly boosting their reputation. Government reputation is typically built on broader policy implementation, public services, and governance capabilities, meaning that individual environmental protection actions have relatively limited impact on overall reputation (Liu et al., 2024b). In contrast, corporate reputation relies more heavily on performance in social responsibility, sustainable development, and environmental protection. Successfully managing chain risks can directly enhance a company’s image in these areas, leading to greater reputational gains. Government stakeholders, such as the public, international organizations, and other government agencies, tend to focus on the overall effectiveness of policies and long-term governance capabilities rather than risk management in individual projects. Corporate stakeholders, including consumers, investors, and environmental organizations, are more sensitive to a company’s performance in environmental protection and risk management, especially in the context of increasing environmental concerns. Proactive actions by enterprises are more likely to receive positive evaluations. Therefore, “the extent to which identifying and managing potential chain risks enhances government reputation” is less than “the extent to which identifying and managing potential chain risks enhances corporate reputation.” The magnitude of this difference, however, is contingent upon the specific socio-cultural landscape that defines the expected role of corporations. Based on the above analysis, and acknowledging this contextual variability, this paper assumes that the degree λ_1 of reputation improvement brought to the government by identifying and managing potential chain risks is 2.2; the degree λ_2 of reputation improvement brought to the enterprises by identifying and managing potential chain risks is 2.5.

In the management of wetland resilience, identifying and managing potential chain risks is significant for both governments and enterprises, but the extent of reputational enhancement differs. As public administrators, governments have broad and complex responsibilities, and wetland restoration is only one aspect of numerous public affairs (Bell-James, 2023). Even if a government excels in identifying and managing chain risks, public evaluation of its overall performance is often based on comprehensive factors such as macro policy effectiveness, social stability, and the quality of public services, rather than the success of a single project. Therefore, while risk management in wetland restoration projects can enhance the government’s professional image, its impact on overall reputation is relatively limited. In contrast, enterprises, particularly those involved in environmental protection, rely more directly on the performance of specific projects for their reputation. Identifying and managing potential chain risks not only demonstrates a company’s professional competence and social responsibility but also strengthens public trust in its brand image. For example, effective risk management in wetland restoration projects may position an enterprise as a leader in environmental protection, significantly enhancing its market reputation and competitiveness. Additionally, reputational gains for enterprises often translate directly into economic benefits, such as attracting more investment or customers, making the motivation and effects more pronounced (Wu et al., 2023). In summary, due to

the complexity and comprehensiveness of government reputation, as well as the direct link between corporate reputation and specific projects, the extent to which identifying and managing potential chain risks enhances government reputation is generally less than its impact on corporate reputation. Based on the above analysis, this paper assumes that the ratio r_1 of increased government's reputation due to increased transparency in governance processes is 0.3; the ratio r_2 of increased enterprises' reputation due to increased transparency in governance processes is 0.4.

An ecological and polycentric governance lens further supports this differential. Enhanced transparency directly publicizes corporate actions that contribute to ecosystem services, such as improving water quality or creating habitat (Costanza et al., 1997). This creates a tangible link between corporate conduct and quantifiable ecological outcomes, which are increasingly valued by markets and civil society. The reputational benefit for enterprises $r_2 = 0.4$ thus mirrors the direct "credit" they receive for supporting wetland resilience. For the government, while transparency is crucial for legitimacy, its reputational gain $r_1 = 0.3$ is derived differently. It accrues not merely from disclosing information but from being perceived as an effective facilitator of multi-stakeholder cooperation—a core tenet of ecological governance. The government's reputation increases by demonstrating that its regulatory framework successfully elicits and showcases responsible corporate behavior, thereby proving the efficacy of the entire governance system. The lower ratio signifies that the government's reputation is more dependent on the ultimate outcome of the process (a resilient wetland) than on the transparency of the process itself.

The discount rate ρ that occurs over time is 0.9; decay δ of reputation is 0.1; the benefits b_{D1} obtained by the government from establishing effective supervision and regulatory mechanisms is 0.2. the positive effects l of reputation is 1; all of them are in the unit state, which is x is 1. The reputation f_1, f_2 gained by the government or enterprises from improving the resilience of wetlands is 1.4.

4.2 Sensitivity analysis of benefits

When the benefits b_{D1} obtained by the government from establishing effective supervision and regulatory mechanisms is 0.2, this article can calculate the social benefits of government (Equations 31–33):

$$V_{D1}^* = 1 + 0.28(b_1 + 1.6)^2 \tag{31}$$

$$V_{B1}^* = 1 + 1.11(b_1 + 2.23)^2 \tag{32}$$

$$V_{F1}^* = 1 + 1.11(b_1 + 1.82)^2 \tag{33}$$

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

When the benefits b_{D1} obtained by the government from establishing effective supervision and regulatory mechanisms is 6, this article can calculate the social benefits of government (Equations 34–36):

$$V_{D1}^* = 1 + 0.28(b_1 + 7.4)^2 \tag{34}$$

$$V_{B1}^* = 1 + 1.11(b_1 + 2.23)^2 \tag{35}$$

$$V_{F1}^* = 1 + 1.11(b_1 + 1.82)^2 \tag{36}$$

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

4.2.1 Conclusion 4

When the benefits derived from establishing effective supervision and regulatory mechanisms are substantial, and the gains from enhancing wetland resilience are relatively minor, the government's wetland governance is more consistent with the dog mastiff effect; otherwise, the government's wetland governance is more consistent with the domino effect.

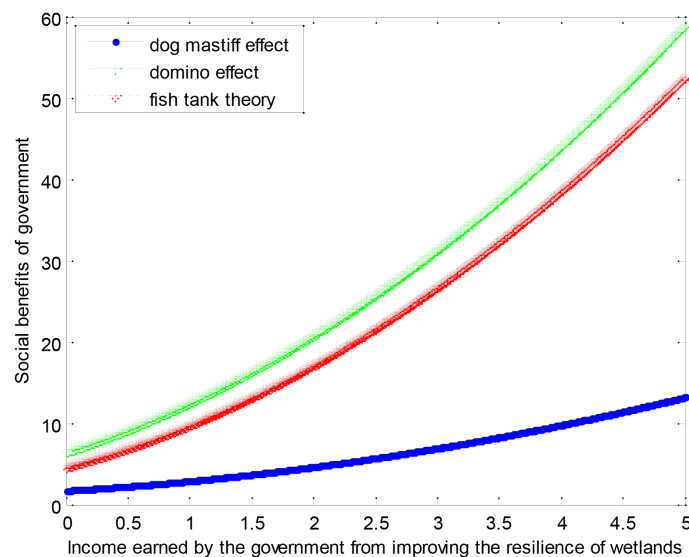


FIGURE 2 Impact of income of government on social welfare.

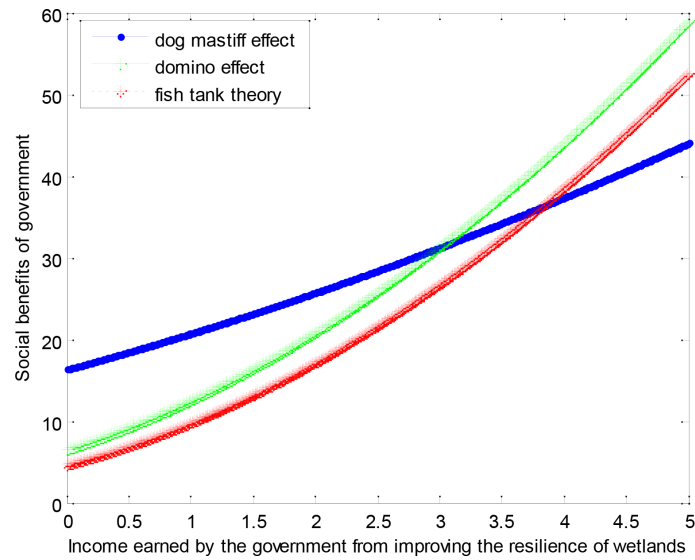


FIGURE 3
Impact of income of government on social welfare.

The critical distinction lies in the primary governance objective and the nature of the risks addressed. The dog mastiff effect is most applicable in scenarios requiring rapid risk containment and behavioral compliance, particularly when facing acute threats of ecosystem degradation or corporate malfeasance. Here, the government prioritizes establishing immediate control and deterrence through a dominant regulatory posture. In contrast, the domino effect strategy is favored when the system is not imminently threatened, and the government aims to catalyze long-term, self-sustaining ecological improvements by strategically incentivizing initial restoration actions that are expected to trigger cascading positive outcomes (Tariq et al., 2025).

When the benefits b_{D2} obtained by the enterprises from establishing effective supervision and regulatory mechanisms is 0.2, this article can calculate the social benefits of enterprises (Equations 37–39):

$$V_{D2}^* = 1 + 0.28(b_2 + 1.6)^2 \tag{37}$$

$$V_{B2}^* = 1 + 1.11(1.65b_2 + 1.4)^2 \tag{38}$$

$$V_{F2}^* = 1 + 1.11(b_2 + 1.96)^2 \tag{39}$$

The following graph (named Figures 4, 5) can also be produced:

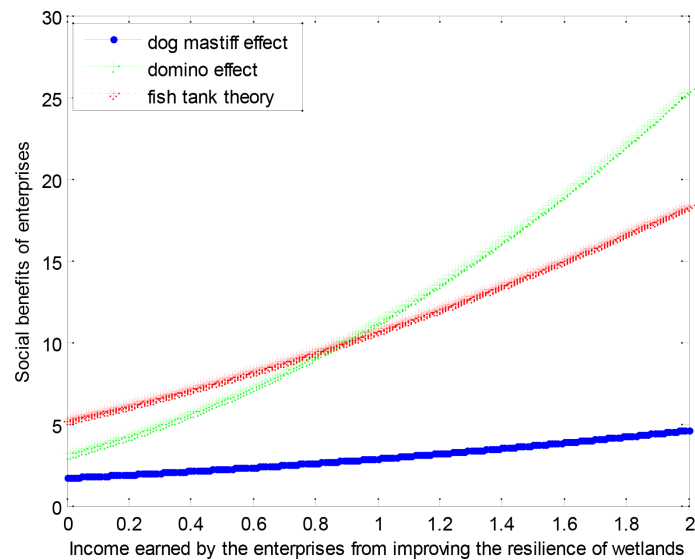
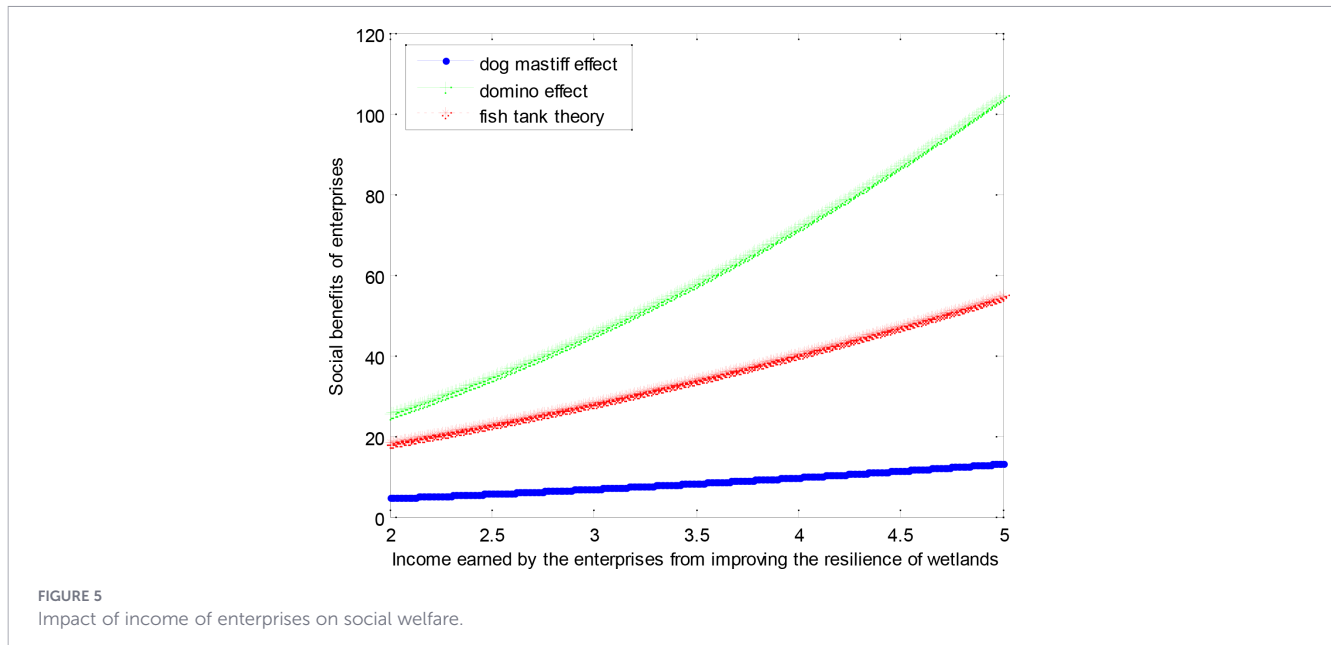


FIGURE 4
Impact of income of enterprises on social welfare.



4.2.2 Conclusion 5

When the benefits derived from establishing effective supervision and regulatory mechanisms are minor, and the gains from enhancing wetland resilience are also minor, the wetland governance of enterprises is more consistent with the fish tank theory; when the benefits derived from establishing effective supervision and regulatory mechanisms are minor, but the gains from enhancing wetland resilience are substantial, the wetland governance of enterprises is more consistent with the domino effect.

These scenarios can be illustrated with practical examples. The fish tank theory is often observed in contexts with weak regulatory enforcement; a company may adopt transparent reporting on its wetland management primarily to mitigate reputational risks and maintain its social license to operate, even in the absence of immediate financial returns. In contrast, the domino effect becomes evident when a company’s investment in wetland restoration—such as creating a premium eco-tourism site—unlocks substantial new revenue streams (Deslippe and Bentley, 2025). The initial success not only improves the ecosystem but also encourages adjacent businesses to follow suit, creating a chain reaction of conservation efforts driven by proven economic viability.

When the benefits b_{D2} obtained by the enterprises from establishing effective supervision and regulatory mechanisms is 6, this article can calculate the social benefits of enterprises (Equations 40–42):

$$V_{D2}^* = 1 + 0.28(b_2 + 7.4)^2 \tag{40}$$

$$V_{B2}^* = 1 + 1.11(1.65b_2 + 1.4)^2 \tag{41}$$

$$V_{F2}^* = 1 + 1.11(b_2 + 1.96)^2 \tag{42}$$

The following graph (named Figure 6) can also be produced:

4.2.3 Conclusion 6

When the benefits derived from establishing effective supervision and regulatory mechanisms are substantial, and the gains from enhancing wetland resilience are minor, the wetland governance of enterprises is more consistent with the dog mastiff effect; when the benefits derived from establishing effective supervision and regulatory mechanisms are substantial, and the gains from enhancing wetland resilience are also substantial, the wetland governance of enterprises is more consistent with the domino effect.

4.3 Sensitivity analysis of reputation

When the degree λ_1 of reputation improvement brought to the government by identifying and managing potential chain risks is 3.5; the degree λ_2 of reputation improvement brought to the enterprises by identifying and managing potential chain risks is 4. This article can calculate the social benefits of government and enterprises (Equations 43–48):

$$V_{D1}^* = 1 + 0.28(b_1 + 1.6)^2 \tag{43}$$

$$V_{B1}^* = 1 + 1.11(b_1 + 2.56)^2 \tag{44}$$

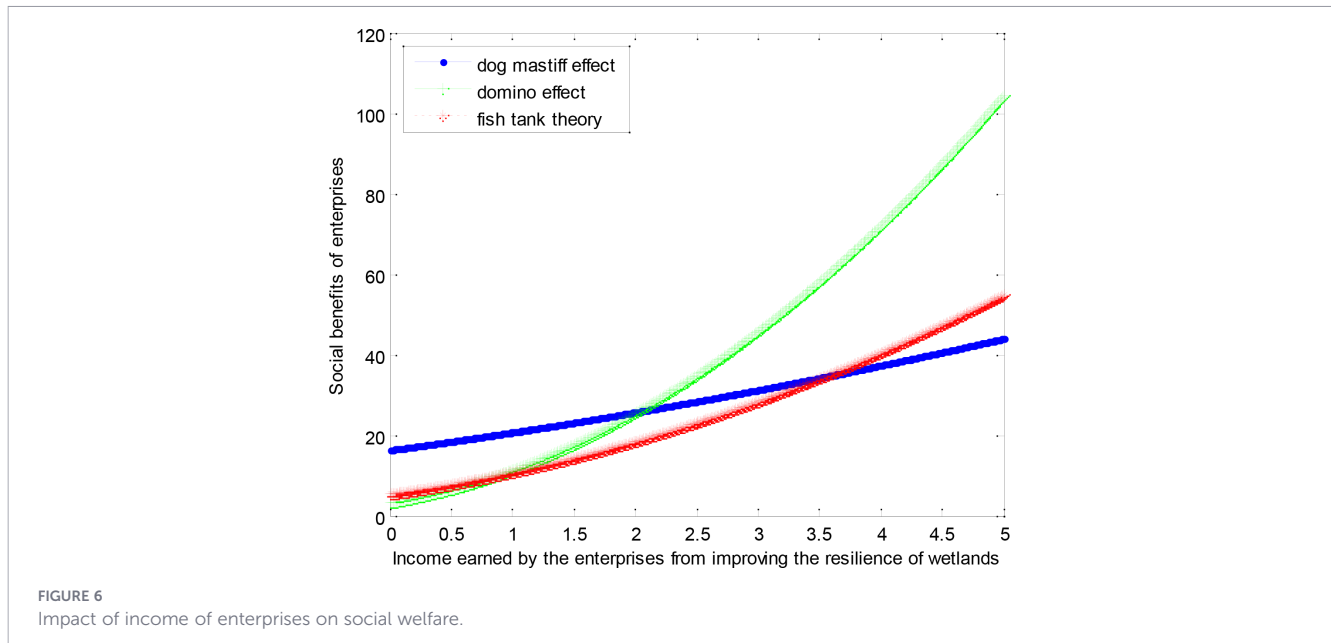
$$V_{F1}^* = 1 + 1.11(b_1 + 1.82)^2 \tag{45}$$

$$V_{D2}^* = 1 + 0.28(b_2 + 1.6)^2 \tag{46}$$

$$V_{B2}^* = 1 + 1.11(1.91b_2 + 1.4)^2 \tag{47}$$

$$V_{F2}^* = 1 + 1.11(b_2 + 1.96)^2 \tag{48}$$

The following graph (named Figures 7, 8) can also be produced:



The conclusions drawn in Figures 7, 8 are similar to those in Conclusions 3 to 6, and will not be elaborated on in detail here.

4.4 Sensitivity analysis of ratio

When the ratio r_1 of increased government’s reputation due to increased transparency in governance processes is 0.5; the ratio r_2 of increased enterprises’ reputation due to increased transparency in governance processes is 0.6. This article can calculate the social benefits of government and enterprises (Equations 49–54):

$$V_{D1}^* = 1 + 0.28(b_1 + 1.6)^2 \tag{49}$$

$$V_{B1}^* = 1 + 1.11(b_1 + 1.55)^2 \tag{50}$$

$$V_{F1}^* = 1 + 1.11(b_1 + 2.1)^2 \tag{51}$$

$$V_{D2}^* = 1 + 0.28(b_2 + 1.6)^2 \tag{52}$$

$$V_{B2}^* = 1 + 1.11(1.14b_2 + 1.4)^2 \tag{53}$$

$$V_{F2}^* = 1 + 1.11(b_2 + 2.24)^2 \tag{54}$$

The following graph (named Figures 9, 10) can also be produced:

The conclusions drawn in Figures 9, 10 are similar to those in Conclusions 3 to 6, and will not be elaborated on in detail here.

4.5 Sensitivity analysis of decay

When the decay δ of reputation is 0.2, this article can calculate the social benefits of government and enterprises (Equations 55–60):

$$V_{D1}^* = 0.91 + 0.28(b_1 + 1.47)^2 \tag{55}$$

$$V_{B1}^* = 0.91 + 0.28(b_1 + 2.03)^2 \tag{56}$$

$$V_{F1}^* = 0.91 + 1.11(b_1 + 1.66)^2 \tag{57}$$

$$V_{D2}^* = 0.91 + 0.28(b_2 + 1.47)^2 \tag{58}$$

$$V_{B2}^* = 0.91 + 1.11(1.65b_2 + 1.27)^2 \tag{59}$$

$$V_{F2}^* = 0.91 + 1.11(b_2 + 1.78)^2 \tag{60}$$

The following graph (named Figures 11, 12) can also be produced:

The conclusions drawn in Figures 11 and 12 are similar to those in Conclusions 3 to 6, and will not be elaborated on in detail here.

5 Extended analysis

5.1 Impact of sudden events

Emergent events, such as extreme weather conditions and sudden pollution accidents, act as stochastic shocks in system dynamics that fundamentally alter the optimal strategic trajectories of stakeholders—including governments, enterprises, and communities—thereby posing a severe test to wetland resilience (Chan et al., 2025). Such events instantaneously modify system state variables (e.g., water quality indices and biodiversity levels), triggering irreversible domino effect that cause previously established progressive risk management measures to fail abruptly.

If government and enterprises encounter sudden events in the process of improving the resilience of wetlands, then their social

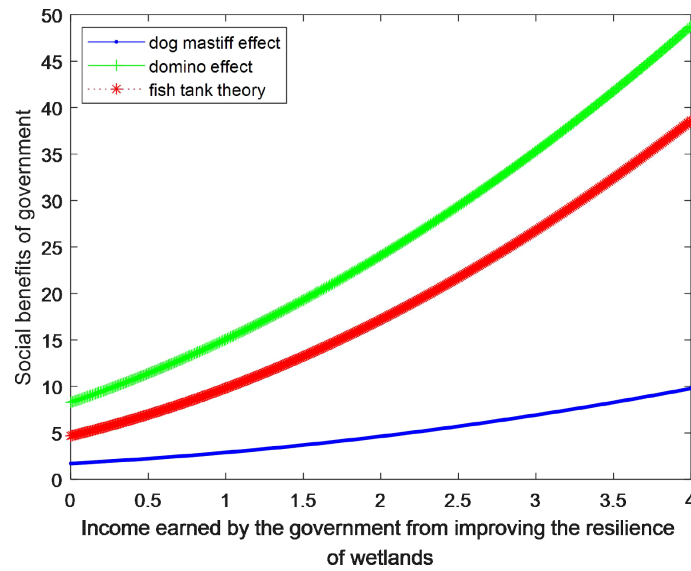


FIGURE 7 Impact of income of government on social welfare.

welfare function can be expressed as Equations 61, 62:

$$J_{S1} = \int_0^\infty \left[b_1 G_{S1}(t) - \frac{c_1(1 + \beta_S)}{2} G_{S1}^2(t) + l x_{S1}(t) \right] e^{-\rho t} dt \quad (61)$$

$$J_{S2} = \int_0^\infty \left[b_2 G_{S2}(t) - \frac{c_2(1 + \beta_S)}{2} G_{S2}^2(t) + l x_{S2}(t) \right] e^{-\rho t} dt \quad (62)$$

In the above formula, $b_1 G_{S1}(t)$ represents the gains the government makes by improving the resilience of wetlands. β_S indicates the proportion of the additional costs caused by the emergency event. $\frac{c_1(1 + \beta_S)}{2} G_{S1}^2(t)$ represents the cost to governments of improving the resilience of wetlands. $l x_{S1}(t)$ represents the positive impact of reputation on the government’s social effectiveness. $b_2 G_{S2}(t)$

represents the benefits gained by companies from improving the resilience of wetlands. $\frac{c_1(1 + \beta_S)}{2} G_{S2}^2(t)$ represents the cost to enterprises of improving the resilience of wetlands. $l x_{S2}(t)$ represents the positive impact of reputation on enterprises’ social performance.

The change in the reputation of government and enterprises when they encounter sudden events can be expressed as

$$\dot{x}_{S1}(t) = f_1 G_{S1}(t) - \delta_1 x_{S1}(t) \quad (63)$$

$$\dot{x}_{S2}(t) = f_2 G_{S2}(t) - \delta_2 x_{S2}(t) \quad (64)$$

In the above formula (Equations 63, 64), $f_1 G_{S1}(t)$ represents the reputation gained by the government from enhancing wetland resilience. $\delta_1 x_{S1}(t)$ represents the decline in the government’s

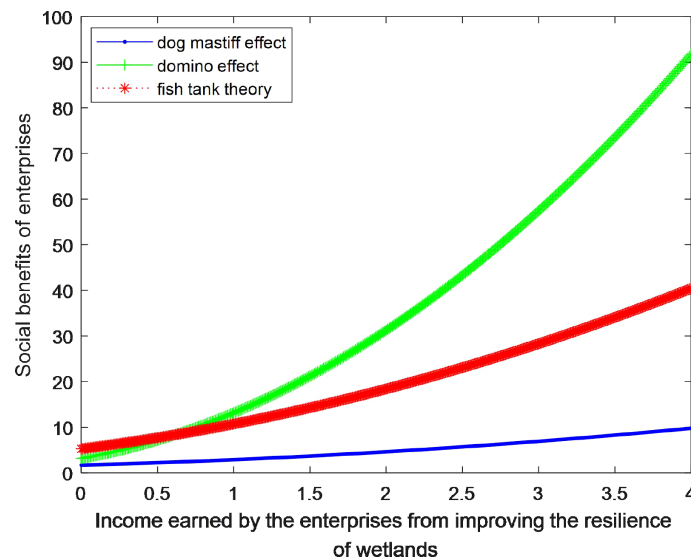


FIGURE 8 Impact of income of enterprises on social welfare.

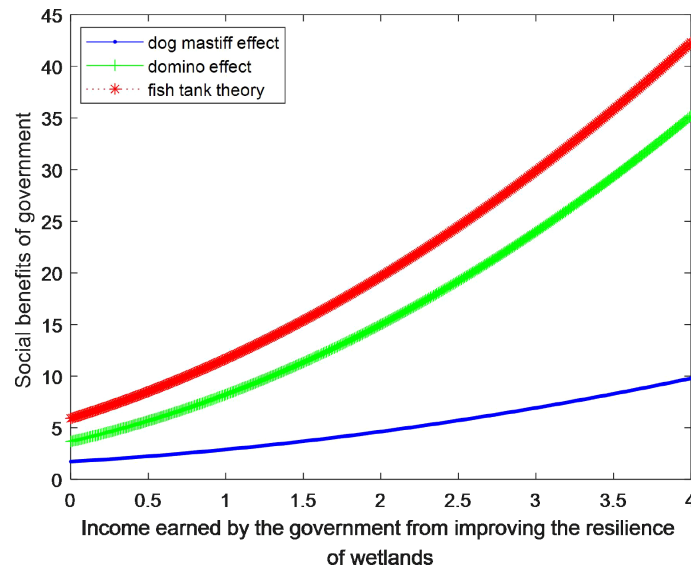


FIGURE 9 Impact of income of government on social welfare.

reputation. $f_2 G_{S2}(t)$ represents the reputation gained by enterprises from enhancing wetland resilience. $\delta_2 x_{S2}(t)$ represents the decline in the enterprises' reputation.

If government and enterprises encounter sudden events, the HJB equation of the social welfare function of the government and enterprises can be shown as Equations 65, 66:

$$\rho V_{S2} = \max_{G_{S2}(t)} \left\{ \begin{aligned} & [b_2 G_{S2}(t) - \frac{c_2(1 + \beta_S)}{2} G_{S2}^2(t) + l x_{S2}(t)] \\ & + \frac{\partial V_{S2}}{\partial x_{S2}} [f_2 G_{S2}(t) - \delta_2 x_{S2}(t)] \end{aligned} \right\} \quad (66)$$

$$\rho V_{S1} = \max_{G_{S1}(t)} \left\{ \begin{aligned} & [b_1 G_{S1}(t) - \frac{c_1(1 + \beta_S)}{2} G_{S1}^2(t) \\ & + l x_{S1}(t)] + \frac{\partial V_{S1}}{\partial x_{S1}} [f_1 G_{S1}(t) - \delta_1 x_{S1}(t)] \end{aligned} \right\} \quad (65)$$

5.1.1 Proposition 4

If government and enterprises encounter sudden events, the efforts to improve the resilience of wetlands, and social benefits of government and enterprises are Equations 67–70 (the specific solving procedure is shown in Appendix 4)

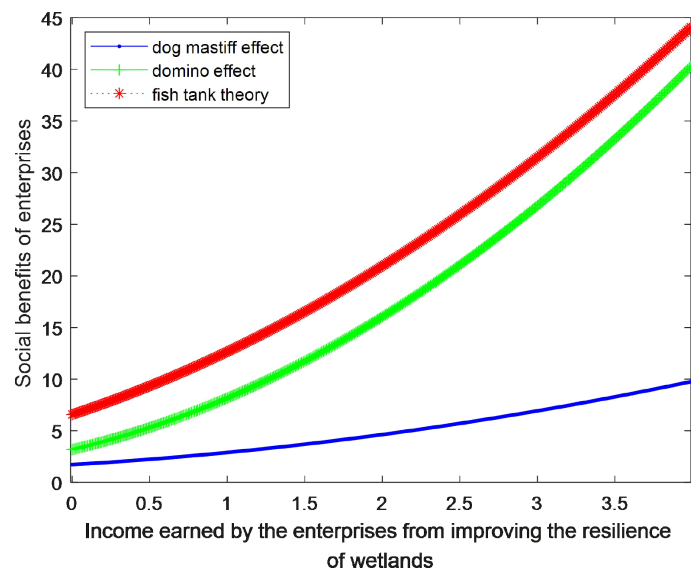


FIGURE 10 Impact of income of enterprises on social welfare.

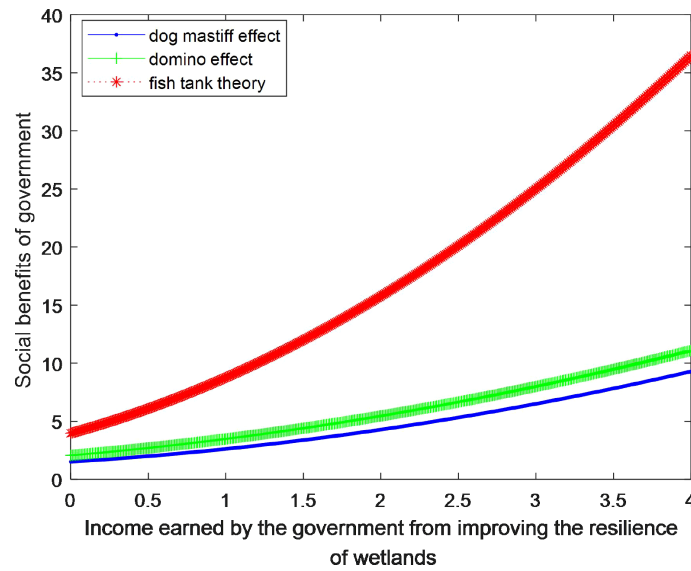


FIGURE 11 Impact of income of government on social welfare.

$$G_{S1}^*(t) = \frac{b_1}{c_1(1+\beta_S)} + \frac{f_1}{c_1(1+\beta_S)} \frac{l}{\rho+\delta} \quad (67)$$

$$G_{S2}^*(t) = \frac{b_2}{c_2(1+\beta_S)} + \frac{f_2}{c_2(1+\beta_S)} \frac{l}{\rho+\delta} \quad (68)$$

$$V_{S2}^* = \frac{l}{\rho+\delta} x_{S2}(t) + \frac{b_2}{\rho} \left[\frac{b_2}{c_2(1+\beta_S)} + \frac{f_2}{c_2(1+\beta_S)} \frac{l}{\rho+\delta} \right] - \left[\frac{b_2}{c_2(1+\beta_S)} + \frac{f_2}{c_2(1+\beta_S)} \frac{l}{\rho+\delta} \right]^2$$

$$\frac{c_2(1+\beta_S)}{2\rho} + \frac{l}{\rho+\delta} \frac{f_2}{\rho} \left[\frac{b_2}{c_2(1+\beta_S)} + \frac{f_2}{c_2(1+\beta_S)} \frac{l}{\rho+\delta} \right] \quad (70)$$

$$V_{S1}^* = \frac{l}{\rho+\delta} x_{S1}(t) + \frac{b_1}{\rho} \left[\frac{b_1}{c_1(1+\beta_S)} + \frac{f_1}{c_1(1+\beta_S)} \frac{l}{\rho+\delta} \right] - \left[\frac{b_1}{c_1(1+\beta_S)} + \frac{f_1}{c_1(1+\beta_S)} \frac{l}{\rho+\delta} \right]^2$$

$$\frac{c_1(1+\beta_S)}{2\rho} + \frac{l}{\rho+\delta} \frac{f_1}{\rho} \left[\frac{b_1}{c_1(1+\beta_S)} + \frac{f_1}{c_1(1+\beta_S)} \frac{l}{\rho+\delta} \right] \quad (69)$$

5.2 Transparency mechanism and information asymmetry

Transparency mechanisms and information asymmetry are fundamentally two sides of the same coin, jointly defining the

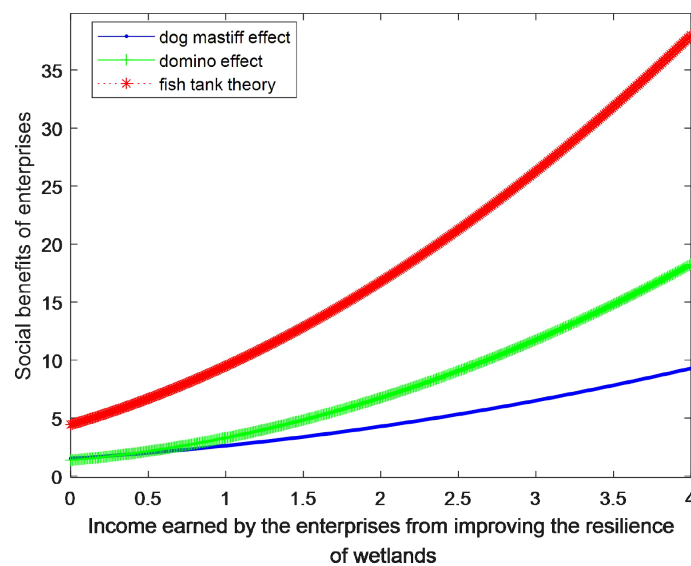


FIGURE 12 Impact of income of enterprises on social welfare.

basic rules of the wetland risk management game. Information asymmetry acts as the premise and root cause of the game; it characterizes a situation where the government cannot fully grasp the true pollution levels, technological costs, or risk aversion of enterprises, while enterprises struggle to accurately discern the government’s regulatory baselines, enforcement intensity, or future ecological compensation policies (Yao et al., 2025). This bidirectional and dynamic information gap serves as the breeding ground for the dog mastiff effect (where individuals over-rely on the efforts of others) and the fish tank theory (where local risks are isolated and overlooked). Conversely, the transparency mechanism is a strategic tool designed to alter this rule of the game, with its core function being the systematic and purposeful reduction of information asymmetry through information injection. Consequently, the dynamics of the entire differential game can be understood as how the government designs transparency strategies (e.g., real-time monitoring, data disclosure platforms) as control variables to transition the system from a high-risk, inefficient equilibrium characterized by information asymmetry to a new equilibrium of high resilience and collaborative governance.

This game-theoretic reshaping of the information state fundamentally alters the decision calculus of both the government and enterprises. For enterprises, a high degree of transparency is equivalent to placing their behavior under a spotlight, significantly increasing the expected penalties for concealed non-compliance (including reputational damage and fines). This compels their decision functions to shift from “short-term profit maximization” to “long-term compliance cost minimization”, thereby actively suppressing the “Mastiff mentality” of over-exploitation and avoiding the domino effect risks triggered by chain reactions. For the government, transparency mechanisms reduce regulatory uncertainty, transforming decision-making (e.g., the allocation of law enforcement resources, the disbursement of ecological compensation) from a “passive response” based on fuzzy inference to an “active proactive control” grounded in precise data. A carefully calibrated transparency mechanism can align government and corporate objectives, integrating isolated, short-sighted decisions into a synergistic strategy that enhances the overall resilience of the wetland.

Under the condition of transparency mechanism and information asymmetry, the social welfare function of government and enterprises can be expressed as Equations 71, 72:

$$J_{T1} = \int_0^\infty \left[b_1(1 + a_T)G_{T1}(t) - \frac{c_1(1 + a_T)}{2}G_{T1}^2(t) + lx_{T1}(t) \right] e^{-\rho t} dt \tag{71}$$

$$J_{T2} = \int_0^\infty \left[b_2G_{T2}(t) - \frac{c_2}{2}G_{T2}^2(t) + lx_{T2}(t) \right] e^{-\rho t} dt \tag{72}$$

In the above formula, a_T indicates the additional costs or benefits to the government resulting from “active pre-control” based on precise data. $b_1(1 + a_T)G_{T1}(t)$ represents the gains the government makes by improving the resilience of wetlands. $\frac{c_1(1+a_T)}{2}$

$G_{T1}^2(t)$ represents the cost to governments of improving the resilience of wetlands. $lx_{T1}(t)$ represents the positive impact of reputation on the government’s social effectiveness. $b_2G_{T2}(t)$ represents the benefits gained by companies from improving the resilience of wetlands. $\frac{c_2}{2}G_{T2}^2(t)$ represents the cost to enterprises of improving the resilience of wetlands. $lx_{T2}(t)$ represents the positive impact of reputation on enterprises’ social performance.

The change in the reputation of government and enterprises under the condition of transparency mechanism and information asymmetry can be expressed as

$$\dot{x}_{T1}(t) = f_1G_{T1}(t) - \delta_1x_{T1}(t) \tag{73}$$

$$\dot{x}_{T2}(t) = (f_2 + f_{T2})G_{T2}(t) - \delta_2x_{T2}(t) \tag{74}$$

In the above formula (Equations 73, 74), $f_1G_{T1}(t)$ represents the reputation gained by the government from enhancing wetland resilience. $\delta_1x_{T1}(t)$ represents the decline in the government’s reputation. $f_2G_{T2}(t)$ represents the reputation gained by enterprises from enhancing wetland resilience. $f_{T2}G_{T2}(t)$ represents the enhanced reputation of the enterprise resulting from the minimization of long-term compliance costs. $\delta_2x_{T2}(t)$ represents the decline in the enterprises’ reputation.

Under the condition of transparency mechanism and information asymmetry, the HJB equation of the social welfare function of the government and enterprises can be shown as Equations 75, 76:

$$\rho V_{T1} = \max_{G_{T1}(t)} \left\{ \begin{aligned} & [b_1(1 + a_T)G_{T1}(t) - \frac{c_1(1 + a_T)}{2}G_{T1}^2(t)] \\ & + lx_{T1}(t) + \frac{\partial V_{T1}}{\partial x_{T1}} [f_1G_{T1}(t) - \delta_1x_{T1}(t)] \end{aligned} \right\} \tag{75}$$

$$\rho V_{T2} = \max_{G_{T2}(t)} \left\{ \begin{aligned} & [b_2G_{T2}(t) - \frac{c_2}{2}G_{T2}^2(t) + lx_{T2}(t)] \\ & + \frac{\partial V_{T2}}{\partial x_{T2}} [(f_2 + f_{T2})G_{T2}(t) - \delta_2x_{T2}(t)] \end{aligned} \right\} \tag{76}$$

5.2.1 Proposition 5

Under the condition of transparency mechanism and information asymmetry, the efforts to improve the resilience of wetlands, and social benefits of government and enterprises are Equations 77–80 (the specific solving procedure is shown in Appendix 5)

$$G_{T1}^*(t) = \frac{b_1(1 + a_T)}{c_1(1 + a_T)} + \frac{f_1}{c_1(1 + a_T)} \frac{l}{\rho + \delta} \tag{77}$$

$$G_{T2}^*(t) = \frac{b_2}{c_2} + \frac{f_2 + f_{T2}}{c_2} \frac{l}{\rho + \delta} \tag{78}$$

$$V_{T1}^* = \frac{l}{\rho+\delta} x_{T1}(t) + \frac{b_1}{\rho} (1 + a_T) \left[\frac{b_1(1+a_T)}{c_1(1+a_T)} + \frac{f_1}{c_1(1+a_T)} \frac{l}{\rho+\delta} \right] - \left[\frac{b_1(1+a_T)}{c_1(1+a_T)} + \frac{f_1}{c_1(1+a_T)} \frac{l}{\rho+\delta} \right]^2 \quad (79)$$

$$\frac{c_1(1+a_T)}{2\rho} + \frac{l}{\rho+\delta} \frac{f_1}{\rho} \left[\frac{b_1(1+a_T)}{c_1(1+a_T)} + \frac{f_1}{c_1(1+a_T)} \frac{l}{\rho+\delta} \right]$$

$$V_{T2}^* = \frac{l}{\rho+\delta} x_{T2}(t) + \frac{b_2}{\rho} \left(\frac{b_2}{c_2} + \frac{f_2+f_{I2}}{c_2} \frac{l}{\rho+\delta} \right) - \frac{c_2}{2\rho} \left(\frac{b_2}{c_2} + \frac{f_2+f_{I2}}{c_2} \frac{l}{\rho+\delta} \right)^2 + \frac{l}{\rho+\delta} \frac{f_2+f_{I2}}{\rho} \left(\frac{b_2}{c_2} + \frac{f_2+f_{I2}}{c_2} \frac{l}{\rho+\delta} \right) \quad (80)$$

5.3 Irrational decision-making

Irrational decision-making, acting as a critical external disturbance, systematically distorts the optimal strategy paths of governments and enterprises that are predicated on assumptions of perfect rationality. For enterprises, constrained by cognitive biases or myopic behaviors (such as excessive optimism leading to the underestimation of ecological thresholds), their decisions may deviate from the Nash equilibrium derived from cost-benefit calculations. This manifests as intensified free-riding behavior within the dog mastiff effect or the risk of triggering the tipping point of a domino effect for short-term gains. Consequently, even under transparency mechanisms, insufficient information processing capabilities can lead to strategic failures (Lu et al., 2025). For the government, irrationality may manifest as policy volatility, overreaction to emergent events, or the neglect of scientific early warnings due to political pressures (resembling the fish tank theory, wherein only explicit risks are prioritized). Such behavior undermines the credibility of regulatory commitments, disrupts the formation of stable expectations by enterprises, and causes the game equilibrium to drift toward a low-resilience state. Therefore, models must incorporate parameters describing decision-making biases (e.g., non-exponential discounting, risk perception distortion). Through stability analysis, these models can reveal how irrational factors induce system oscillations near the saddle-point path or even lead to instability, thereby underscoring that risk management measures must encompass “soft” interventions designed to guide rational decision-making to genuinely enhance wetland resilience.

Under the condition of irrational decision-making, the social welfare function of government and enterprises can be expressed as Equations 81, 82:

$$J_{I1} = \int_0^\infty \left[(b_1 - b_{I1})G_{I1}(t) - \frac{c_1}{2} G_{I1}^2(t) + lx_{I1}(t) \right] e^{-\rho t} dt \quad (81)$$

$$J_{I2} = \int_0^\infty \left[b_2G_{I2}(t) - \frac{c_2 - c_{I2}}{2} G_{I2}^2(t) + lx_{I2}(t) \right] e^{-\rho t} dt \quad (82)$$

In the above formula, $b_1G_{I1}(t)$ represents the gains the government makes by improving the resilience of wetlands. $b_{I1}G_{I1}(t)$ represents the reduction in government revenue caused by policy fluctuations. $\frac{c_1}{2}G_{I1}^2(t)$ represents the cost to governments of improving the resilience of wetlands. $lx_{I1}(t)$ represents the positive impact of reputation on the government’s social

effectiveness. $b_2G_{I2}(t)$ represents the benefits gained by companies from improving the resilience of wetlands. $\frac{c_2}{2}G_{I2}^2(t)$ represents the cost to enterprises of improving the resilience of wetlands. $\frac{c_{I2}}{2}G_{I2}^2(t)$ represents the level of reduced costs for enterprises resulting from the occurrence of free-riding behavior. $lx_{I2}(t)$ represents the positive impact of reputation on enterprises’ social performance.

The change in the reputation of government and enterprises under the condition of irrational decision-making can be expressed as

$$\dot{x}_{I1}(t) = f_1G_{I1}(t) - \delta_1x_{I1}(t) \quad (83)$$

$$\dot{x}_{I2}(t) = (f_2 - f_{I2})G_{I2}(t) - \delta_2x_{I2}(t) \quad (84)$$

In the above formula (Equations 83, 84), $f_1G_{I1}(t)$ represents the reputation gained by the government from enhancing wetland resilience. $\delta_1x_{I1}(t)$ represents the decline in the government’s reputation. $f_2G_{I2}(t)$ represents the reputation gained by enterprises from enhancing wetland resilience. $f_{I2}G_{I2}(t)$ represents the level of reduced corporate reputation resulting from the free-rider behavior. $\delta_2x_{I2}(t)$ represents the decline in the enterprises’ reputation.

Under the condition of irrational decision-making, the HJB equation of the social welfare function of the government and enterprises can be shown as Equations 85, 86:

$$\rho V_{I1} = \max_{G_{I1}(t)} \left\{ \begin{aligned} &[(b_1 - b_{I1})G_{I1}(t) - \frac{c_1}{2} G_{I1}^2(t) + lx_{I1}(t)] \\ &+ \frac{\partial V_{I1}}{\partial x_{I1}} [f_1G_{I1}(t) - \delta_1x_{I1}(t)] \end{aligned} \right\} \quad (85)$$

$$\rho V_{I2} = \max_{G_{I2}(t)} \left\{ \begin{aligned} &[b_2G_{I2}(t) - \frac{c_2 - c_{I2}}{2} G_{I2}^2(t) + lx_{I2}(t)] \\ &+ \frac{\partial V_{I2}}{\partial x_{I2}} [(f_2 - f_{I2})G_{I2}(t) - \delta_2x_{I2}(t)] \end{aligned} \right\} \quad (86)$$

5.3.1 Proposition 6

Under the condition of irrational decision-making, the efforts to improve the resilience of wetlands, and social benefits of government and enterprises are Equations 87–90 (the specific solving procedure is shown in Appendix 6)

$$G_{I1}^*(t) = \frac{b_1 - b_{I1}}{c_1} + \frac{f_1}{c_1} \frac{l}{\rho + \delta} \quad (87)$$

$$G_{I2}^*(t) = \frac{b_2}{c_2 - c_{I2}} + \frac{f_2 - f_{I2}}{c_2 - c_{I2}} \frac{l}{\rho + \delta} \quad (88)$$

$$V_{I1}^* = \frac{l}{\rho+\delta} x_{I1}(t) + \frac{b_1 - b_{I1}}{\rho} \left(\frac{b_1 - b_{I1}}{c_1} + \frac{f_1}{c_1} \frac{l}{\rho+\delta} \right) - \frac{c_1}{2\rho} \left(\frac{b_1 - b_{I1}}{c_1} + \frac{f_1}{c_1} \frac{l}{\rho+\delta} \right)^2 + \frac{l}{\rho+\delta} \frac{f_1}{\rho} \left(\frac{b_1 - b_{I1}}{c_1} + \frac{f_1}{c_1} \frac{l}{\rho+\delta} \right) \quad (89)$$

$$\begin{aligned}
 V_{I2}^* &= \frac{l}{\rho+\delta} x_{I2}(t) + \frac{b_2}{\rho} \left(\frac{b_2}{c_2-c_{I2}} + \frac{f_2-f_{I2}}{c_2-c_{I2}} \frac{l}{\rho+\delta} \right) - \frac{c_2-c_{I2}}{2\rho} \left(\frac{b_2}{c_2-c_{I2}} + \frac{f_2-f_{I2}}{c_2-c_{I2}} \frac{l}{\rho+\delta} \right)^2 \\
 &\quad + \frac{l}{\rho+\delta} \frac{f_2-f_{I2}}{\rho} \left(\frac{b_2}{c_2-c_{I2}} + \frac{f_2-f_{I2}}{c_2-c_{I2}} \frac{l}{\rho+\delta} \right) \tag{90}
 \end{aligned}$$

$$\rho V_{P3} = \max_{G_{P3}(t)} \left\{ \begin{aligned} &\left[\frac{b_3}{1+v_3} G_{P3}(t) - \frac{c_3}{2} G_{P3}^2(t) + l x_{P3}(t) \right] \\ &+ \frac{\partial V_{P3}}{\partial x_{P3}} [f_3 G_{P3}(t) - \delta_3 x_{P3}(t)] \end{aligned} \right\} \tag{93}$$

5.4 Participation of other stakeholders

In differential game frameworks where the community is modeled as an active governance agent, the core challenge lies in the strategic fragility resulting from the mismatch between decision-making authority and resources. Although communities possess local knowledge and an informational advantage in monitoring enterprises, their governance efforts—such as daily patrols and ecological restoration—often fall prey to the dog mastiff effect due to deficiencies in financial and technical resources (Leo et al., 2025). The efficacy of their inputs is highly contingent upon the stringency of government regulation and corporate compliance; should the strategies of these two stakeholders be passive, the community’s isolated struggle proves insufficient to halt the domino effect of ecological degradation. Simultaneously, communities confront the dilemma encapsulated by the fish tank theory: while their local perspective enables the acute detection of subtle risk indicators, limited access to higher-level policy coordination and informational resources may cause their risk warnings to be overlooked or met with delayed responses, thereby squandering the critical window for risk control. In the context of the game model, this implies that the efficiency of the community’s control variable (governance investment) is strongly dependent on the state variables of other players. Consequently, the community must strategically allocate its limited governance efforts under conditions of incomplete information and resource constraints to leverage collaborative action from the government and enterprises, ultimately enhancing overall wetland resilience.

In the process of improving the resilience of wetlands, the social welfare function of communities can be expressed as Equation 91:

$$J_{P3} = \int_0^\infty \left[\frac{b_3}{1+v_3} G_{P3}(t) - \frac{c_3}{2} G_{P3}^2(t) + l x_{P3}(t) \right] e^{-\rho t} dt \tag{91}$$

In the above formula, v_3 represents the extent of the shortage of financial and technical resources. $\frac{b_3}{1+v_3} G_{P3}(t)$ represents the benefits gained by communities from improving the resilience of wetlands. $\frac{c_3}{2} G_{P3}^2(t)$ represents the cost to communities of improving the resilience of wetlands. $l x_{P3}(t)$ represents the positive impact of reputation on communities’ social performance.

The change in the reputation of communities can be expressed as

$$\dot{x}_{P3}(t) = f_3 G_{P3}(t) - \delta_3 x_{P3}(t) \tag{92}$$

In the above formula (Equation 92), $f_3 G_{P3}(t)$ represents the reputation gained by the communities from enhancing wetland resilience. $\delta_3 x_{P3}(t)$ represents the decline in the communities’ reputation.

The HJB equation of the social welfare function of the communities can be shown as Equation 93:

5.4.1 Proposition 7

The efforts to improve the resilience of wetlands, and social benefits of communities are Equations 94, 95 (the specific solving procedure is shown in Appendix 7)

$$G_{P3}^*(t) = \frac{b_1}{(1+v_3)c_3} + \frac{f_3}{c_3} \frac{l}{\rho+\delta} \tag{94}$$

$$\begin{aligned}
 V_{P3}^* &= \frac{l}{\rho+\delta} x_{P3}(t) + \frac{b_3}{\rho(1+v_3)} \left[\frac{b_1}{(1+v_3)c_3} + \frac{f_3}{c_3} \frac{l}{\rho+\delta} \right] - \frac{c_3}{2\rho} \left[\frac{b_1}{(1+v_3)c_3} + \frac{f_3}{c_3} \frac{l}{\rho+\delta} \right]^2 \\
 &\quad + \frac{l}{\rho+\delta} \frac{f_3}{\rho} \left[\frac{b_1}{(1+v_3)c_3} + \frac{f_3}{c_3} \frac{l}{\rho+\delta} \right] \tag{95}
 \end{aligned}$$

6 Discussion

Under the conditions of the dog mastiff effect, the process of increasing risk management measures to enhance wetland resilience can be understood as an issue of incentive mechanisms in social collaboration. The dog mastiff effect (also known as agency cost theory or the principal-agent problem) refers to a situation where, in the relationship between a principal (such as the government) and an agent (such as a company), when their goals are not entirely aligned, reasonable supervision and regulatory mechanisms can effectively reduce the agent’s opportunistic behavior and increase their contribution to the principal’s goals.

Specifically, for the enhancement of wetland resilience, the relationship between the government and corporations constitutes a classic case of a principal-agent problem, effectively modeled as a regulatory game. This perfectly aligns with the core dynamic of the dog mastiff effect. In this framework, the public (as the ultimate principal) delegates the authority to protect wetland resources to the government. The government, acting as a supervising agent for the public and a principal to the corporations, aims to enforce high standards of wetland protection. Corporations, as agents driven by economic interests, may initially prioritize cost-saving over environmental compliance (Yi and Liu, 2025), creating the goal misalignment central to the theory. The government’s establishment of a robust supervisory framework—comprising clear restoration standards, financial incentives for compliance, and substantial penalties for violations—serves as the essential mechanism to mitigate this agency problem. By sharply increasing the costs of non-compliance, this framework makes proactive conservation the more economically rational choice for corporate agents. Thus, the dog mastiff effect is realized through a

regulatory strategy that directly addresses the inherent incentives within the principal-agent relationship, compelling corporations to align their actions with public environmental goals.

In this scenario, the efforts made by the government and enterprises to improve wetland resilience will be greater, for the following reasons. First, for the government, effective regulation and standardization not only promote better environmental responsibility among enterprises but also help to disseminate successful wetland restoration cases on a larger scale, thereby raising public environmental awareness and attracting more social resources to wetland restoration, forming a virtuous cycle. Second, for enterprises, when they realize that adhering to wetland restoration standards can bring tangible benefits, such as enjoying various incentives provided by the government, enhancing brand image and market competitiveness, and avoiding potential legal risks, they will naturally be more proactive in increasing their investment in wetland restoration. In summary, under the framework of the dog mastiff effect, effective supervision and regulatory mechanisms serve as a bridge connecting the government's environmental goals and corporate economic benefits, effectively incentivizing both parties to work together and improve the capacity and efficiency of wetland restoration (Kim and Kwon, 2023).

Under the conditions of the domino effect, the process of improving wetland resilience by identifying and managing potential chain risks actually emphasizes the interconnectivity and cumulative effects of various risks within the ecosystem (Greiner et al., 2022). In wetland restoration projects, once a problem arises in a particular area, it may trigger a series of negative consequences, affecting the success of the entire restoration project. Therefore, effectively managing these potential chain risks is essential for improving wetland resilience.

According to Conclusion 2, if governments and businesses can identify and properly manage these potential chain risks, their reputations in wetland restoration will be significantly enhanced. This is due to the following reasons:

First, preventive risk management. By identifying and managing potential risks early, serious accidents such as pollutant leaks and ecological imbalances can be avoided (Greiner et al., 2022). This not only helps ensure the smooth progress of the project but also reduces the occurrence of public safety and ecological crises, thereby avoiding negative social impacts and public pressure.

Second, transparency and trust. Governments and businesses adopting transparent and open approaches in the risk management process can demonstrate their professional capabilities and sense of responsibility to society. When the public sees that governments and businesses are actively addressing and managing risks, they are more likely to support their work and even participate in it.

Third, long-term benefits. Effective management of potential risks helps ensure the long-term success and sustainable development of the project. Good performance in wetland restoration projects by governments and businesses can not only enhance the reputation of the current project but also set a positive example for future environmental projects, attracting more resources and collaboration opportunities (Liu et al., 2024b).

Fourth, social recognition. By successfully managing and preventing risks, governments and businesses can gain higher social recognition. This recognition extends beyond the governmental level to include international organizations, environmental groups, and the general public. High social recognition will further motivate governments and businesses to increase their investment and efforts in wetland restoration.

In summary, under the conditions of a domino effect, identifying and managing potential chain risks can significantly improve the reputations of governments and businesses in this area. The enhancement of this reputation will translate into more social support and resource investment, thereby encouraging governments and businesses to participate more actively in and promote wetland restoration projects, improving the overall capacity and effectiveness of wetland restoration.

Under the conditions of the fish tank theory, increasing the transparency of the governance process can significantly enhance the reputation of wetland restoration projects, thereby boosting the efforts of governments and businesses in this area. The fish tank theory emphasizes that in a highly transparent environment, the behaviors of participants are more easily monitored and evaluated by outsiders, which in turn encourages them to act more normatively and efficiently. The following is a detailed explanation of Conclusion 3.

First, a highly transparent governance process will increase public trust in the sincerity and capabilities of governments and businesses. When the public knows that governments and businesses are taking wetland restoration projects seriously and can see concrete actions and results, they are more willing to support and participate in these projects. A transparent governance process is more easily subject to media and public scrutiny, and any misconduct or negligence will be promptly exposed, creating strong public pressure. This pressure compels governments and businesses to be more cautious in implementing the project, avoiding negative social impacts. Transparency can strengthen the sense of social responsibility in governments and businesses, encouraging them to pay more attention to environmental protection and sustainable development in their decision-making and implementation processes. This sense of responsibility not only manifests in the project itself but also influences their performance in other areas.

Second, there is a positive correlation between reputation enhancement and increased effort. When governments and businesses demonstrate high transparency in wetland restoration projects, their reputation is significantly enhanced. This not only attracts more external support, such as funds, technology, and volunteer resources, but also improves their international image and influence. Critically, this reputational capital is tested and solidified during external shocks, such as extreme climate events or regional economic downturns. A proven track record of transparency allows governments and businesses to maintain stakeholder trust and secure continued support even under duress, transforming the reputation cycle into a more resilient feedback loop. Increased transparency makes internal management more efficient and standardized. Employees and

management are more actively involved in wetland restoration projects because they know their efforts will be seen and recognized by the public and superiors. High transparency can be part of the incentive mechanism; governments and businesses can further motivate participants through transparent performance evaluations and reward systems (Greiner et al., 2022). For example, outstanding departments or companies can be commended and rewarded, while underperforming ones can be encouraged to improve.

In some successful wetland restoration projects, the positive effects of high transparency are evident. For instance, some local governments have established dedicated websites and social media platforms to regularly publish the progress and outcomes of wetland restoration projects, attracting significant public attention and participation. Companies have also enhanced their brand image and market competitiveness by publicly disclosing their environmental protection measures and achievements. Under the fish tank theory, increasing the transparency of the governance process can significantly boost the reputation of governments and businesses, thus motivating greater effort and investment in wetland restoration projects (Houde et al., 2024). This transparency not only helps build public trust but also establishes effective external oversight and internal incentive mechanisms, ensuring the efficiency and success of the projects. Therefore, governments and businesses should actively adopt measures to enhance the transparency of wetland restoration governance to achieve better ecological and social benefits.

According to Conclusion 4, in the process of studying how risk management measures can improve the capacity for wetland restoration, when the benefits of establishing effective supervision and regulatory mechanisms are significant, and the gains from enhancing wetland resilience are relatively small, the government's wetland governance is more inclined to align with the dog mastiff effect. For example, the government can establish strict environmental regulations and standards, set up dedicated wetland protection zones, and increase the intensity of supervision over enterprises and individuals around the wetlands (Chen et al., 2025). The primary advantage of this strategy lies in its favorable cost-benefit ratio: by establishing clear, enforceable rules and focusing monitoring resources on compliance, the government can deter destructive behaviors at a relatively low administrative cost compared to funding large-scale, direct restoration projects. This strict supervision and regulatory mechanism not only effectively curbs illegal landfilling, pollutant emissions, and other destructive behaviors but also compels enterprises to make necessary environmental investments through legal means. Although these measures may not significantly enhance the ecological restoration capacity of wetlands in the short term, by preventing new destructive activities, they can maintain the relative stability and health of wetland ecosystems over the long term, creating favorable conditions for natural recovery (Han et al., 2023).

Conversely, when the benefits of establishing effective supervision and regulatory mechanisms are significant, and the gains from enhancing wetland resilience are also substantial,

the government's wetland governance more closely aligns with the domino effect. In this scenario, the government not only enacts strict environmental regulations but also implements a series of proactive ecological restoration measures to gradually improve the wetland environment. For instance, the government can promote the recovery of wetland vegetation, regulate hydrological systems, and protect biodiversity. While these measures may have limited impact individually, when implemented systematically, they form a virtuous cycle, gradually enhancing the overall ecological function of the wetland. Additionally, the government's proactive actions can encourage participation from businesses and the public, fostering the development of more environmental protection and restoration projects, thereby achieving rapid and comprehensive restoration of wetland ecosystems (Adam et al., 2024).

In summary, the strategy choices of the government in wetland governance depend on the benefits of supervision and regulatory mechanisms and the potential gains from wetland resilience. When the benefits of supervision and regulatory mechanisms are significant, but the direct benefits of wetland restoration are relatively small, the government tends to rely more on strict legal and regulatory measures to protect wetlands by preventing destruction, which aligns with the logic of the dog mastiff effect. Conversely, when both the benefits of supervision and regulatory mechanisms and the direct benefits of wetland restoration are significant, the government will adopt more proactive ecological restoration measures, creating a positive chain reaction that ultimately leads to effective wetland recovery, which aligns more closely with the principles of the domino effect (Jiang et al., 2024). This comprehensive governance approach can more flexibly address the challenges of different wetland restoration scenarios, maximize the utilization of limited resources and measures, and achieve the long-term goals of wetland governance (Greenberg, 2023).

According to Conclusion 5, when the benefits of establishing effective supervision and regulatory mechanisms are small, and the gains from enhancing wetland resilience are also limited, the wetland governance practices of businesses align more closely with the fish tank theory. In this situation, businesses may lack the external driving force of mandatory regulation. However, by establishing and improving environmental awareness and norms within the company, they can gradually form positive environmental behaviors in a relatively closed and autonomous environment. For example, businesses can guide employees to focus on and participate in wetland protection activities through internal training, the formulation of environmental regulations, and employee incentive measures. Although these measures may have limited direct economic benefits and social recognition, they can promote a consensus and culture of environmental protection within the company, gradually improving the overall environmental performance and laying the foundation for the long-term recovery of wetlands (Lin et al., 2022).

When the benefits of establishing effective supervision and regulatory mechanisms are small, but the gains from enhancing

wetland resilience are significant, the wetland governance practices of businesses align more closely with the domino effect. In this context, although businesses are not under external regulatory pressure, they can significantly improve the ecological functions and environmental quality of wetlands by voluntarily implementing restoration measures, thereby bringing multiple benefits to the company. For instance, businesses can enhance the ecosystem services of wetlands, such as water purification, flood control, and carbon sequestration, by restoring wetland vegetation, improving hydrological conditions, and protecting biodiversity (Beheshti et al., 2023). Improvements in these ecosystem services not only help enhance the company's brand image and social responsibility but also attract more green investors and supporters. Therefore, businesses are inclined to adopt a series of coherent wetland restoration actions. While each step may have limited impact individually, the long-term accumulation can form a strong recovery momentum, leading to significant improvements in the wetland ecosystem.

In summary, the strategy choices of businesses in wetland governance are influenced by the benefits of external regulatory mechanisms and the potential gains from wetland restoration. When the benefits of external supervision and regulatory mechanisms are small, and the direct gains from wetland restoration are also limited, businesses rely more on internal environmental awareness and behavioral norms, gradually accumulating positive environmental practices and culture, which aligns with the logic of the fish tank theory. Conversely, when the benefits of external regulatory mechanisms are small, but the direct gains from wetland restoration are significant, businesses will adopt a series of proactive ecological restoration measures. These measures gradually form a positive chain reaction, ultimately leading to effective wetland recovery, which aligns more closely with the principles of the domino effect (Greiner et al., 2022). This comprehensive governance approach can help businesses better address different wetland restoration challenges and achieve a win-win situation between ecology and the economy.

According to Conclusion 6, when the benefits of establishing effective supervision and regulatory mechanisms are significant, but the gains from enhancing wetland resilience are relatively small, the wetland governance practices of businesses align more closely with the dog mastiff effect. In this situation, the strict legal and regulatory requirements imposed by the government and regulatory agencies compel businesses to invest resources and efforts in compliance to avoid legal penalties and reputational damage (Bell-James, 2023). This compliance, however, entails substantial costs for enterprises, including direct investments in monitoring equipment, reporting systems, and dedicated personnel to meet regulatory standards (Jiang et al., 2024). Although these measures may not significantly improve the ecological recovery of wetlands in the short term, they help prevent further damage through stringent external supervision and internal norms. Thus, the enterprise's strategy under the dog mastiff effect represents a cost-benefit calculation where the costs of compliance are weighed against the risks of non-compliance. This preventive strategy creates favorable external conditions for the

natural recovery of wetlands, ensuring the relative stability and health of the wetland ecosystem.

Conversely, when the benefits of establishing effective supervision and regulatory mechanisms are significant, and the gains from enhancing wetland resilience are also substantial, the wetland governance practices of businesses align more closely with the domino effect. In this context, stringent external regulation not only compels businesses to adhere to environmental laws but also motivates them to take more proactive wetland restoration measures. Businesses realize that by improving the ecological functions and environmental quality of wetlands, they can achieve multiple positive impacts, such as enhancing their brand value, increasing social recognition, and attracting environmentally conscious consumers and investors. For example, businesses can gradually improve the overall ecological function of wetlands through specific measures like restoring vegetation, enhancing hydrological conditions, and increasing biodiversity (Liu et al., 2024b). These measures not only provide direct economic benefits to the business but also create a positive demonstration effect, encouraging participation from neighboring businesses and communities in the restoration efforts.

In summary, the strategy choices of businesses in wetland governance are influenced by the benefits of external regulatory mechanisms and the potential gains from wetland restoration. When the benefits of external regulatory mechanisms are significant, but the direct gains from wetland restoration are relatively small, businesses are more likely to focus on strict compliance with regulations and norms to prevent damage, thereby maintaining the health of the wetland ecosystem while avoiding legal and reputational risks, which aligns with the logic of the dog mastiff effect (Bell-James, 2023). On the other hand, when both the benefits of external regulatory mechanisms and the direct gains from wetland restoration are significant, businesses will not only comply with environmental laws but also take a series of proactive ecological restoration measures. These measures gradually form a positive chain reaction, ultimately leading to substantial improvements in the wetland ecosystem, which aligns more closely with the principles of the domino effect. This flexible governance approach can maximize the effectiveness of wetland restoration in different situations, ensuring the coordinated development of ecology and the economy.

7 Conclusion

In wetland restoration, the dog mastiff effect emphasizes the protection of wetland ecology through robust management measures and strict enforcement to prevent human-induced damage. The domino effect highlights the interconnectedness of wetland ecosystem components, indicating that issues in one area may trigger chain reactions, necessitating comprehensive risk management by considering all factors. The fish tank theory underscores transparent management and public participation, enhancing societal awareness and support for wetland conservation

through open information platforms and participatory mechanisms. The application of these risk management approaches provides critical guidance for improving wetland resilience, not only effectively restoring and protecting wetland ecosystems but also promoting biodiversity, improving water quality, regulating climate, and delivering multiple environmental benefits, thereby establishing a solid ecological foundation for achieving regional and global sustainable development goals.

Research indicates that when the benefits of establishing effective supervision and regulatory mechanisms are substantial, and the benefits of enhancing wetland resilience are relatively limited, the management of wetlands by the government and enterprises aligns more closely with the dog mastiff effect. Conversely, when the benefits of enhancing wetland resilience are significant, government wetland governance aligns more closely with the domino effect. When the benefits of establishing effective supervision and regulatory mechanisms are limited, and the benefits of enhancing wetland resilience are also limited, corporate wetland governance aligns more closely with the fish tank theory. When the benefits of enhancing wetland resilience are substantial, corporate wetland governance aligns more closely with the domino effect.

In the process of government wetland governance, the choice between the dog mastiff effect and the domino effect should be contextualized, particularly considering the level of institutional maturity and resource availability. For jurisdictions with strong governance capacity, well-established legal frameworks, and sufficient fiscal resources—conditions often found in developed regions—if establishing effective supervision yields significant benefits while direct restoration benefits are limited, adopting the dog mastiff effect strategy is highly advisable. This approach leverages existing institutional strength to enforce compliance efficiently. Conversely, in contexts where governance resources are constrained, or where improving wetland resilience promises substantial multiplicative benefits—a scenario common in developing regions prioritizing cost-effective solutions—the domino effect strategy is more appropriate. It focuses on catalyzing a chain reaction of conservation through targeted initial investments, maximizing impact under budget limitations.

For enterprises, if the benefits of establishing effective supervision and regulatory mechanisms are limited and the benefits of improving wetland resilience are also small, it is recommended that enterprises follow the fish tank theory. This approach focuses on enhancing the transparency of governance processes, strengthening social oversight, and increasing public trust and support. If the benefits of improving wetland resilience are substantial, or if the benefits of establishing effective supervision and regulatory mechanisms are significant while the benefits of improving wetland resilience are limited, enterprises should adopt the dog mastiff effect or domino effect strategies. The former emphasizes strict management and efficient execution in the short term to achieve rapid results, while the latter focuses on long-term, systematic efforts to gradually realize the overarching goals of wetland governance.

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

ZS: Conceptualization, Formal analysis, Investigation, Methodology, Project administration, Software, Validation, Writing – original draft, Writing – review & editing. YB: Formal analysis, Methodology, Writing – original draft.

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Appendix 1

Take the derivatives of G_{D1} with respect to (13), and take the derivatives of G_{D2} with respect to (14), and set them equal to zero, we can get [Equations 96, 97](#):

$$G_{D1}^*(t) = \frac{b_1 + b_{D1}}{c_1 + c_{D1}} + \frac{f_1}{c_1 + c_{D1}} \frac{\partial V_{D1}}{\partial x_{D1}} \tag{96}$$

$$G_{D2}^*(t) = \frac{b_2 + b_{D2}}{c_2 + c_{D2}} + \frac{f_2}{c_2 + c_{D2}} \frac{\partial V_{D2}}{\partial x_{D2}} \tag{97}$$

Substituting (96) into (13) and substituting (97) into (14), we can get [Equations 98, 99](#):

$$\begin{aligned} \rho V_{D1} = & (b_1 + b_{D1}) \left(\frac{b_1 + b_{D1}}{c_1 + c_{D1}} + \frac{f_1}{c_1 + c_{D1}} \frac{\partial V_{D1}}{\partial x_{D1}} \right) - \frac{c_1 + c_{D1}}{2} \\ & \left(\frac{b_1 + b_{D1}}{c_1 + c_{D1}} + \frac{f_1}{c_1 + c_{D1}} \frac{\partial V_{D1}}{\partial x_{D1}} \right)^2 + Ix_{D1}(t) \\ & + \frac{\partial V_{D1}}{\partial x_{D1}} \left[f_1 \left(\frac{b_1 + b_{D1}}{c_1 + c_{D1}} + \frac{f_1}{c_1 + c_{D1}} \frac{\partial V_{D1}}{\partial x_{D1}} \right) - \delta_1 x_{D1}(t) \right] \end{aligned} \tag{98}$$

$$\begin{aligned} \rho V_{D2} = & (b_2 + b_{D2}) \left(\frac{b_2 + b_{D2}}{c_2 + c_{D2}} + \frac{f_2}{c_2 + c_{D2}} \frac{\partial V_{D2}}{\partial x_{D2}} \right) - \frac{c_2 + c_{D2}}{2} \\ & \left(\frac{b_2 + b_{D2}}{c_2 + c_{D2}} + \frac{f_2}{c_2 + c_{D2}} \frac{\partial V_{D2}}{\partial x_{D2}} \right)^2 + Ix_{D2}(t) \\ & + \frac{\partial V_{D2}}{\partial x_{D2}} \left[f_2 \left(\frac{b_2 + b_{D2}}{c_2 + c_{D2}} + \frac{f_2}{c_2 + c_{D2}} \frac{\partial V_{D2}}{\partial x_{D2}} \right) - \delta_2 x_{D2}(t) \right] \end{aligned} \tag{99}$$

Let $V_{D1}^* = k_1 x_{D1} + k_2$, $V_{D2}^* = k_3 x_{D2} + k_4$, 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 [Equations 100, 101](#):

$$\left\{ \begin{aligned} k_1 &= \frac{1}{\rho + \delta} \\ k_2 &= \frac{1}{\rho} (b_1 + b_{D1}) \left(\frac{b_1 + b_{D1}}{c_1 + c_{D1}} + \frac{f_1}{c_1 + c_{D1}} \frac{1}{\rho + \delta} \right) - \frac{c_1 + c_{D1}}{2} \frac{1}{\rho} \\ & \quad \left(\frac{b_1 + b_{D1}}{c_1 + c_{D1}} + \frac{f_1}{c_1 + c_{D1}} \frac{1}{\rho + \delta} \right)^2 \\ & \quad + \frac{1}{\rho + \delta} \frac{1}{\rho} f_1 \left(\frac{b_1 + b_{D1}}{c_1 + c_{D1}} + \frac{f_1}{c_1 + c_{D1}} \frac{1}{\rho + \delta} \right) \end{aligned} \right. \tag{100}$$

$$\left\{ \begin{aligned} k_3 &= \frac{1}{\rho + \delta} \\ k_4 &= \frac{1}{\rho} (b_2 + b_{D2}) \left(\frac{b_2 + b_{D2}}{c_2 + c_{D2}} + \frac{f_2}{c_2 + c_{D2}} \frac{1}{\rho + \delta} \right) - \frac{c_2 + c_{D2}}{2} \frac{1}{\rho} \\ & \quad \left(\frac{b_2 + b_{D2}}{c_2 + c_{D2}} + \frac{f_2}{c_2 + c_{D2}} \frac{1}{\rho + \delta} \right)^2 \\ & \quad + \frac{1}{\rho + \delta} \frac{1}{\rho} f_2 \left(\frac{b_2 + b_{D2}}{c_2 + c_{D2}} + \frac{f_2}{c_2 + c_{D2}} \frac{1}{\rho + \delta} \right) \end{aligned} \right. \tag{101}$$

Therefore, the [Equations 19–22](#) can be calculated.

Appendix 2

Take the derivatives of G_{B1} with respect to (15), and take the derivatives of G_{B2} with respect to (16), and set them equal to zero, we can get [Equations 102, 103](#):

$$G_{B1}^*(t) = \frac{b_1}{c_1} + \frac{f_1 \ln(e + \lambda_1)}{c_1} \frac{\partial V_{B1}}{\partial x_{B1}} \tag{102}$$

$$G_{B2}^*(t) = \frac{b_2 \ln(e + \lambda_2)}{c_2} + \frac{f_2}{c_2} \frac{\partial V_{B2}}{\partial x_{B2}} \tag{103}$$

Substituting (102) into (15) and substituting (103) into (16), we can get [Equations 104, 105](#):

$$\begin{aligned} \rho V_{B1} = & b_1 \left[\frac{b_1}{c_1} + \frac{f_1 \ln(e + \lambda_1)}{c_1} \frac{\partial V_{B1}}{\partial x_{B1}} \right] - \frac{c_1}{2} \left[\frac{b_1}{c_1} + \frac{f_1 \ln(e + \lambda_1)}{c_1} \frac{\partial V_{B1}}{\partial x_{B1}} \right]^2 + Ix_{B1}(t) \\ & + \frac{\partial V_{B1}}{\partial x_{B1}} f_1 \ln(e + \lambda_1) \left[\frac{b_1}{c_1} + \frac{f_1 \ln(e + \lambda_1)}{c_1} \frac{\partial V_{B1}}{\partial x_{B1}} \right] \\ & - \frac{\partial V_{B1}}{\partial x_{B1}} \delta_1 x_{B1}(t) \end{aligned} \tag{104}$$

$$\begin{aligned} \rho V_{B2} = & b_2 \ln(e + \lambda_2) \left[\frac{b_2 \ln(e + \lambda_2)}{c_2} + \frac{f_2}{c_2} \frac{\partial V_{B2}}{\partial x_{B2}} \right] - \frac{c_2}{2} \\ & \left[\frac{b_2 \ln(e + \lambda_2)}{c_2} + \frac{f_2}{c_2} \frac{\partial V_{B2}}{\partial x_{B2}} \right]^2 + Ix_{B2}(t) \\ & + \frac{\partial V_{B2}}{\partial x_{B2}} f_2 \left[\frac{b_2 \ln(e + \lambda_2)}{c_2} + \frac{f_2}{c_2} \frac{\partial V_{B2}}{\partial x_{B2}} \right] - \delta_2 \frac{\partial V_{B2}}{\partial x_{B2}} x_{B2}(t) \end{aligned} \tag{105}$$

Let $V_{B1}^* = k_5 x_{B1} + k_6$, $V_{B2}^* = k_7 x_{B2} + k_8$, 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 [Equations 106, 107](#):

$$\left\{ \begin{aligned} k_5 &= \frac{1}{\rho + \delta} \\ k_6 &= \frac{1}{\rho} b_1 \left[\frac{b_1}{c_1} + \frac{f_1 \ln(e + \lambda_1)}{c_1} \frac{1}{\rho + \delta} \right] - \frac{c_1}{2} \frac{1}{\rho} \left[\frac{b_1}{c_1} + \frac{f_1 \ln(e + \lambda_1)}{c_1} \frac{1}{\rho + \delta} \right]^2 \\ & \quad + \frac{1}{\rho} \frac{1}{\rho + \delta} f_1 \ln(e + \lambda_1) \left[\frac{b_1}{c_1} + \frac{f_1 \ln(e + \lambda_1)}{c_1} \frac{1}{\rho + \delta} \right] \end{aligned} \right. \tag{106}$$

$$\left\{ \begin{aligned} k_7 &= \frac{1}{\rho + \delta} \\ k_8 &= \frac{1}{\rho} b_2 \ln(e + \lambda_2) \left[\frac{b_2 \ln(e + \lambda_2)}{c_2} + \frac{f_2}{c_2} \frac{1}{\rho + \delta} \right] - \frac{c_2}{2} \frac{1}{\rho} \left[\frac{b_2 \ln(e + \lambda_2)}{c_2} + \frac{f_2}{c_2} \frac{1}{\rho + \delta} \right]^2 \\ & \quad + \frac{1}{\rho} \frac{1}{\rho + \delta} f_2 \left[\frac{b_2 \ln(e + \lambda_2)}{c_2} + \frac{f_2}{c_2} \frac{1}{\rho + \delta} \right] \end{aligned} \right. \tag{107}$$

Therefore, the [Equations 23–26](#) can be calculated.

Appendix 3

Take the derivatives of G_{F1} with respect to (17), and take the derivatives of G_{F2} with respect to (18), and set them equal to zero, we can get [Equations 108, 109](#):

$$G_{F1}^*(t) = \frac{b_1}{c_1} + \frac{f_1(1 + r_1)}{c_1} \frac{\partial V_{F1}}{\partial x_{F1}} \tag{108}$$

$$G_{F2}^*(t) = \frac{b_2}{c_2} + \frac{f_2(1 + r_2)}{c_2} \frac{\partial V_{F2}}{\partial x_{F2}} \tag{109}$$

Substituting (108) into (17) and substituting (109) into (18), we can get [Equations 110, 111](#):

$$\begin{aligned} \rho V_{F1} = & b_1 \left[\frac{b_1}{c_1} + \frac{f_1(1 + r_1)}{c_1} \frac{\partial V_{F1}}{\partial x_{F1}} \right] - \frac{c_1}{2} \left[\frac{b_1}{c_1} + \frac{f_1(1 + r_1)}{c_1} \frac{\partial V_{F1}}{\partial x_{F1}} \right]^2 + Ix_{F1}(t) \\ & + \frac{\partial V_{F1}}{\partial x_{F1}} f_1(1 + r_1) \left[\frac{b_1}{c_1} + \frac{f_1(1 + r_1)}{c_1} \frac{\partial V_{F1}}{\partial x_{F1}} \right] - \delta_1 \frac{\partial V_{F1}}{\partial x_{F1}} x_{F1}(t) \end{aligned} \tag{110}$$

$$\rho V_{F2} = b_2 \left[\frac{b_2}{c_2} + \frac{f_2(1+r_2)}{c_2} \frac{\partial V_{F2}}{\partial x_{F2}} \right] - \frac{c_2}{2} \left[\frac{b_2}{c_2} + \frac{f_2(1+r_2)}{c_2} \frac{\partial V_{F2}}{\partial x_{F2}} \right]^2 + l x_{F2}(t) + \frac{\partial V_{F2}}{\partial x_{F2}} f_2(1+r_2) \left[\frac{b_2}{c_2} + \frac{f_2(1+r_2)}{c_2} \frac{\partial V_{F2}}{\partial x_{F2}} \right] - \delta_2 \frac{\partial V_{F2}}{\partial x_{F2}} x_{F2}(t) \tag{111}$$

Let $V_{F1}^* = k_9 x_{F1} + k_{10}$, $V_{F2}^* = k_{11} x_{F2} + k_{12}$, 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 Equations 112, 113:

$$\begin{cases} k_9 = \frac{l}{\rho + \delta} \\ k_{10} = \frac{1}{\rho} b_1 \left[\frac{b_1}{c_1} + \frac{f_1(1+r_1)}{c_1} \frac{l}{\rho + \delta} \right] - \frac{c_1}{2} \frac{1}{\rho} \left[\frac{b_1}{c_1} + \frac{f_1(1+r_1)}{c_1} \frac{l}{\rho + \delta} \right]^2 \\ \quad + \frac{1}{\rho} \frac{l}{\rho + \delta} f_1(1+r_1) \left[\frac{b_1}{c_1} + \frac{f_1(1+r_1)}{c_1} \frac{l}{\rho + \delta} \right] \end{cases} \tag{112}$$

$$\begin{cases} k_{11} = \frac{l}{\rho + \delta} \\ k_{12} = \frac{1}{\rho} b_2 \left[\frac{b_2}{c_2} + \frac{f_2(1+r_2)}{c_2} \frac{l}{\rho + \delta} \right] - \frac{c_2}{2} \frac{1}{\rho} \left[\frac{b_2}{c_2} + \frac{f_2(1+r_2)}{c_2} \frac{l}{\rho + \delta} \right]^2 \\ \quad + \frac{1}{\rho} \frac{l}{\rho + \delta} f_2(1+r_2) \left[\frac{b_2}{c_2} + \frac{f_2(1+r_2)}{c_2} \frac{l}{\rho + \delta} \right] \end{cases} \tag{113}$$

Therefore, the Equations 27-30 can be calculated.

Appendix 4

Take the derivatives of G_{S1} with respect to (65), and take the derivatives of G_{S2} with respect to (66), and set them equal to zero, we can get Equations 114, 115:

$$G_{S1}^*(t) = \frac{b_1}{c_1(1+\beta_S)} + \frac{f_1}{c_1(1+\beta_S)} \frac{\partial V_{S1}}{\partial x_{S1}} \tag{114}$$

$$G_{S2}^*(t) = \frac{b_2}{c_2(1+\beta_S)} + \frac{f_2}{c_2(1+\beta_S)} \frac{\partial V_{S2}}{\partial x_{S2}} \tag{115}$$

Substituting (114) into (65) and substituting (115) into (66), we can get Equations 116, 117:

$$\rho V_{S1} = b_1 \left[\frac{b_1}{c_1(1+\beta_S)} + \frac{f_1}{c_1(1+\beta_S)} \frac{\partial V_{S1}}{\partial x_{S1}} \right] - \frac{c_1(1+\beta_S)}{2} \left[\frac{b_1}{c_1(1+\beta_S)} + \frac{f_1}{c_1(1+\beta_S)} \frac{\partial V_{S1}}{\partial x_{S1}} \right]^2 + l x_{S1}(t) + \frac{\partial V_{S1}}{\partial x_{S1}} f_1 \left[\frac{b_1}{c_1(1+\beta_S)} + \frac{f_1}{c_1(1+\beta_S)} \frac{\partial V_{S1}}{\partial x_{S1}} \right] - \delta_1 \frac{\partial V_{S1}}{\partial x_{S1}} x_{S1}(t) \tag{116}$$

$$\rho V_{S2} = b_2 \left[\frac{b_2}{c_2(1+\beta_S)} + \frac{f_2}{c_2(1+\beta_S)} \frac{\partial V_{S2}}{\partial x_{S2}} \right] - \frac{c_2(1+\beta_S)}{2} \left[\frac{b_2}{c_2(1+\beta_S)} + \frac{f_2}{c_2(1+\beta_S)} \frac{\partial V_{S2}}{\partial x_{S2}} \right]^2 + l x_{S2}(t) + \frac{\partial V_{S2}}{\partial x_{S2}} f_2 \left[\frac{b_2}{c_2(1+\beta_S)} + \frac{f_2}{c_2(1+\beta_S)} \frac{\partial V_{S2}}{\partial x_{S2}} \right] - \delta_2 \frac{\partial V_{S2}}{\partial x_{S2}} x_{S2}(t) \tag{117}$$

Let $V_{S1}^* = k_{13} x_{S1} + k_{14}$, $V_{S2}^* = k_{15} x_{S2} + k_{16}$, wherein, k_{13} , k_{14} , k_{15} and k_{16} are all constants. The parameters of the optimal social welfare function can be obtained by calculation as Equations 118, 119:

$$\begin{cases} k_{13} = \frac{l}{\rho + \delta} \\ k_{14} = \frac{1}{\rho} b_1 \left[\frac{b_1}{c_1(1+\beta_S)} + \frac{f_1}{c_1(1+\beta_S)} \frac{l}{\rho + \delta} \right] - \frac{1}{\rho} \frac{c_1(1+\beta_S)}{2} \left[\frac{b_1}{c_1(1+\beta_S)} + \frac{f_1}{c_1(1+\beta_S)} \frac{l}{\rho + \delta} \right]^2 \\ \quad + \frac{1}{\rho} \frac{l}{\rho + \delta} f_1 \left[\frac{b_1}{c_1(1+\beta_S)} + \frac{f_1}{c_1(1+\beta_S)} \frac{l}{\rho + \delta} \right] \end{cases} \tag{118}$$

$$\begin{cases} k_{15} = \frac{l}{\rho + \delta} \\ k_{16} = \frac{1}{\rho} b_2 \left[\frac{b_2}{c_2(1+\beta_S)} + \frac{f_2}{c_2(1+\beta_S)} \frac{l}{\rho + \delta} \right] - \frac{1}{\rho} \frac{c_2(1+\beta_S)}{2} \left[\frac{b_2}{c_2(1+\beta_S)} + \frac{f_2}{c_2(1+\beta_S)} \frac{l}{\rho + \delta} \right]^2 \\ \quad + \frac{1}{\rho} \frac{l}{\rho + \delta} f_2 \left[\frac{b_2}{c_2(1+\beta_S)} + \frac{f_2}{c_2(1+\beta_S)} \frac{l}{\rho + \delta} \right] \end{cases} \tag{119}$$

Therefore, the Equations 67-70 can be calculated.

Appendix 5

Take the derivatives of G_{T1} with respect to (75), and take the derivatives of G_{T2} with respect to (76), and set them equal to zero, we can get Equations 120, 121:

$$G_{T1}^*(t) = \frac{b_1(1+a_T)}{c_1(1+a_T)} + \frac{f_1}{c_1(1+a_T)} \frac{\partial V_{T1}}{\partial x_{T1}} \tag{120}$$

$$G_{T2}^*(t) = \frac{b_2}{c_2} + \frac{f_2 + f_{T2}}{c_2} \frac{\partial V_{T2}}{\partial x_{T2}} \tag{121}$$

Substituting (120) into (75) and substituting (121) into (76), we can get Equations 122, 123:

$$\rho V_{T1} = b_1(1+a_T) \left[\frac{b_1(1+a_T)}{c_1(1+a_T)} + \frac{f_1}{c_1(1+a_T)} \frac{\partial V_{T1}}{\partial x_{T1}} \right] - \frac{c_1(1+a_T)}{2} \left[\frac{b_1(1+a_T)}{c_1(1+a_T)} + \frac{f_1}{c_1(1+a_T)} \frac{\partial V_{T1}}{\partial x_{T1}} \right]^2 + l x_{T1}(t) + \frac{\partial V_{T1}}{\partial x_{T1}} f_1 \left[\frac{b_1(1+a_T)}{c_1(1+a_T)} + \frac{f_1}{c_1(1+a_T)} \frac{\partial V_{T1}}{\partial x_{T1}} \right] - \delta_1 \frac{\partial V_{T1}}{\partial x_{T1}} x_{T1}(t) \tag{122}$$

$$\rho V_{T2} = b_2 \left(\frac{b_2}{c_2} + \frac{f_2 + f_{T2}}{c_2} \frac{\partial V_{T2}}{\partial x_{T2}} \right) - \frac{c_2}{2} \left(\frac{b_2}{c_2} + \frac{f_2 + f_{T2}}{c_2} \frac{\partial V_{T2}}{\partial x_{T2}} \right)^2 + l x_{T2}(t) + \frac{\partial V_{T2}}{\partial x_{T2}} \left[(f_2 + f_{T2}) \left(\frac{b_2}{c_2} + \frac{f_2 + f_{T2}}{c_2} \frac{\partial V_{T2}}{\partial x_{T2}} \right) - \delta_2 x_{T2}(t) \right] \tag{123}$$

Let $V_{T1}^* = k_{17} x_{T1} + k_{18}$, $V_{T2}^* = k_{19} x_{T2} + k_{20}$, wherein, k_{17} , k_{18} , k_{19} and k_{20} are all constants. The parameters of the optimal social welfare function can be obtained by calculation as Equations 124, 125:

$$\begin{cases} k_{17} = \frac{l}{\rho + \delta} \\ k_{18} = \frac{1}{\rho} b_1(1+a_T) \left[\frac{b_1(1+a_T)}{c_1(1+a_T)} + \frac{f_1}{c_1(1+a_T)} \frac{l}{\rho + \delta} \right] - \frac{1}{\rho} \frac{c_1(1+a_T)}{2} \left[\frac{b_1(1+a_T)}{c_1(1+a_T)} + \frac{f_1}{c_1(1+a_T)} \frac{l}{\rho + \delta} \right]^2 \\ \quad + \frac{1}{\rho} \frac{l}{\rho + \delta} f_1 \left[\frac{b_1(1+a_T)}{c_1(1+a_T)} + \frac{f_1}{c_1(1+a_T)} \frac{l}{\rho + \delta} \right] \end{cases} \tag{124}$$

$$\begin{cases} k_{19} = \frac{l}{\rho+\delta} \\ k_{20} = \frac{1}{\rho} b_2 \left(\frac{b_2}{c_2} + \frac{f_2+f_{I2}}{c_2} \frac{l}{\rho+\delta} \right) - \frac{c_2}{2} \frac{1}{\rho} \left(\frac{b_2}{c_2} + \frac{f_2+f_{I2}}{c_2} \frac{l}{\rho+\delta} \right)^2 \\ \quad + \frac{l}{\rho+\delta} \frac{1}{\rho} (f_2 + f_{I2}) \left(\frac{b_2}{c_2} + \frac{f_2+f_{I2}}{c_2} \frac{l}{\rho+\delta} \right) \end{cases} \quad (125)$$

Therefore, the Equations 77-80 can be calculated.

Appendix 6

Take the derivatives of G_{I1} with respect to (85), and take the derivatives of G_{I2} with respect to (86), and set them equal to zero, we can get Equations 126, 127:

$$G_{I1}^*(t) = \frac{b_1 - b_{I1}}{c_1} + \frac{f_1}{c_1} \frac{\partial V_{I1}}{\partial x_{I1}} \quad (126)$$

$$G_{I2}^*(t) = \frac{b_2}{c_2 - c_{I2}} + \frac{f_2 - f_{I2}}{c_2 - c_{I2}} \frac{\partial V_{I2}}{\partial x_{I2}} \quad (127)$$

Substituting (126) into (85) and substituting (127) into (86), we can get Equations 128, 129:

$$\begin{aligned} \rho V_{I1} &= (b_1 - b_{I1}) \left(\frac{b_1 - b_{I1}}{c_1} + \frac{f_1}{c_1} \frac{\partial V_{I1}}{\partial x_{I1}} \right) - \frac{c_1}{2} \left(\frac{b_1 - b_{I1}}{c_1} + \frac{f_1}{c_1} \frac{\partial V_{I1}}{\partial x_{I1}} \right)^2 + l x_{I1}(t) \\ &\quad + \frac{\partial V_{I1}}{\partial x_{I1}} \left[f_1 \left(\frac{b_1 - b_{I1}}{c_1} + \frac{f_1}{c_1} \frac{\partial V_{I1}}{\partial x_{I1}} \right) - \delta_1 x_{I1}(t) \right] \end{aligned} \quad (128)$$

$$\begin{aligned} \rho V_{I2} &= b_2 \left(\frac{b_2}{c_2 - c_{I2}} + \frac{f_2 - f_{I2}}{c_2 - c_{I2}} \frac{\partial V_{I2}}{\partial x_{I2}} \right) - \frac{c_2 - c_{I2}}{2} \left(\frac{b_2}{c_2 - c_{I2}} + \frac{f_2 - f_{I2}}{c_2 - c_{I2}} \frac{\partial V_{I2}}{\partial x_{I2}} \right)^2 + l x_{I2}(t) \\ &\quad + \frac{\partial V_{I2}}{\partial x_{I2}} \left[(f_2 - f_{I2}) \left(\frac{b_2}{c_2 - c_{I2}} + \frac{f_2 - f_{I2}}{c_2 - c_{I2}} \frac{\partial V_{I2}}{\partial x_{I2}} \right) - \delta_2 x_{I2}(t) \right] \end{aligned} \quad (129)$$

Let $V_{I1}^* = k_{21}x_{I1} + k_{22}$, $V_{I2}^* = k_{23}x_{I2} + k_{24}$, wherein, k_{21} , k_{22} , k_{23} and k_{24} are all constants. The parameters of the optimal social welfare function can be obtained by calculation as Equations 130, 131:

$$\begin{cases} k_{21} = \frac{l}{\rho+\delta} \\ k_{22} = \frac{1}{\rho} (b_1 - b_{I1}) \left(\frac{b_1 - b_{I1}}{c_1} + \frac{f_1}{c_1} \frac{l}{\rho+\delta} \right) - \frac{c_1}{2} \frac{1}{\rho} \left(\frac{b_1 - b_{I1}}{c_1} + \frac{f_1}{c_1} \frac{l}{\rho+\delta} \right)^2 \\ \quad + \frac{1}{\rho} \frac{l}{\rho+\delta} f_1 \left(\frac{b_1 - b_{I1}}{c_1} + \frac{f_1}{c_1} \frac{l}{\rho+\delta} \right) \end{cases} \quad (130)$$

$$\begin{cases} k_{23} = \frac{l}{\rho+\delta} \\ k_{24} = \frac{1}{\rho} b_2 \left(\frac{b_2}{c_2 - c_{I2}} + \frac{f_2 - f_{I2}}{c_2 - c_{I2}} \frac{l}{\rho+\delta} \right) - \frac{1}{\rho} \frac{c_2 - c_{I2}}{2} \left(\frac{b_2}{c_2 - c_{I2}} + \frac{f_2 - f_{I2}}{c_2 - c_{I2}} \frac{l}{\rho+\delta} \right)^2 \\ \quad + \frac{1}{\rho} \frac{l}{\rho+\delta} (f_2 - f_{I2}) \left(\frac{b_2}{c_2 - c_{I2}} + \frac{f_2 - f_{I2}}{c_2 - c_{I2}} \frac{l}{\rho+\delta} \right) \end{cases} \quad (131)$$

Therefore, the Equations 87-90 can be calculated.

Appendix 7

Take the derivatives of G_{P3} with respect to (93), and set it equal to zero, we can get Equation 132:

$$G_{P3}^*(t) = \frac{b_1}{(1 + \nu_3)c_3} + \frac{f_3}{c_3} \frac{\partial V_{P3}}{\partial x_{P3}} \quad (132)$$

Substituting (132) into (93), we can get Equation 133:

$$\begin{aligned} \rho V_{P3} &= \frac{b_3}{1 + \nu_3} \left[\frac{b_1}{(1 + \nu_3)c_3} + \frac{f_3}{c_3} \frac{\partial V_{P3}}{\partial x_{P3}} \right] - \frac{c_3}{2} \left[\frac{b_1}{(1 + \nu_3)c_3} + \frac{f_3}{c_3} \frac{\partial V_{P3}}{\partial x_{P3}} \right]^2 + l x_{P3}(t) \\ &\quad + \frac{\partial V_{P3}}{\partial x_{P3}} f_3 \left[\frac{b_1}{(1 + \nu_3)c_3} + \frac{f_3}{c_3} \frac{\partial V_{P3}}{\partial x_{P3}} \right] - \delta_3 \frac{\partial V_{P3}}{\partial x_{P3}} x_{P3}(t) \end{aligned} \quad (133)$$

Let $V_{P1}^* = k_{25}x_{P1} + k_{26}$, wherein, k_{25} and k_{26} are all constants. The parameters of the optimal social welfare function can be obtained by calculation as Equation 134:

$$\begin{cases} k_{25} = \frac{l}{\rho+\delta} \\ k_{26} = \frac{1}{\rho} \frac{b_3}{1 + \nu_3} \left[\frac{b_1}{(1 + \nu_3)c_3} + \frac{f_3}{c_3} \frac{l}{\rho+\delta} \right] - \frac{1}{\rho} \frac{c_3}{2} \left[\frac{b_1}{(1 + \nu_3)c_3} + \frac{f_3}{c_3} \frac{l}{\rho+\delta} \right]^2 \\ \quad + \frac{1}{\rho} \frac{l}{\rho+\delta} f_3 \left[\frac{b_1}{(1 + \nu_3)c_3} + \frac{f_3}{c_3} \frac{l}{\rho+\delta} \right] \end{cases} \quad (134)$$

Therefore, the Equations 94, 95 can be calculated.