

Original Article



Analysis of Media Strategies for Japan's Nuclear Wastewater Discharge Incident - A Tripartite Stochastic Evolutionary Game Approach

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Abstract:

The Japanese nuclear wastewater discharge into the ocean has attracted worldwide attention and discussion, and media coverage has significantly shaped the evolution of this event. This paper analyzes the strategic behavior of three different media entities—Japanese media, media from short-distance countries (SDM), and media from long-distance countries (LDM)—by constructing a stochastic evolutionary game model. To account for external environmental uncertainties, Gaussian white noise is introduced into the replicated dynamic equations. Stability conditions are then established and numerical approximations are computed by stochastic Taylor expansions. Subsequent numerical simulations are performed to illustrate the evolution of the tripartite dynamics. The results of the study are as follows: 1) Japanese media tend to choose the non-positive reporting strategy in the current scenario, while SDM tends to choose the positive reporting strategy. LDM generally takes a neutral stance, with a gradual decline in the tendency to report positively. 2) The decision-making process of Japanese media and LDM depends on several factors, especially the coefficients of public opinion impact, economic impact intensity, loss of sponsorship by Japanese media, as well as political and prestige influences, which significantly affect the evolutionary trajectories and results. In addition, SDM shows a propensity for positive reporting. The sponsorships acquired by SDM have minimal influence on the strategic decisions of Japanese media. 3) The coefficient of public opinion influence significantly affects both the extent of change and the speed of convergence in the strategic choices of decision-makers. Similarly, the intensity of economic influence significantly affects the stability of the decision-making. It is more important to adjust the coefficient of public opinion influence than to adjust the intensity of economic influence. This study combines stochastic evolutionary gaming and scenario analysis methods to provide new insights aimed at enhancing media attention and promoting positive coverage of the Japan nuclear wastewater discharge incident. The goal is to encourage various stakeholders to engage in unbiased and constructive coverage of this incident, thereby protecting the marine environment and promoting sustainable development.

Keywords: Nuclear wastewater discharge, Media strategy, Stochastic tripartite evolutionary games, Marine environmental

1. Introduction

On March 11, 2011, at 2:46 PM Japan Standard Time, a magnitude 9 earthquake hit the Pacific Ocean's northeastern region, which caused a massive tsunami. One of the most noteworthy

nuclear catastrophes since the 1986 Chernobyl disaster was denoted by the hydrogen explosion at the Fukushima Daiichi nuclear power plant in Japan as a result. To rapidly cool the nuclear

reactors, the operating company of the Japanese nuclear power plant used an unusual amount of water, including seawater, resulting in the collection of a significant amount of nuclear wastewater (Reuters, 2021). This nuclear wastewater is presently held in storage tanks on the power plant premises after undergoing specific treatment procedures, with the accumulated amount exceeding 1.15 million tons (Nogrady, 2021). As the accumulation of nuclear wastewater persists, the storage tanks provided by Japanese nuclear power plant companies are nearing capacity. Accordingly, the Japanese government, as reported by a related media outlet on April 13, 2021, intends to release this nuclear wastewater into the Pacific Ocean in 2023 (Yang et al., 2022).

Japan's decision to discharge nuclear wastewater into the Pacific Ocean in the wake of the Fukushima Daiichi disaster has sparked global concern. It is estimated that the effects of this action will reverberate around the world within the next decade (The Beijing News, 2021). The environmental impact of nuclear effluents is evident and has raised a variety of political, economic, and public opinion concerns. Within Japan, opposition to the discharge of nuclear wastewater comes from Fukushima's municipal governments and Japanese fishing cooperatives (Greenpeace, 2020). Moreover, beyond Japan's borders, other nations have engaged in political confrontations with Japan through international legal action (The Korea Times, 2021). Neighboring countries such as China and South Korea have vehemently expressed their reservations and dissatisfaction, viewing Japan's decision as a potential threat to their security and environmental well-being. As a result, they strongly oppose Japan's planned nuclear wastewater discharge (Ministry of Foreign Affairs of the People's Republic of China, 2021; Climate Change Diplomatic Department, 2021). Apart from neighboring countries, reports from the

United Kingdom describe Japan's nuclear wastewater discharge as a major disaster facing mankind (Liu et al., 2021). International organizations, especially those closely associated with Japan's nuclear waste discharge, such as Greenpeace International, have vehemently criticized Japan's decision (Greenpeace International, 2021). In addition to political concerns, Japan's decision to discharge nuclear wastewater has economic and public relations implications. Food from Fukushima, Japan, is being ostracized by several regions, particularly affecting consumers' willingness to buy (Matsumoto and Hoang, 2019). In response, numerous countries, including China, South Korea, and the United States, have imposed import bans and restrictions on Japanese seafood (Japan Times, 2022). Citizens of various countries, especially those neighboring Japan, are expressing deep concern about the disposal of nuclear wastewater. Online discussions about this event are widespread, with participants expressing predominantly negative emotions (Pu et al., 2022). As a result, this sentiment is reflected in consumers' decreased willingness to purchase Japanese products and a decrease in planned travel to Japan. The resulting decline in both purchases of Japanese products and tourism to Japan inevitably directs consumer interest toward alternative products and destinations. Thus, public perception of this event has a significant impact on both economic dynamics and public opinion (Guo et al., 2022).

As reported by BBC NEWS, Japan has begun discharging nuclear wastewater into the Pacific Ocean beginning August 24, 2023, once again drawing global attention (BBC NEWS, 2023). Since Japan decided to proceed with the release of nuclear wastewater, nations around the world have been closely monitoring the situation. The actual discharge by Japan has heightened this scrutiny, resulting in extensive coverage by various international media outlets. As a result,

this incident has generated widespread concern and discussion among individuals in various countries, reigniting significant interest in issues related to Japan's discharge of nuclear wastewater. This renewed attention has resulted in a variety of responses. For example, Chinese tourists initiated mass cancellations of Japanese travel bookings, while calls for a boycott of Japanese goods gained momentum. In addition, protests were held in Korea, with Lee Jae-myung, a prominent political figure, going on a 24-day hunger strike to protest Japan's discharge of nuclear wastewater (Reuters, 2023).

The public's response depends significantly on the perspective and content presented in media coverage. When the media disseminates information about nuclear contamination, its role goes beyond mere information transmission; it serves as a central force in shaping public ideology. The manner and content of media reports exert a profound influence on the public's understanding and perception of Japan's nuclear contamination, which is influenced by a confluence of political, economic, public opinion, and social development factors. As the primary conduit of information dissemination, the media's selection of content and narrative approach directly shape the public's perspectives and attitudes toward Japan's nuclear contamination. Through their reports, the media selectively present facts, interpret events, and assign specific meanings, thereby guiding audiences to form perceptions and make judgments. In addition, the positions and stances taken by the media significantly influence public perceptions. These editorial choices are driven not only by political leanings but also by the media's economic interests and the preferences of its readership. As a stakeholder, the media's reporting practices are thus influenced by external political and economic pressures while being driven by internal demands for relevance. The media thus emerges as a crucial and central participant in the

discourse surrounding Japan's nuclear wastewater discharge.

On the contrary, the discharge of nuclear effluents has a significant impact on the Pacific Rim (Zhao *et al.*, 2021). Scholars have categorized the affected countries and regions based on their geographic proximity to Japan, delineating two categories: highly contaminated areas in the Pacific Rim that are more affected, and others that are less affected (Guo *et al.*, 2022). Consequently, this study posits different interests and strategic choices among media outlets based on their geographic proximity to Japan. These categories include media from shorter-distance countries (SDM), media from longer-distance countries (LDM), and Japanese media.

Existing literature primarily focuses on the economic impacts of nuclear wastewater discharges, with minimal attention paid to media interests and reporting strategies, especially post-discharge incidents. In this context, it is important to explore the Evolutionary Stable Strategies (ESSs) adopted by different stakeholders - namely, the Japanese media, SDM, and LDM - following a prolonged evolutionary game, and to identify the key factors influencing these strategies. This research can facilitate an analysis of the media reactions of all parties involved, thereby allowing an assessment of the impact on the political economy and public opinion. The goal is to maximize the respective interests of the Japanese media, the SDM, and the LDM in reducing the impact of nuclear wastewater discharge and promoting global sustainable development. Given the multiplicity of media outlets in each country and the influence of emerging platforms such as self-media, there is a certain degree of unpredictability. Therefore, this paper constructs a three-party stochastic evolutionary game model for analysis. The purpose of this paper is to discuss (1) What are the payoff matrix and replicated dynamics equations for the tripartite media in the Japanese

nuclear wastewater discharge incident? (2) Is there a stable equilibrium solution to the stochastic replicator dynamics equation with the introduction of Gaussian white noise? If so, what are the stable conditions? (3) How some key parameters affect evolutionary results and trajectories? (4) How can media be promoted to report positively on nuclear wastewater incidents in order to protect the marine environment and achieve sustainable development?

To address the aforementioned concerns, this study develops a three-party stochastic evolutionary game model for the media regarding the nuclear wastewater discharge incident in Japan. Utilizing finite rationality theory, it formulates the payoff matrix, replicates the dynamic equations, substitutes Gaussian white noise into the $\hat{I}t\hat{o}$ formula, and investigates stable conditions. In addition, stochastic Taylor expansion aids in numerical approximation, allowing the representation of dynamic evolutionary trajectories through numerical simulation. Furthermore, key impact parameters—including the coefficient of public opinion impact, economic impact intensity, synergy costs borne by LDM, diminished sponsorship from Japanese media, political influence, and reputation subjected to numerical simulations. This endeavor aims to provide theoretical insights for various stakeholders to devise more effective strategies. The strategic decisions made by the media regarding Japan's nuclear wastewater discharges involve multiple stakeholders, requiring a balance of interests to improve coverage and promote sustainable development. Given the uncertainties in the external environment, incorporating Gaussian white noise into a deterministic system and formulating $\hat{I}t\hat{o}$ stochastic differential equations further enhances the application of stochastic evolutionary game theory. This study

aims to provide actionable recommendations for improving media scrutiny and oversight of the nuclear wastewater incident. It also seeks to promote more effective reporting practices among both Japanese media and media outlets in geographically distant countries. The ultimate goal of this research is to present optimal strategies conducive to protecting the marine environment and advancing sustainable development efforts.

This paper may contribute to the existing literature in two key aspects. First, it innovates by addressing the current focal point of Japan's nuclear wastewater discharge into the ocean and analyzing relevant media coverage through the construction of a three-party stochastic game model involving the Japanese media, SDM, and LDM. It extends the application of stochastic evolutionary game theory by offering an expanded media-centric perspective on the Japanese nuclear wastewater incident. Second, it incorporates Gaussian white noise to account for environmental uncertainty in participants' behavioral decisions within the replicator dynamic equation. In addition, stability conditions are determined within the $\hat{I}t\hat{o}$ stochastic differential equation framework. The study utilizes stochastic Taylor expansion to solve numerical approximations and outlines the tripartite evolutionary trajectory in terms of stability, variability, and convergence rate. Finally, this research provides theoretical guidance by exploring the influence of key parameters on evolutionary outcomes and trajectories. It aims to encourage proactive reporting by the tripartite media on pertinent events while providing effective strategies for protecting the marine environment and promoting sustainable development.

The rest of the paper is organized as follows. Section 2 summarizes the previous literature and identifies gaps in the literature. Section 3

describes the setup of the evolutionary game model, analyzes the existence and stability of equilibrium solutions, and uses stochastic Taylor expansions to obtain approximate solutions. Section 4 presents numerical simulations. Finally, Section 5 provides conclusions and policy implications, with limitations and directions for future research.

Literature Review

Japan Discharges Nuclear Wastewater

Research on nuclear wastewater discharges from Japan has focused mainly on biochemistry and the study of the influence of related events.

Researchers widely acknowledge that the discharge of nuclear wastewater into the sea can have catastrophic effects on the marine environment, natural habitat, organisms, and human health (Awual *et al.*, 2014). Japan's release of nuclear effluents involves substantial amounts of radioactive elements, especially the hydrogen isotope ^3H , which raises significant concerns (de With *et al.*, 2021; Normile, 2021). The management of large amounts of ^3H is proving to be extremely challenging (Shozugawa *et al.*, 2020). Aquatic plants will absorb these elements through photosynthesis, subsequently transferring them to fish and shellfish, eventually integrating into the food chain (de With *et al.*, 2021). Apart from ^3H , Japan's treated nuclear wastewater still contains detectable amounts of other radioactive elements like ^{134}Cs , ^{137}Cs , and ^{131}I , even after Japan declared completion of treatment. These elements are readily absorbed by marine organisms (Buessler, 2020). Although the oceans are vast and have the capacity to treat pollution, the discharge of various radioactive elements can still have long-lasting effects on the marine environment, marine organisms, and consequently human health (Men *et al.*, 2017).

Beyond the biochemical effects, researchers have examined the impact of a nuclear waste event from a variety of perspectives. Using the Global

Trade Analysis Project (GTAP) model, researchers have outlined the impact of the event on the economic output of countries and regions worldwide under various scenarios. Their conclusions highlight a significant decline in global social welfare and an exacerbation of trade imbalances in several regions due to the event (Guo *et al.*, 2022). Considering China's geographical proximity to Japan and the important role of aquatic products in the Chinese diet, researchers have investigated Chinese consumers' willingness to pay for aquatic products. Their findings confirm a significantly lower willingness to pay among Chinese consumers for seafood products from the ocean (Chen *et al.*, 2023). Scholars have focused their attention on examining the new impacts and potential remedies resulting from Japan's nuclear wastewater discharge on China's fish trade. In response, China is urged to proactively adopt technological innovations, strengthen regulatory measures, and optimize fishing technology to effectively manage the fallout from this event (Hai, 2021). Concurrently, studies of Japan's fisheries have shown that the impact of nuclear wastewater on aquatic products is far-reaching, resulting in significant losses in Japanese fisheries (Liu, 2023). Some scholars have used PEST analysis to examine Japan's nuclear wastewater discharge, revealing it to be a multifaceted issue that is not only linked to environmental concerns, but also intertwined with Japan's political, economic, technological, cultural, and historical contexts. These scholars suggest that international environmental law may offer potential solutions (Yang, 2022). In terms of public sentiment, other scholars have used machine learning techniques on online text data from Sina Weibo to assess Chinese public opinion on Japan's nuclear waste discharge. Their findings indicate widespread negative sentiment among Chinese netizens. The dominant topics of discussion include nuclear contamination, marine ecology, seafood imports, food safety, international responsibility, and

public morality (Pu et al., 2022). However, the analysis did not include media strategies.

Stochastic Evolutionary Game

The formal beginnings of evolutionary game theory can be traced back to the introduction of basic concepts such as evolutionary games and evolutionary stable strategies (Maynard Smith, 1974). Subsequently, a major advance in the theory came with the proposal of replication dynamics (Taylor and Jonker, 1978). As a result, evolutionary game theory underwent a breakthrough development. This theory has since proven to be a promising tool for modeling social dilemmas rooted in individual cooperation problems (Wu et al., 2017). It allows researchers to effectively represent and simulate outcomes arising from interactions between game participants or groups whose strategic behaviors affect each other's payoffs (Jiang et al., 2019). Several scholars have used evolutionary game analysis to examine the behavioral strategies of local governments and manufacturers regarding the cancellation of subsidies for new energy vehicles (Ji et al., 2019). Similarly, the collective intelligence design ecosystem has been analyzed and studied using evolutionary game theory (Fu et al., 2022). In particular, researchers have used a tripartite evolutionary game to examine the strategic choices made by Japan, other countries, and the International Environmental Protection Organization (IEPO) regarding the strategy for nuclear wastewater discharge. Their findings contribute to policy recommendations for all three parties to mitigate the hazards posed by nuclear wastewater (Liu et al., 2021).

Nevertheless, the deterministic nature of the evolutionary game model inadequately reflects reality, particularly in cases where uncertainty prevails, especially in the context of the media involvement in this study and the variability in reporting behavior across countries. Drawing from analogous scenarios, introduces random perturbations for correlation analysis (Foster and

Young, 1990), aiming to assess stability under random perturbations (Cobb, 1978). It is noteworthy that stochastic evolutionary games are widely used in research. Some scholars have conducted an analysis of cross-regional collaborative governance in the process of transferring polluting industries, using stochastic evolutionary game analysis with Chinese enclave parks as a case study. This research led to the proposal of three collaborative governance paths (Li et al., 2023). Stochastic evolutionary game analysis was also used to study e-waste recycling in the context of a dual-track governance system. This study provides recommendations for the design of relevant environmental protection laws and also advocates for recyclers to adopt qualified dismantling practices (X. Liu et al., 2021). Some scholars employed stochastic evolutionary game theory to examine the issue of data sharing in the construction of digital government. Their goal is to stimulate greater interdepartmental engagement in interagency data-sharing efforts (Dong et al., 2023). In addition, the use of stochastic evolutionary game analysis to study the operational strategies of online trading platforms can provide insights for more equitable regulation of platform-based e-commerce (Zhang et al., 2022).

Literature Gaps

Following the literature review, four major gaps were identified. First, research on Japan's nuclear effluent discharges predominantly addresses the effects of such events, focusing primarily on the biochemical domain. However, little attention is given to the post-event impacts of these discharges. Second, existing studies of Japan's nuclear wastewater discharges focus on governmental behavior, economic impacts, and related issues, while neglecting to examine media coverage of these events. Third, while stochastic evolutionary game theory has been extensively applied to multi-party decision-making, its integration with media coverage strategies

remains conspicuously absent from the current literature. Finally, the majority of studies consider countries beyond Japan as stakeholders, overlooking how media strategies differ based on different distances from Japan. In reality, geographic distance influences the selection of media strategies.

This paper addresses these gaps through two main approaches. First, it examines Japan's nuclear wastewater discharge, an issue of considerable concern, by analyzing the responses of the Japanese media, SDM, and LDM. Second, recognizing the uncertainties of the real-world scenario, this study pioneers the application of a stochastic evolutionary game model to assess media coverage strategies related to Japan's nuclear wastewater discharge incident. To achieve this, assumptions are formulated, payoff matrices are constructed, replicated dynamic equations are established, and Gaussian white noise is introduced for a comprehensive analysis of stability and equilibrium conditions for each party. The paper uses numerical simulations to illustrate current evolutionary trends and identifies key parameters that influence these results and trajectories. In addition, the study categorizes the influencing factors into ratio and non-ratio categories, thereby providing efficient policy insights. These insights aim to encourage active reporting of relevant events, protect the marine environment, promote sustainable development, and maximize benefits for all stakeholders.

Methodology: Tripartite Stochastic Evolutionary Games

Basic Assumption

The Japanese media, media from shorter-distance countries (SDM), and media from longer-distance countries (LDM) are the main entities reporting on Japan's nuclear waste discharge, each with different strategic positions. They share a common pursuit of economic interests. These

media may compete for a larger readership or audience to increase advertising revenue. However, there are instances where cooperation in joint reporting is preferred to reduce costs and pool resources, particularly for extensive investigative or in-depth reporting. Advertisers have to make choices among media outlets, and the level of audience engagement and the quality of reporting influence this decision-making process. As a result, competition among media outlets can drive up advertising costs, particularly during high-profile events. On the contrary, these media outlets are also subject to political influence. Governments often use regulations or other mechanisms to influence the content of media coverage. In cases where a government wants to downplay an event, it might try to limit coverage by domestic media. Conversely, the government on the other side of the border may encourage active coverage by its media to advance its political goals. Such media coverage can have a significant impact on international political relations, influencing diplomatic relations, trade dynamics, and cooperative relationships. Governments often use the media as a tool to disseminate information and shape political images both domestically and internationally, thereby influencing the direction of media coverage. In addition, participants in evolutionary games exhibit limited rationality and dynamically adapt to reflect participants' decision-making behavior and external environmental influences (Liu *et al.*, 2022).

Based on relevant theoretical and practical considerations, the interaction between Japanese media, SDM, and LDM is shown in Figure 1. Understanding the coverage of nuclear wastewater discharge as a multi-stage dynamic process, this phenomenon is susceptible to stochastic disturbances. Therefore, this study deals with the stochastic dynamic evolutionary game of media coverage of nuclear wastewater discharge using a hybrid mechanism approach.

Based on this premise, the paper proposes the following assumptions.

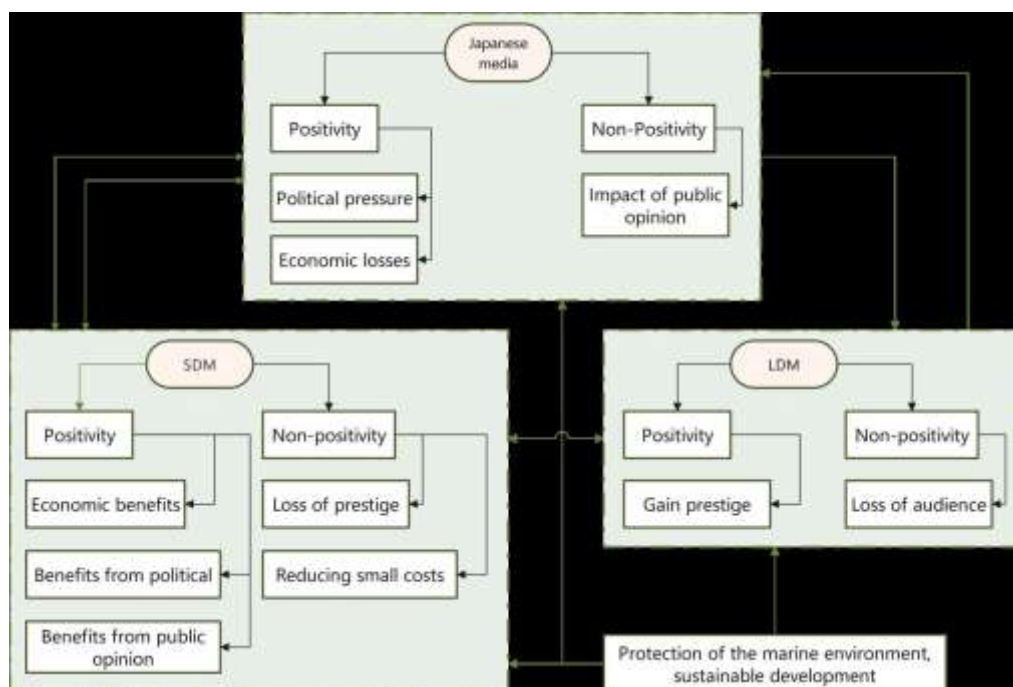


Figure 1. The relationship and strategy set between the players

Assumption 1: The evolutionary game revolving around nuclear wastewater reporting involves three integral parties: Japanese media, SDM, and LDM. These Japanese media, SDM, and LDM are assumed to be homogeneous entities with no significant heterogeneity among them. In the context of the Japanese media, the government may exert political influence to limit or change the coverage of the nuclear wastewater incident to protect national interests. Some Japanese media outlets may rely on corporate sponsorship or advertising, which may involve them in considerations of financial interest, especially if these companies are associated with the nuclear waste incident. In a delicate balance, the Japanese media faces the challenge of considering the public's reaction and navigating between the prospect of public dissatisfaction if they downplay the incident too much and the risk of causing panic if they emphasize it too much. For SDM, Japan's neighboring countries could use the nuclear wastewater incident to criticize Japan, strengthen their position in international public

opinion, strengthen national identity among their people, and thereby strengthen the government's authority. Extensive coverage of the nuclear wastewater incident in Japan may lead to higher media engagement and viewership, thereby increasing advertising revenue - a notable economic benefit for SDM. In addition, public hostility toward Japan could potentially turn into an aversion toward Japanese products, thereby stimulating the growth of the domestic market for domestic products. Representing media from more distant countries, LDM is primarily concerned with maintaining its nation's global standing while avoiding involvement in political disputes to maintain an aura of impartiality and neutrality. However, the LDM remains vulnerable to advertising and readership concerns. While coverage of certain issues may attract a larger readership, it could cause advertisers to withdraw support if controversy arises. In this context, the three parties involved must strike a delicate balance between domestic political, economic, and societal interests in their coverage of nuclear waste incidents. At the same time, they must

consider international relations, public opinion, and commercial interests. Each stakeholder is assumed to be a finite rational actor who learns, imitates, and evolves within the dynamics of the game to maximize its interests (Friedman, 1998).

Assumption 2: The strategy set of the Japanese media includes the {positivity, non-positivity}. Within this set, the positive strategy implies a positive attitude of the Japanese media in reporting on the nuclear wastewater discharge in Japan. This strategy aims to draw attention to the situation and encourage relevant entities, including corporations and governments, to take responsibility for marine environmental protection and sustainable development. The probability of the Japanese media choosing the positive strategy is denoted as x ($x \in [0,1]$), while the probability of the Japanese government choosing the non-positivity strategy is $1-x$. SDM's strategy set includes {positivity, non-positivity}. Within this set, the positive strategy involves SDM's positive involvement in reporting on Japan's nuclear wastewater discharge. This strategy aims to advocate for a constructive resolution of the nuclear effluent incident, prioritize marine environmental protection, and promote sustainable development while protecting its interests. The probability of SDM choosing the positive strategy is denoted as y ($y \in [0,1]$), while the complementary probability of SDM choosing the non-positivity strategy is $1-y$. LDM's strategy includes {positivity, non-positivity}. Under the positive strategy, LDM positively engages in reporting on Japan's nuclear wastewater discharge to attract global attention and advocate for the protection and sustainable development of the marine environment. The probability that LDM chooses the positive strategy is represented by z ($z \in [0,1]$), and the complementary probability that LDM chooses the non-positivity strategy is $1-z$.

Assumption 3: In choosing the positive strategy, the Japanese media faces political pressure,

denoted as P , while simultaneously arousing public concern, denoted as A . Positive coverage of the nuclear wastewater leads to economic repercussions, symbolized as M_1 , due to reduced sponsorship from related companies. Implementing the positivity strategy entails additional costs, denoted by C , but also provides benefits in the form of increased clicks and attention, denoted by R_1 . When the Japanese media chooses the non-active strategy, it receives a political reward, denoted by P , but its decision to refrain from reporting significant nuclear wastewater incidents triggers public discontent, denoted by B . When the SDM chooses the active strategy, the Japanese media experiences reduced attention and revenue, resulting in a recorded loss, denoted by C_{12} . Similarly, LDM's choice of the active strategy also results in a loss to the Japanese media, denoted by C_{13} . If either SDM or LDM chooses a positive strategy, the Japanese media will experience a loss of prestige and image due to inaction, denoted by S . α is the coefficient indicating the influence of public opinion on the Japanese media's choice of positive strategies. It indicates the strength of the influence of public opinion on the Japanese media's choice of strategies.

Assumption 4: When SDM chooses a positive strategy, it incurs a reporting cost, denoted by C . Active reporting on the Japanese nuclear wastewater incident meets the needs of the government, resulting in a political benefit, denoted by P . As the public reduces its purchases of Japanese products and services, thereby redirecting demand to local businesses, those businesses provide SDM with sponsorship, denoted by M_2 . By covering relevant trending topics, SDM can generate revenue from click-through rates and advertising, labeled R_2 . When the Japanese media chooses an inactive strategy and the LDM chooses an active strategy, the LDM relies heavily on the content reported by SDM, thus saving its reporting costs, and pays a

certain amount to SDM, recorded as R_{23} . If both the Japanese media and the LDM choose the non-positive strategy, SDM takes responsibility for reporting on the marine pollution and gains prestige, denoted by S . If SDM chooses the non-positive strategy, it faces political pressure, denoted by P , while public dissatisfaction with the media's inaction is denoted by B . If either the LDM or the Japanese media choose the positive strategy, SDM loses benefits such as click-through rates, denoted by R_2 . The β variable indicates the strength of the economic impact; if the Japanese media chooses the non-positive strategy and SDM chooses the positive strategy, SDM will gain greater economic benefits.

Assumption 5: When LDM chooses a positive strategy, it incurs additional reporting costs, denoted as C , but at the same time gains revenues from clicks and ads, denoted as R_3 . To reduce reporting costs, it relies on the content reported by the Japanese media or SDM and pays them a fee, labeled R_{23} . If LDM does not choose a positive strategy, in such a scenario, if either the Japanese media or SDM chooses the positive strategy, LDM will lose clicks and advertising revenue, denoted as R_3 , and will also experience a loss of prestige, denoted as S .

The notations and their respective meanings are provided in Table 1.

Table 1. Parameters and their meanings.

Parameters	Description
α	Coefficient of influence on public opinion when Japanese media choose positivity strategy
β	Intensity of impact of various media decisions on economic interests
R_{23}	Payment by the LDM to the Japanese media or the SDM for joint coverage
M_1	Company sponsorship lost when Japanese media choose positivity strategy
P	The impact of politics on the strategies of media choice
A	People's fear of nuclear wastewater incident
C	Additional costs of reporting on nuclear wastewater incidents
R_1	Benefits for Japanese media when choosing positivity strategy
S	The influence of prestige on the selection of strategy among different media
C_{12}	Additional costs given to Japanese media when SDM chooses positivity strategy
C_{13}	Additional costs given to Japanese media when LDM chooses positivity strategy
B	Public discontent with the lack of media reporting on nuclear wastewater
M_2	Increase in company sponsorship benefits when SDM chooses positivity strategy
R_2	Benefits for SDM when choosing positivity strategy
R_3	Benefits for LDM when choosing positivity strategy
x	Probability of Japanese media choosing the positivity strategy
$1 - x$	Probability of Japanese media choosing the non-positivity strategy
y	Probability of SDM choosing the positivity strategy
$1 - y$	Probability of SDM choosing the non-positivity strategy
z	Probability of LDM choosing the positivity strategy
$1 - z$	Probability of LDM choosing the non-positivity strategy

Payoff Matrix and Replicator Dynamics Equations

Based on the above analysis, the payoff matrix for

Japanese media, LDM, and SDM under different strategy combinations is shown in Table 2.

Table 2. Payoff matrix of Japanese media, LDM, and SDM.

Stakeholders				LDM	
				Positivity (z)	Non-positivity (1 - z)
Japanese media	Positivity (x)	SDM	Positivity (y)	$-P - \alpha A - (1 - \beta)M_1 - C + R_1 + \alpha R_{23},$	$-P - \alpha A - (1 - \beta)M_1 - C + R_1,$
				$-C + P + (1 - \beta)M_2 + R_2 + (1 - \alpha)R_{23},$	$-C + P + (1 - \beta)M_2 + R_2,$
				$-C + R_3 - R_{23}$	$-R_3 - S$
			Non-Positivity (1 - y)	$-P - \alpha A - (1 + \beta)M_1 - C + R_1 + R_{23},$	$-P - \alpha A - (1 + \beta)M_1 - C + R_1,$
				$-P - B - R_2 - S,$	$-P - B - R_2 - S,$
				$-C + R_3 - R_{23}$	$-R_3 - S$
	Non-Positivity (1 - x)	SDM	Positivity (y)	$P - \alpha B - C_{12} - C_{13} - S,$	$P - \alpha B - C_{12},$
				$-C + P + (1 + \beta)M_2 + R_2 + R_{23},$	$-C + P + (1 + \beta)M_2 + R_2 + S,$
				$-C + R_3 - R_{23}$	$-R_3$
			Non-Positivity (1 - y)	$P - \alpha B - C_{13},$	$P - \alpha B,$
				$-P - B - R_2,$	$-P - B,$
				$-C + R_3 + S$	0

Let J_{11} and J_{12} represent the expected revenues of Japanese media choosing positivity and non-positivity strategies, respectively, and then the average revenue is denoted by \bar{J} .

$$J_{11} = yz[-P - \alpha A - (1 - \beta)M_1 + \alpha M_{11} - C + R_1 + \alpha R_{23}] + y(1 - z)[-P - \alpha A - (1 - \beta)M_1 + \alpha M_{11} - C + R_1] + (1 - y)z[-P - \alpha A - (1 + \beta)M_1 + \alpha M_{11} - C + R_1 + R_{23}] + (1 - y)(1 - z)[-P - \alpha A - (1 + \beta)M_1 + \alpha M_{11} - C + R_1] = yz\alpha R_{23} + yM_1\beta + zR_{23} - yzR_{23} - P - \alpha A - M_1 - \beta M_1 + \alpha M_{11} - C + R_1 + yM_1 \tag{1}$$

$$J_{12} = yz(P - \alpha B - C_{12} - C_{13} - S) + y(1 - z)(P - \alpha B - C_{12}) + (1 - y)z(P - \alpha B - C_{13}) + (1 - y)(1 - z)(P - \alpha B) = -yzS - yC_{12} - zC_{13} + P - \alpha B \tag{2}$$

$$\bar{J} = xJ_{11} + (1 - x)J_{12} \tag{3}$$

Then, we can calculate the replicated dynamics equation of Japanese media as Equation (4).

$$F(x) = dx/dt = x(J_{11} - \bar{J}) = x(1 - x)(J_{11} - J_{12}) \tag{4}$$

Let S_{11} and S_{12} represent the expected revenues of SDM choosing positivity and non-positivity strategies, respectively, and then the average revenue is denoted by \bar{S} .

$$S_{11} = xz(-C + P + M_2 - \beta M_2 + R_2 + R_{23} - \alpha R_{23}) + (1-x)z(-C + P + M_2 + \beta M_2 + R_2 + R_{23}) + x(1-z)(-C + P + M_2 - \beta M_2 + R_2) + (1-x)(1-z)(-C + P + M_2 + \beta M_2 + R_2 + S) = -xz\alpha R_{23} + zR_{23} - x\beta M_2 - C + P + M_2 + \beta M_2 + R_2 + S - x\beta M_2 - xS - zS + xzS \tag{5}$$

$$S_{12} = xz(-P - B - R_2 - M_{11} - \beta M_{11} - S) + (1-x)z(-P - B - R_2) + x(1-z)(-P - B - R_2 - M_{11} - \beta M_{11} - S) + (1-x)(1-z)(-P - B) \tag{6}$$

$$\bar{S} = yS_{11} + (1-y)S_{12} \tag{7}$$

Then, we can calculate the replicated dynamics equation of SDM as Equation (8).

$$F(y) = dy/dt = y(S_{11} - \bar{S}) = y(1-y)(S_{11} - S_{12}) \tag{8}$$

Let L_{11} and L_{12} represent the expected revenues of LDM choosing positivity and non-positivity strategies, respectively, and then the average revenue is denoted by \bar{L} .

$$L_{11} = xy(-C + R_3 - R_{23}) + (1-x)y(-C + R_3 - R_{23}) + x(1-y)(-C + R_3 - R_{23}) + (1-x)(1-y)(-C + R_3 + S) = -R_{23}y + R_{23}xy - R_{23}x - C + R_3 + S - Sx - Sy + Sxy \tag{9}$$

$$L_{12} = xy(-R_3 - S) + (1-x)y(-R_3) + x(1-y)(-R_3 - S) + (1-x)(1-y)(0) = -R_3y + R_3xy - R_3x - Sx \tag{10}$$

$$\bar{L} = zL_{11} + (1-z)L_{12} \tag{11}$$

Then, we can calculate the replicated dynamics equation of Japanese media as Equation (12).

$$F(z) = dz/dt = z(L_{11} - \bar{L}) = z(1-z)(L_{11} - L_{12}) \tag{12}$$

Given that x , y , and z belong to the interval $[0, 1]$, while $1-x$, $1-y$, and $1-z$ remain non-negative and do not affect the result of the tripartite evolutionary game (X. Liu et al., 2021), the

replicated dynamics equations for Japanese media, SDM, and LDM can be rewritten as Equations (13), (14), and (15).

$$F(x) = dx/dt = x(J_{11} - J_{12}) = x(\alpha R_{23}yz + 2\beta M_1y + R_{23}z - R_{23}yz - 2P - \alpha A - M_1 - \beta M_1 - C + R_1 + Syz + C_{12}y + C_{13}z + \alpha B) \tag{13}$$

$$F(y) = dy/dt = y(S_{11} - S_{12}) = y(-\alpha R_{23}xz + R_{23}z - 2\beta M_2x - C + 2P + M_2 + \beta M_2 + R_2 + S - Sz + Sxz + R_2z + R_2x + R_2xz + B) \tag{14}$$

$$F(z) = dz/dt = z(L_{11} - L_{12}) = z(-R_{23}y + R_{23}xy - R_{23}x - C + R_3 + S - Sy + Sxy + R_3y - R_3xy + R_3x) \tag{15}$$

Stochastic Evolutionary Game Model

Considering the bounded rationality of real

stakeholders, the immediate choice of the optimal strategy to maximize utility is difficult. Instead, the participants tend to evolve progressively

toward higher payoffs, following the principles of the evolutionary game model. However, due to the complex and highly uncertain external environment, the interactions among Japanese media, SDM, and LDM are fraught with

uncertainty, prompting the study of random perturbations in the three-party game. In this study, Gaussian white noise is introduced into the replicated dynamics equation, forming a stochastic evolutionary game model for analysis.

$$dx(t) = (\alpha R_{23}yz + 2\beta M_1y + R_{23}z - R_{23}yz - 2P - \alpha A - M_1 - \beta M_1 - C + R_1 + Syz + C_{12}y + C_{13}z + \alpha B)x(t)dt + \sigma x(t)d\omega(t) \quad (16)$$

$$dy(t) = (-\alpha R_{23}xz + R_{23}z - 2\beta M_2x - C + 2P + M_2 + \beta M_2 + R_2 + S - Sz + Sxz + R_2z + R_2x + R_2xz + B)y(t)dt + \sigma y(t)d\omega(t) \quad (17)$$

$$dz(t) = (-R_{23}y + R_{23}xy - R_{23}x - C + R_3 + S - Sy + Sxy + R_3y - R_3xy + R_3x)z(t)dt + \sigma z(t)d\omega(t) \quad (18)$$

In the equations provided, $\omega(t)$ denotes a one-dimensional standard Brownian motion that represents $\omega(t)$ as an independent incremental process that represents the impact of random disturbances on the game dynamics. For all t greater than 0 and a step $h > 0$, the increment $\Delta \omega(t) = \omega(t+h) - \omega(t)$ follows a normal distribution $N(0, \sqrt{h})$. The term $d\omega(t)$ denotes Gaussian white noise, while σ represents the magnitude of the random disturbance. Consequently, Equations (16), (17) and (18)

equations illustrating the evolutionary replicated dynamic equations for the Japanese media, SDM, and LDM under the influence of random disturbances.

Existence and Stability Analysis of Equilibrium Solutions

For a stochastic differential equation of the $It\hat{o}$ type, where $t = 0$ represents the initial moment, $x(0) = 0$, $y(0) = 0$, and $z(0) = 0$, the following equations are obtained.

denote one-dimensional $It\hat{o}$ stochastic differential

$$(\alpha R_{23}yz + 2\beta M_1y + R_{23}z - R_{23}yz - 2P - \alpha A - M_1 - \beta M_1 - C + R_1 + Syz + C_{12}y + C_{13}z + \alpha B) \cdot 0 + \sigma x(t)d\omega(t) = 0 \quad (19)$$

$$(-\alpha R_{23}xz + R_{23}z - 2\beta M_2x - C + 2P + M_2 + \beta M_2 + R_2 + S - Sz + Sxz + R_2z + R_2x + R_2xz + B) \cdot 0 + \sigma y(t)d\omega(t) = 0 \quad (20)$$

$$(-R_{23}y + R_{23}xy - R_{23}x - C + R_3 + S - Sy + Sxy + R_3y - R_3xy + R_3x) \cdot 0 + \sigma z(t)d\omega(t) = 0 \quad (21)$$

The above equations imply that $d\omega(t)|_{t=0} = \omega'(t)dt|_{t=0} = 0$, leading to null solution for Equations (16), (17), and (18). If $\sigma = 0$, then $x(t) \equiv 0$, $y(t) \equiv 0$ and $z(t) \equiv 0$. This illustrates that in the absence of external interference, the tripartite media game system remains in this initial state, thus the null solution is the equilibrium solution. In reality, however, the

tripartite media's coverage strategy decisions are influenced by external factors, and these random factors can affect the stability of the system. Therefore, it is necessary to consider random disturbances (Foster and Young, 1990). The stability of the stochastic evolutionary game equations can be assessed after the introduction of stochastic perturbations, using the judgment

theorem for the stability of stochastic differential equations (Baker and Buckwar, 2005).

$$\begin{cases} dx(t) = f(t, x(t))dt + g(t, x(t))d\omega(t) \\ x(t_0) = x_0 \end{cases} \quad (22)$$

We make the assumption that $x(t)$, $f(t, x)$ and $g(t, x)$ are scalars. Then let $x(t) = x(t, x_0)$ be the solution to Equation (22).

Suppose there is a smooth function $V(t, x)$ satisfying $c_1|x|^p \leq V(t, x) \leq c_2|x|^p$, $t \geq 0$, with c_1 and c_2 as positive constants. A stability evaluation is performed here, and two scenarios are presented.

Scenario 1: If there is a constant $\gamma > 0$ such that $LV(t, x) \leq -\gamma V(t, x)$, and $t \geq 0$, then the null solution of Equation (22) is exponentially stable in p-th mean, with $E|x(t, x_0)|^p < \frac{c_2}{c_1}|x_0|^p e^{-\gamma t}$,

Given the stochastic differential equation as in Equation (22).

$t \geq 0$.

Scenario 2: If there is a constant $\gamma > 0$ such that $LV(t, x) \geq -\gamma V(t, x)$, and $t \geq 0$, then the null solution of Equation (22) is not exponentially stable in p-th mean, with $E|x(t, x_0)|^p \geq \frac{c_2}{c_1}|x_0|^p e^{-\gamma t}$, $t \geq 0$.

For the replicated dynamic equations in Equations (16), (17), and (18), by setting $V_t(t, x) = x$, $V_t(t, y) = y$, $V_t(t, z) = z$ and considering $c_1 = 1$, $c_2 = 1$, $p = 1$, $\gamma = 1$, where $x \in [0,1]$, $y \in [0,1]$, $z \in [0,1]$, we derive the following equations.

$$LV(t, x) = f(t, x) = (\alpha R_{23}yz + 2\beta M_1y + R_{23}z - R_{23}yz - 2P - \alpha A - M_1 - \beta M_1 - C + R_1 + Syz + C_{12}y + C_{13}z + \alpha B)x \quad (23)$$

$$LV(t, y) = f(t, y) = (-\alpha R_{23}xz + R_{23}z - 2\beta M_2x - C + 2P + M_2 + \beta M_2 + R_2 + S - Sz + Sxz + R_2z + R_2x + R_2xz + B)y \quad (24)$$

$$LV(t, z) = f(t, z) = (-R_{23}y + R_{23}xy - R_{23}x - C + R_3 + S - Sy + Sxy + R_3y - R_3xy + R_3x)z \quad (25)$$

Consequently, the conditions that are satisfied for the null solution of Equations (16), (17), (18) to be exponentially stable at the p-th order moment are given below:

$$(\alpha R_{23}yz + 2\beta M_1y + R_{23}z - R_{23}yz - 2P - \alpha A - M_1 - \beta M_1 - C + R_1 + Syz + C_{12}y + C_{13}z + \alpha B)x < -x \quad (26)$$

$$(-\alpha R_{23}xz + R_{23}z - 2\beta M_2x - C + 2P + M_2 + \beta M_2 + R_2 + S - Sz + Sxz + R_2z + R_2x + R_2xz + B)y < y \quad (27)$$

$$(-R_{23}y + R_{23}xy - R_{23}x - C + R_3 + S - Sy + Sxy + R_3y - R_3xy + R_3x)z < z \quad (28)$$

Taylor Expansion of the Evolutionary Equations

Since Equations (16), (17), and (18) are nonlinear $\hat{I}t\hat{o}$ stochastic differential equations, obtaining explicit solutions proves to be challenging.

Therefore, stochastic Taylor expansions and $\hat{I}t\hat{o}$ formulas are employed to solve the numerical approximations.

In the case of a stochastic differential equation, as follows,

$$dx(t) = f(t, x(t))dt + g(t, x(t))d\omega(t) \tag{29}$$

Let the above equation be $t_0 \leq t \leq T$, $x(t_0) = x_0$, while $\omega(t)$ is a standard Wiener process. Moreover, assuming $h = (T - t_0)/N$ and $t_n = t_0 + nh$, the stochastic Taylor expansion can be obtained as follows,

$$x(t_{n+1}) = x(t_n) + I_0f(x(t_n)) + I_1g(x(t_n)) + I_{11}L^1g(x(t_n)) + I_{00}L^0f(x(t_n)) + R \tag{30}$$

In the above equation, $L^0 = f(x) \frac{\partial}{\partial x} + \frac{1}{2}g^2(x) \frac{\partial^2}{\partial x^2}$, $L^1 = g(x) \frac{\partial}{\partial x}$, $I_0 = h$, $I_1 = \Delta \omega_n$, $I_{00} = \frac{1}{2}h^2$, $I_{11} = \frac{1}{2}[(\Delta \omega_n)^2 - h]$, and R is the remainder term of the Taylor expansion.

Therefore, the above equation can be taken as the following equation,

$$x(t_{n+1}) = x(t_n) + hf(x(t_n)) + \Delta \omega_n g(x(t_n)) + \frac{1}{2}[(\Delta \omega_n)^2 - h]g(x(t_n))g'(x(t_n)) + \frac{1}{2}h^2[f(x(t_n))f'(x(t_n)) + \frac{1}{2}g^2(x(t_n))f''(x(t_n))] + R \tag{31}$$

In this study, the Milstein numerical method is used to address this problem, resulting in the Taylor expansion of the Japanese media, SDM, and LDM as shown in the following.

$$x(t_{n+1}) = x(t_n) + h(\alpha R_{23}y(t_n)z(t_n) + 2\beta M_1y(t_n) + R_{23}z(t_n) - R_{23}y(t_n)z(t_n) - 2P - \alpha A - M_1 - \beta M_1 - C + R_1 + Sy(t_n)z(t_n) + C_{12}y(t_n) + C_{13}z(t_n) + \alpha B)x(t_n) + \frac{1}{2}[(\Delta \omega_n)^2 - h]\sigma^2x(t_n) + \frac{1}{2}h^2(\alpha R_{23}y(t_n)z(t_n) + 2\beta M_1y(t_n) + R_{23}z(t_n) - R_{23}y(t_n)z(t_n) - 2P - \alpha A - M_1 - \beta M_1 - C + R_1 + Sy(t_n)z(t_n) + C_{12}y(t_n) + C_{13}z(t_n) + \alpha B)^2x(t_n) + \Delta \omega_n \sigma x(t_n) + R_1 \tag{32}$$

$$y(t_{n+1}) = y(t_n) + h(-\alpha R_{23}x(t_n)z(t_n) + R_{23}z(t_n) - 2\beta M_2x(t_n) - C + 2P + M_2 + \beta M_2 + R_2 + S - Sz(t_n) + Sx(t_n)z(t_n) + R_2z(t_n) + R_2x(t_n) + R_2x(t_n)z(t_n) + B)y(t_n) + \frac{1}{2}[(\Delta \omega_n)^2 - h]\sigma^2y(t_n) + \frac{1}{2}h^2(-\alpha R_{23}x(t_n)z(t_n) + R_{23}z(t_n) - 2\beta M_2x(t_n) - C + 2P + M_2 + \beta M_2 + R_2 + S - Sz(t_n) + Sx(t_n)z(t_n) + R_2z(t_n) + R_2x(t_n) + R_2x(t_n)z(t_n) + B)^2y(t_n) + \Delta \omega_n \sigma y(t_n) + R_2 \tag{33}$$

$$z(t_{n+1}) = z(t_n) + h(-R_{23}y(t_n) + R_{23}x(t_n)y(t_n) - R_{23}x(t_n) - C + R_3 + S - Sy(t_n) + Sx(t_n)y(t_n) + R_3y(t_n) - R_3x(t_n)y(t_n) + R_3x(t_n))z(t_n) + \frac{1}{2}[(\Delta \omega_n)^2 - h]\sigma^2z(t_n) + \frac{1}{2}h^2(-R_{23}y(t_n) + R_{23}x(t_n)y(t_n) - R_{23}x(t_n) - C + R_3 + S - Sy(t_n) + Sx(t_n)y(t_n) + R_3y(t_n) - R_3x(t_n)y(t_n) + R_3x(t_n))^2z(t_n) + \Delta \omega_n \sigma z(t_n) + R_3 \tag{34}$$

Numerical Simulation

Based on the previous analysis, this section examines the impact of various parameters on the media strategies regarding wastewater discharge incidents. Furthermore, this section explores the evolutionary process of the three parties through numerical simulations.

Data Collection and Parameter Settings

In this study, we performed numerical simulations using MATLAB 2020a software. These simulations visualize the iterative strategies of the involved entities and provide a quantitative analysis of their interactions, showing the evolution of strategies across different stages and parameters. In configuring the initial parameters for the model, we followed two guiding principles: 1) relevance to real-world scenarios, and 2) consideration of the logical relationships between parameters. To accommodate numerical simulations, certain parameters were rounded. Based on the current situation and the recommendations of the experts, here are the specific parameters of the scenario.

Several countries and regions, including China, Macau, Hong Kong, the United States, and South Korea, decided to either fully or partially halt imports of Japanese aquatic products after Japan began releasing nuclear-contaminated water. The ban imposed by China and South Korea alone is estimated to affect their combined aquatic product exports of US\$870 million. According to Kyodo News, Japan began discharging nuclear wastewater and subsequently established an 80 billion yen fund to support the affected aquatic industry. According to a research report by Founder Securities, Chinese companies expect to capture a market worth 676 million yuan as a result of the nuclear wastewater discharge incident. Revenue generated from consumption by foreign tourists contributed significantly to Japan's tourism economy, reaching 4.8 trillion yen in 2019, with Chinese tourists contributing

55.6%. However, after Japan dumped nuclear wastewater into the sea, people in China and South Korea felt dissatisfaction and resistance, which especially affected their willingness to travel to Japan. Statistically, 87% of Weibo users expressed their unwillingness to consider traveling to Japan in the near future. In addition, users on social media platforms conveyed a decline in confidence in Japanese products and considered suspending their use or purchase (Tencent News, 2023). Consequently, most of the market share lost by Japanese firms is expected to be absorbed by neighboring countries, leading to the assumption that $M_1 = M_2 = 10$. In evaluating the economic subsidies provided by the Japanese government, it appears that the primary political influence on the media is due to economic factors, so P is set to 10. Given the credibility and accountability of the Japanese media in reporting on the nuclear waste incident, their benefit is slightly greater than the economic influence, so R_1 is set at 13. Correspondingly, the benefits of SDM are assumed to be equal to its costs, lagging behind those of the Japanese media. LDM is assumed to have slightly higher benefits than SDM due to its geographical distance and commitment, which leads to R_2 being set at 5 and R_3 at 6. The media primarily serve the audience, so public dissatisfaction is a key factor influencing the audience's reluctance to engage with the media's information. Given the greater impact of public dissatisfaction on the media, B is set at 8. As for the coefficient of influence of public opinion on strategy choice (α) and economic impact intensity (β), both are set at 0.4. This decision reflects the current early stage of Japan's nuclear wastewater release, where the magnitude of related impacts is not yet significant. The Japanese media face a strategic dilemma, but generally lean toward a non-positivity strategy, initializing their willingness at 0.4, resulting in an initial willingness of 0.6 for the SDM. Currently, the LDM maintains a neutral stance, reflecting an initial willingness of 0.5. It is

important to note that the simulated system evolves in virtual time (t), not in real time.

Analysis of Evolutionary Results under the Current Scenario

Based on the previously defined parameters, this study simulates and evaluates the strategy preferences of the Japanese media, SDM, and LDM, and presents the results in Figure 2. The initial analysis shows that the Japanese media show some initial oscillation before leaning towards a non-positive reporting strategy and eventually stabilizing in this choice. Conversely,

SDM immediately adopts positive coverage strategies for nuclear wastewater events, with minor oscillations, and eventually settles on consistently positive strategies. LDM, however, exhibits oscillations between positivity and non-positivity strategy choices due to the relatively low impact of nuclear effluents on more distant countries at present. As a result, LDM does not pay much attention to the Japanese nuclear accident. Furthermore, the likelihood of LDM choosing positive strategies gradually decreases as the incident becomes less salient over time, leading LDM to prefer non-positivity strategies.

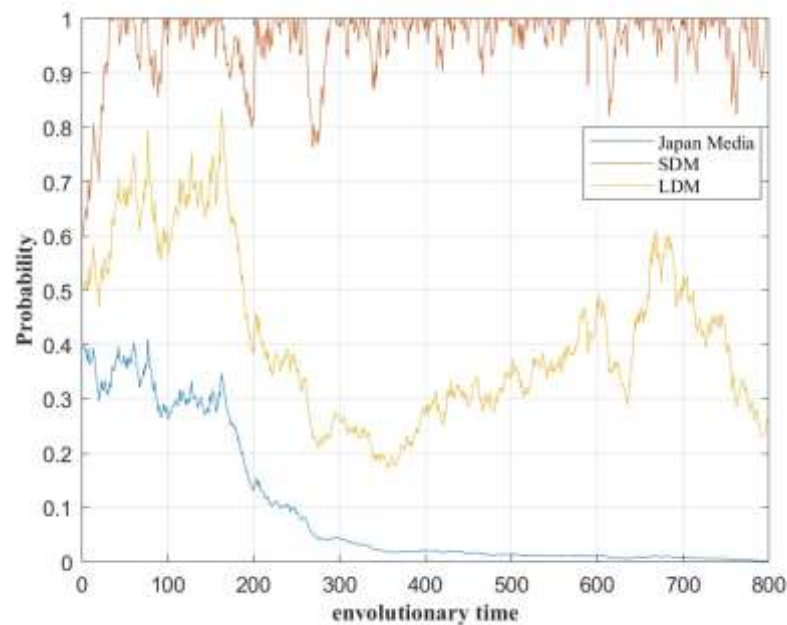


Figure 2. Evolutionary results under the current scenario

Impact of Non-Ratio Parameters

According to the analysis in the previous section, SDM consistently tends to choose the positive strategy, while the Japanese media tends to choose the non-active strategy, and LDM shows oscillation but tends to gradually shift toward the non-active strategy. In order to mitigate the impact of Japan's nuclear wastewater discharge and promote sustainable development, the positive participation of Japanese media and LDM in covering related events is crucial.

Therefore, this study deals with the influence of the parameters on their evolution, categorizing the relevant parameters into ratio and non-ratio segments. This paper conducts separate analyses for these two parameter categories.

Impact of C

The impact of C on the strategic choices of Japanese media and LDM is shown in Figure 3. Figure 3(a) shows a decreasing trend in the probability of Japanese media choosing positive strategies as C increases. In particular, when C is

greater than 5, there is a significant decrease in the Japanese media's propensity to choose positive strategies. Similarly, Figure 3(b) illustrates a decrease in the probability of LDM choosing positive strategies as C increases. Once C is greater than 5, there is also a significant decrease in the probability of LDM choosing positive strategies. In addition, the decrease in the probability of LDM choosing positive strategies appears to be more gradual compared to Japanese

media, suggesting that Japanese media are more reluctant to choose positive strategies for the same C value. This discrepancy suggests that Japanese media strategy choices are influenced by more factors than those impacting LDM, with the cost of positive strategies having a significant impact on Japanese media decision-making. Lower costs seem to encourage both Japanese media and LDM to choose positive strategies.

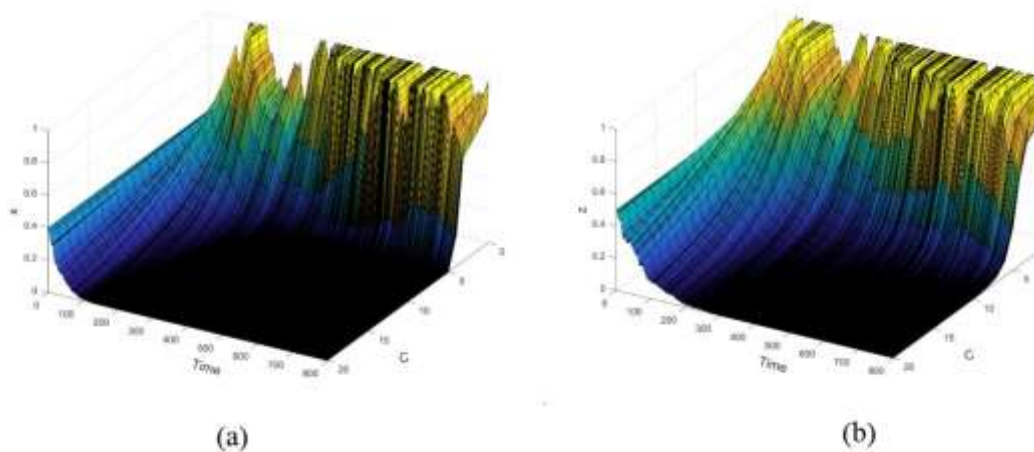


Figure 3. Impact of C on evolutionary results and trajectories. (a) on Japanese media; (b) on LDM

Impact of M_1

The impact of M_1 on the strategic choices of LDM and Japanese media is shown in Figure 4. Figure 4(a) shows that the probability of Japanese media choosing positive strategies decreases as M_1 increases. In particular, when M_1 is less than 5, Japanese media gradually lean toward positive strategies due to the reduced impact of M_1 on their strategic choices. Other factors gradually push the Japanese media to choose positive strategies in such cases. However, when M_1 is greater than 5, the Japanese media's willingness to choose positive strategies decreases significantly. During the early evolutionary stage, the maximum probability of Japanese media choosing positive strategies is reached at time 163, which coincides with an M_1 value of 0. Conversely, at the same time, with an M_1 of 20, the probability of Japanese media choosing positive strategies

decreases significantly to only 0.12. Figure 4(b) shows that the probability of LDM choosing positive strategies decreases as M_1 increases. Initially, at time 163, the probability of LDM choosing a positive strategy remains at 1 with M_1 of 0 and drops to 0.74 when M_1 increases to 20. This suggests that M_1 has a minimal impact on LDM's strategy choices in the early evolutionary phase. However, in the later stages, as M_1 increases, the probability of LDM choosing a positive strategy decreases, although with a smaller impact compared to Japanese media. The decrease in sponsorship from other firms due to the choice of positive strategies by Japanese media significantly impacts their strategic choices, and a smaller M_1 tends to bias both Japanese media and LDM toward positive strategies. This implies that maintaining sponsorship from domestic firms remains an effective strategy for Japanese media.

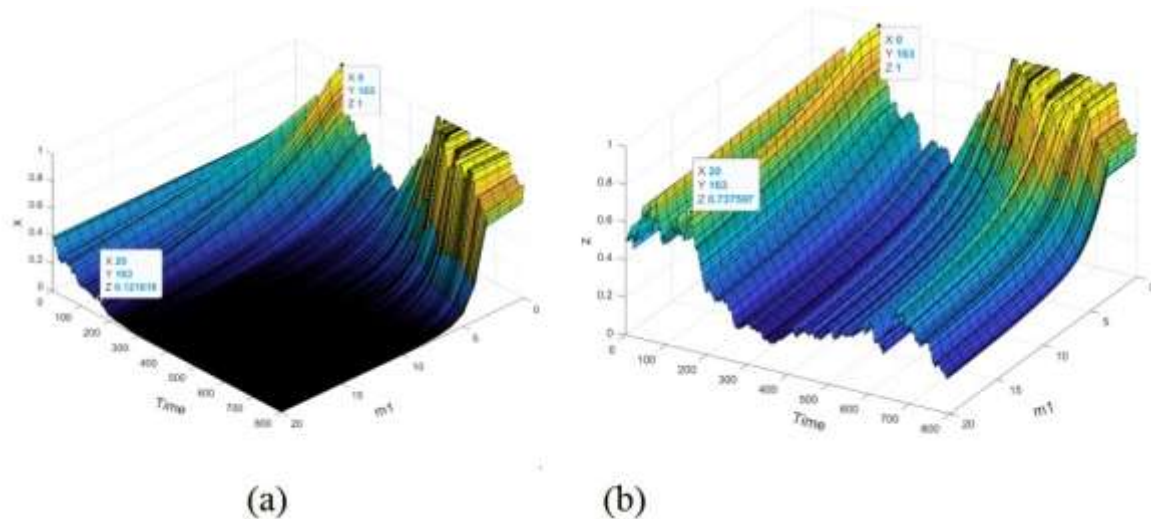


Figure 4. Impact of M_1 on evolutionary results and trajectories. (a) on Japanese media; (b) on LDM

Impact of M_2

The results of the evolutionary impact of M_2 on LDM strategy choice for Japanese media are shown in Figure 5. As shown in Figure 5(a), M_2 has a small impact on Japanese media strategy choices. Conversely, Figure 5(b) shows that the probability of LDM choosing positive strategies decreases as M_2 increases. When M_2 is less than 5, LDM tends to choose positive strategies. However, when M_2 is greater than 5, there's a

significant decrease in LDM's tendency toward positive strategies. While the revenue that SDM receives from adopting a positive strategy doesn't influence the Japanese media's decision, an escalation in M_2 significantly reduces the probability that LDM chooses a positive strategy. This disparity is due to the fact that M_2 doesn't directly impact the Japanese media, but rather affects the dynamic between LDM and SDM, with increased SDM coverage decreasing LDM's motivation to report.

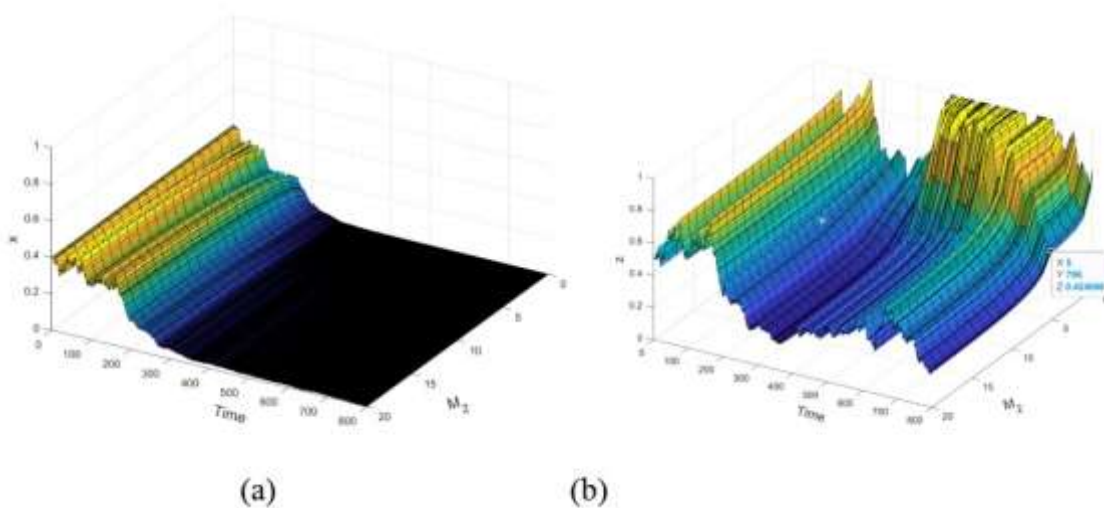


Figure 5. Impact of M_2 on evolutionary results and trajectories. (a) on Japanese media; (b) on LDM

Impact of P

Figure 6 shows the results of the evolution of the

P value regarding the strategy choice of Japanese media and LDM. As shown in Figure 6(a), the probability of Japanese media choosing positive

strategies decreases as P increases. When P is less than 9, Japanese media initially tend to choose positive strategies, then tend to choose non-positive strategies, and finally stabilize their choice of positive strategies. Conversely, when P is greater than 9, the probability of Japanese media choosing positive strategies decreases significantly. Figure 6(b) shows that the probability of LDM choosing positive strategies decreases as P increases. When P is less than 9,

LDM tends to choose a positive strategy, but this probability decreases as P increases to more than 9. The effect of P on Japanese media strategy choice is more significant than for LDM. This difference arises because Japan, as the country responsible for nuclear wastewater discharge, is subject to more political impact, and Japanese media are particularly sensitive to political factors.

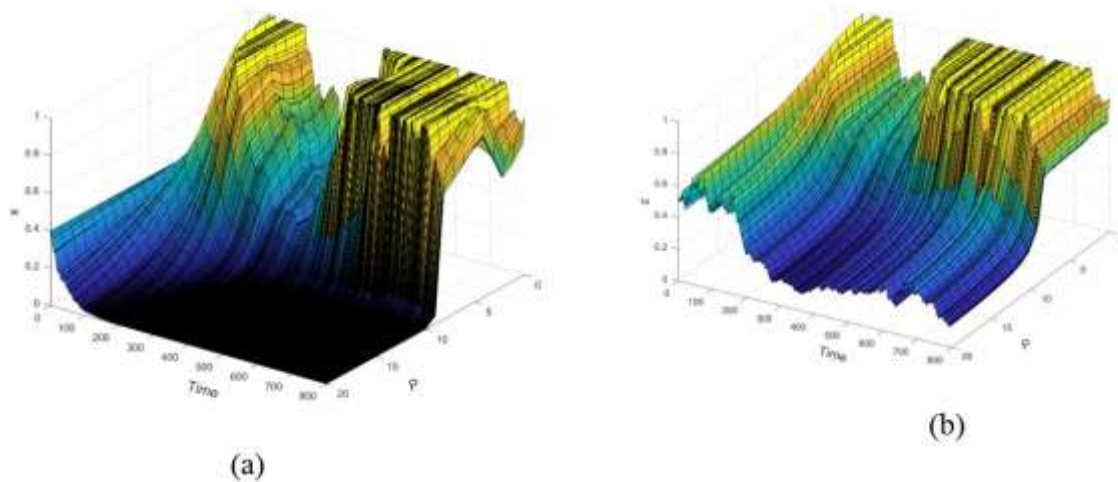


Figure 6. Impact of P on evolutionary results and trajectories. (a) on Japanese media; (b) on LDM

Impact of R_3

Figure 7 shows the results of the evolution of R_3 concerning the strategy choice of LDM and Japanese media. In Figure 7(a), the probability of Japanese media choosing a positive strategy increases as R_3 increases. When R_3 is less than 8, Japanese media tend to choose a non-positive strategy. Conversely, when R_3 is greater than 8, Japanese media tend to choose a positive strategy. Figure 7(b) shows that the probability of LDM choosing a positive strategy increases with increasing R_3 . When R_3 is less than 8, LDM chooses a non-positive strategy, but when $R_3 > 8$, the probability of LDM choosing the positive strategy increases significantly and eventually evolves towards choosing the positive strategy.

The increase in R_3 makes both Japanese media and LDM more likely to choose the positive strategy, with LDM being more affected by R_3 . At $R_3 = 8$, the probability of LDM choosing the positive strategy reaches 0.81, while for Japanese media the probability reaches 0.62. This difference is due to R_3 being the primary determinant of LDM's choice of strategy. R_3 exerts its impact on the Japanese media by affecting LDM's strategic decisions, which in turn affect other factors such as the synergistic fees paid by LDM to the Japanese media, the prestige of the media's image, and more. This chain of influence ultimately shapes the strategic decisions of the Japanese media.

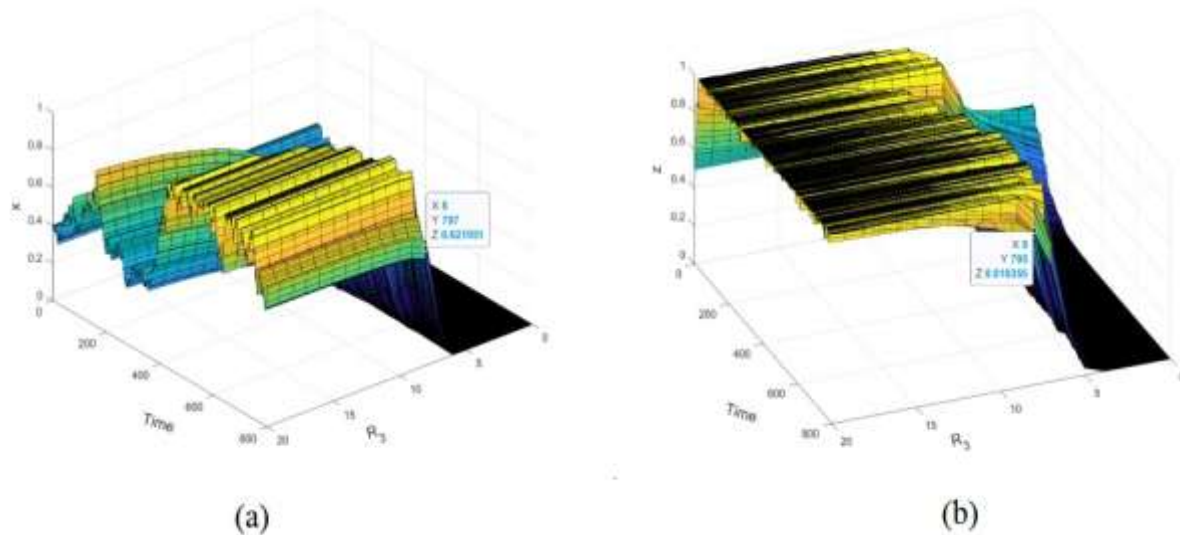


Figure 7. Impact of R_3 on evolutionary results and trajectories. (a) on Japanese media; (b) on LDM

Impact of R_{23}

The results of the impact of R_{23} on the strategy choice of LDM and Japanese media are shown in Figure 8. In Figure 8(a), it can be seen that the strategy choice of Japanese media is relatively unaffected by R_{23} ; regardless of the R_{23} , Japanese media consistently choose the non-positive strategy. As shown in Figure 8(b), the probability of LDM choosing the positive strategy decreases

as R_{23} increases. When R_{23} is less than 7, LDM tends to choose the positive strategy. However, for R_{23} values greater than 7, the probability of LDM choosing the positive strategy decreases significantly, ultimately leading to the choice of the non-positive strategy. This suggests that the LDM's choice of strategy is affected by the cost of collaborative reporting it faces; the lower the additional cost, the more willing the LDM is to choose the positive strategy.

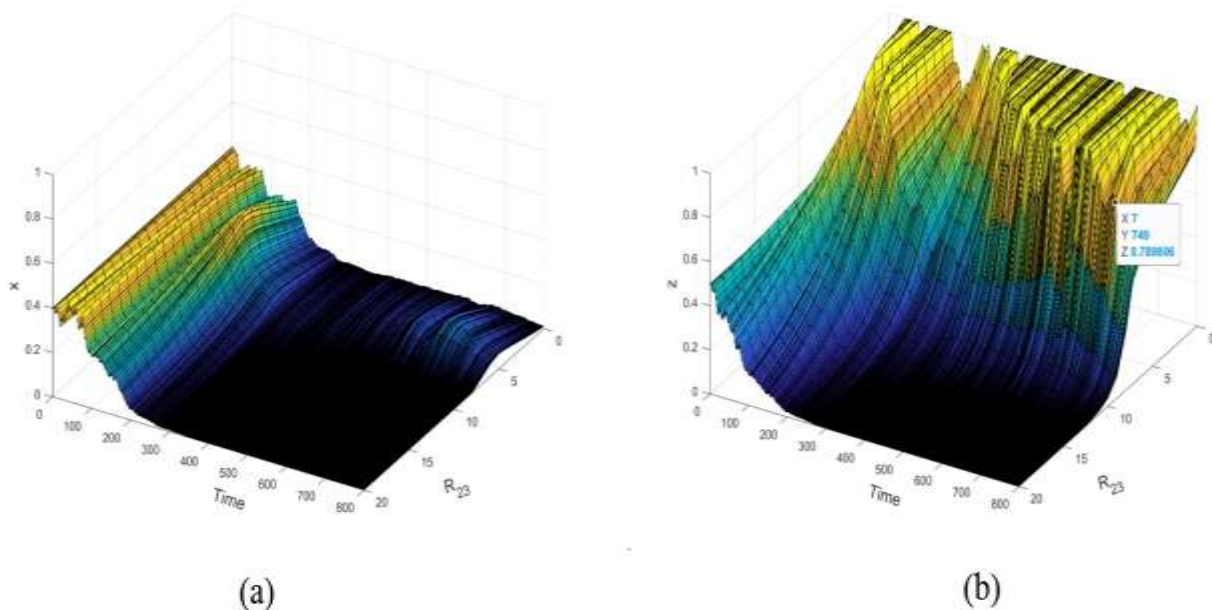


Figure 8. Impact of R_{23} on evolutionary results and trajectories. (a) on Japanese media; (b) on LDM

Impact of S

The results of the S impact on LDM and Japanese media are shown in Figure 9. In Figure 9(a), it's clear that the probability of Japanese media choosing the positive strategy increases as S increases. When S is less than 8, Japanese media tend to choose the non-positive strategy; however, when S is greater than 8, there is a significant increase in the Japanese media's tendency to choose positive strategies, which eventually evolves into a consistent choice of positive strategies. As shown in Figure 9(b), the probability of LDM choosing positive strategies

also increases with higher S values. For S values less than 8, LDM tends to choose the non-positive strategy. When S is greater than 5, the probability of LDM choosing the positive strategy increases significantly. Moreover, LDM's tendency to choose the positive strategy increases at a slower rate compared to Japanese media, indicating that Japanese media have a greater tendency to choose the positive strategy for the same S value. This difference suggests that the strategy choice of Japanese media is more affected by S due to Japan's role as a nuclear discharging country, which affects the reputation and image of the media based on their reporting strategy choice.

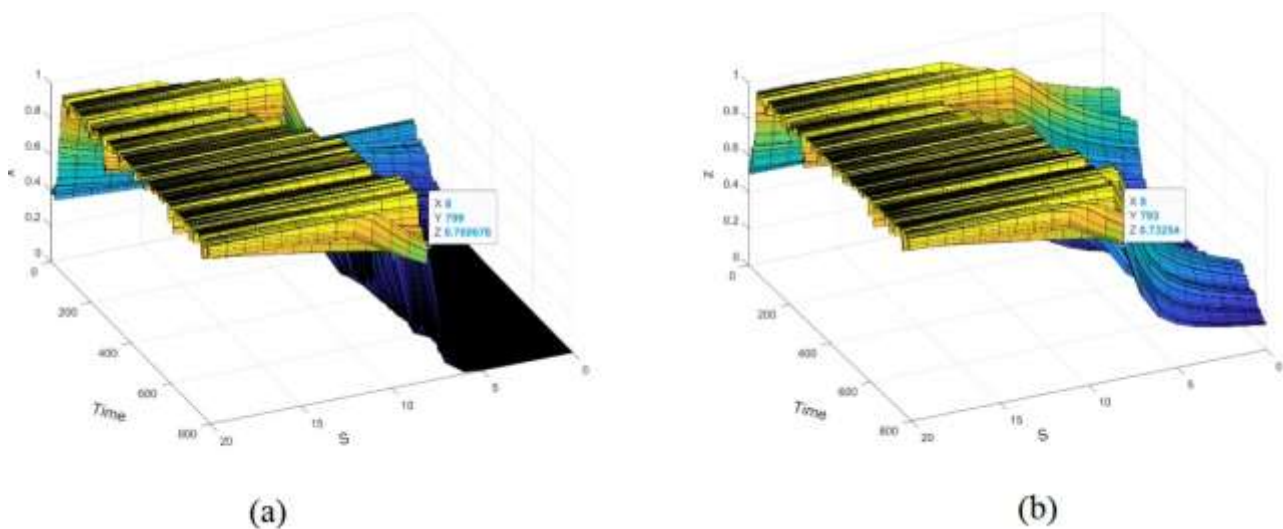


Figure 9. Impact of S on evolutionary results and trajectories. (a) on Japanese media; (b) on LDM

Impact of Ratio Type Parameters

In this section, we examine the impact of the ratio type parameter, which measures intensity, on the strategy choice of Japanese media and LDM. The data parameters are adjusted to satisfy the conditions of Equations (26), (27), (28). Through the analysis of Figures 10 and 11, we aim to observe the impact of the α and β parameters on the primary strategy choice. Three different scenarios with parameter values of 0.2, 0.4, and 0.6 are simulated and analyzed. The degree of overlap between the lines reflects the impact of the parameter on the strategy choice of the

subject, whereas a higher overlap indicates a lower impact of the parameter. The range of variation in a single line is more significant, indicating that the impact of the parameter on the subject's strategy choice becomes more significant over evolutionary time.

The vertical coordinates represent the probability of the Japanese media choosing the positive strategy (x) and the probability of the LDM choosing the positive strategy (z). The horizontal axis denotes the evolution time, using a time step of 0.00125. Three scenarios with parameter values of 0.2, 0.4, and 0.6 are examined, and the

data coordinates at the time when the probability

of evolution reaches its peak are labeled.

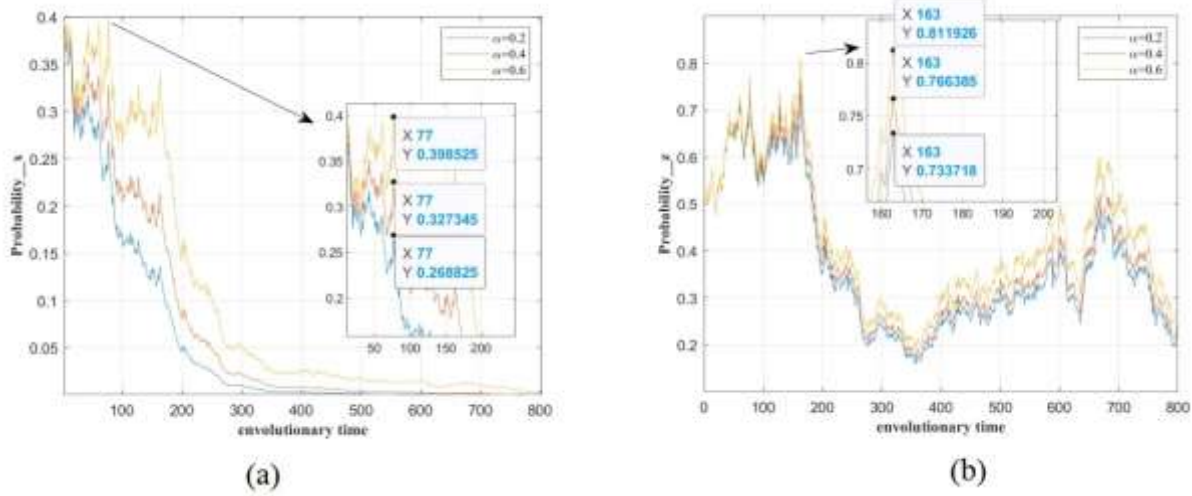


Figure 10. Impact of α on evolutionary results and trajectories. (a) on Japanese media; (b) on LDM

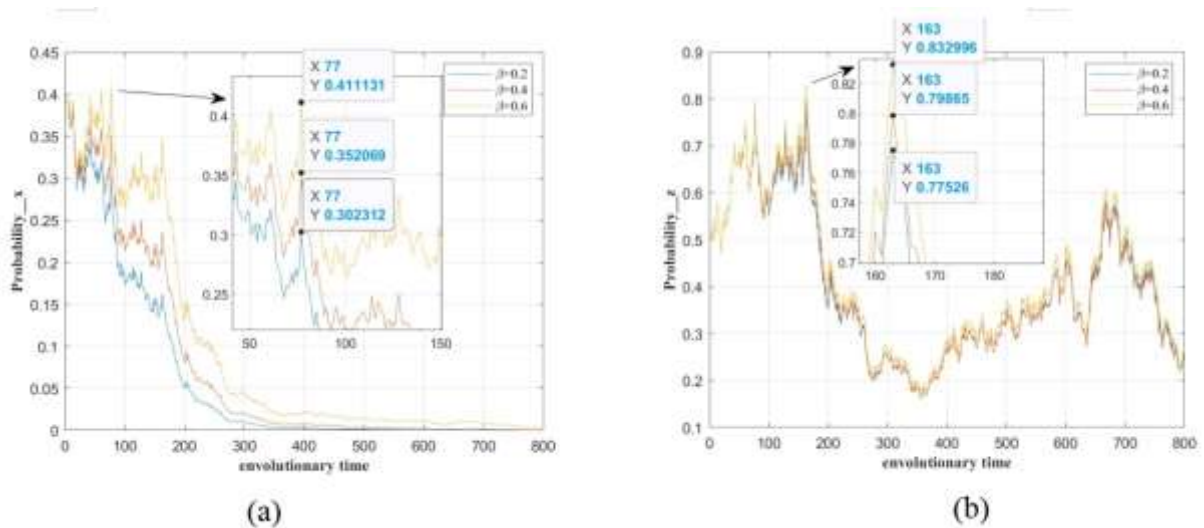


Figure 11. Impact of β on evolutionary results and trajectories. (a) on Japanese media; (b) on LDM

The discussion and analysis of the data are presented in Table 3. Symbols such as "*", **, ***" are used to distinguish between the validity of parameter values and the priority of variable adjustment. In the "value of the time when the probability of choosing the strategy first reaches zero" data group, the relative effectiveness of the parameter values is represented by three intervals, intercepted at 1/3 increments. The initial and final values are noted, with a smaller value indicating a faster convergence of the main strategy probability to

zero, indicating greater effectiveness in the data. The categorization criteria are as follows: "*" for intervals [287, 397), "**" for intervals [397, 507], and "***" for intervals (507, 617]. Similarly, for the data group "maximum difference in the value of the time when the strategy choice probability of a strategy subject first reaches zero", "*" represents the interval [303, 312), "**" for intervals [312, 321], and "***" for intervals (321, 330]. For the data group "difference in peaks", "*" represents the interval [0.058, 0.082), "**" for intervals [0.082, 0.106], and "***" for intervals (0.106,

0.13]. The evolution of a variable under random perturbation is characterized by "↑" and "↓". If the maximum value of a variable during evolution is less than the initial value, it is labeled "↓";

otherwise, it is labeled "↑". The term "maximum" denotes the probability of the Japanese media and LDM choosing a positive strategy at different values of the parameter.

Table 3. Discussion and results of ratio type parameters

	Value	Maximum values (time value)	The value of the time when the probability of choosing the strategy first reaches zero	Maximum difference in the value of the time when the strategy choice probability of a strategy subject first reaches zero	Difference in peaks (peaks of respective choice of positive strategies)
α	0.2	$x = 0.269$ (77)↓	287(x) *	330***	0.13(x)***
		$z = 0.734$ (163)↑			0.078(z) *
	0.4	$x = 0.327$ (77)↓	351(x) *		
		$z = 0.766$ (163)↑			
	0.6	$x = 0.399$ (77)↓	617(x)***		
		$z = 0.812$ (163)↑			
β	0.2	$x = 0.302$ (77)↓	287(x) *	303*	0.109(x)***
		$z = 0.775$ (163)↑			0.058(z) *
	0.4	$x = 0.352$ (77)↓	339(x) *		
		$z = 0.799$ (163)↑			
	0.6	$x = 0.411$ (77)↑	590(x)***		
		$z = 0.833$ (163)↑			

Analysis of Peak Differences

In general, the peak difference serves as a measure of the change in the strategy choices of the decision-makers. By comparing Figures 10 and 11 with Table 3, it's obvious that the peak probability of the Japanese media choosing a positive strategy occurs at evolution time 77, while the peak probability of the LDM choosing a positive strategy occurs at evolution time 163.

Peak differences in the subjects' strategy choices were assessed by adjusting the values of α and β . The larger the peak difference, the more significant the change in strategy choice. Through comparative analysis, the priority of variable adjustment was obtained by first adjusting the impact of α on Japanese media, and then adjusting the impact of β on Japanese media. Next, adjustment of the impact of α on LDM and then adjustment of the impact of β on LDM.

The initial setting for α is 0.4, which indicates the strength of the influence of public opinion on strategy decisions. While α primarily affects Japanese media, its influence extends to some degree to LDM due to their synergistic relationship. Simulation data shows that increasing α to 0.6 increases the probability that both Japanese media and LDM will choose a positive strategy. Similarly, the initial value of β is set to 0.4, which represents the economic influence on Japanese media and SDM regarding the coverage of nuclear wastewater-related events. The simulation results show that an increase in β also increases the probability of choosing a positive strategy for both Japanese media and LDM.

In conclusion, increasing the value of α serves as a more effective means to increase the adoption of positive strategies by both Japanese media and LDM.

Analysis of the value of the time when the probability first reaches 0

The earliest moment when the probability of a positive strategy reaches zero indicates the convergence speed of the subject's decision process. A comparative analysis of Figures 10 and 11 along with Table 3 reveals a notable trend: within the parameter range defined in this study, the probability of LDM choosing a positive strategy gradually decreases but doesn't eventually reach zero. Conversely, the probability of Japanese media choosing a positive strategy reaches zero. Notably, at α value of 0.2, convergence occurs rapidly at time 287, reflecting the Japanese media's strong adherence to the non-positive strategy. In contrast, at α of 0.6, the convergence extends to time 617, indicating a more pronounced inclination of the Japanese media toward the positive strategy. Notably, the time difference for changes in α extends to time 330, exceeding the time difference for β , highlighting the stronger influence of α as a determining factor. Thus, the primary focus for

variable adjustment lies in increasing the α value, followed by increasing the β value.

Analysis of the Peak Values

Due to the variety of media platforms and the complex impact of external influences, fluctuations in strategy choices manifest as peaks. These peaks, which represent the highest probability of choosing the positive strategy for both Japanese media and LDM, signify an expected evolutionary game result and serve as a metric for measuring the stability of strategy choices. Among the various conditions observed in this study, the maximum peak for Japanese media reaches 0.411, which exceeds the initial probability only once, and the β at this moment is 0.6. Meanwhile, the maximum peak of LDM under the condition of β of 0.6 is 0.833, which means that the β parameter produces the highest peak for both Japanese media and LDM.

On the other hand, " \uparrow " indicates that the probability of the subject choosing a positive strategy exceeds the initial value. Specifically, there are 3 instances " \uparrow " in the α evaluation, while there are 4 instances " \uparrow " in the β evaluation. The change in the β variable is more likely to incentivize both the Japanese media and the LDM to choose positive strategies.

Consequently, the primary emphasis in variable adjustment lies in increasing the β value, with subsequent attention directed toward changing the α value.

Ratio-Type Parameter Combinatorial Analysis

Given limited resources, prioritizing the most effective strategy is essential. While increasing β significantly impacts the strategic choices of both Japanese media and LDMs, leading to a higher probability of choosing the positive strategy, increasing α emerges as a more effective approach overall. α has a greater impact on Japanese media in particular, as indicated by the peak difference analysis and the earliest convergence time to zero probability. Japan, as a

country that discharges nuclear wastewater, is significantly influenced by the strategic choices of its media, which profoundly affect the development of such events. Therefore, the effective adjustment of the variables should aim to exert more influence on the strategic choices of the Japanese media. Conversely, the difference in the impact of α and β , each set at 0.6, on the Japanese media and the peak of LDM is 0.012 and 0.021, respectively, reflecting relatively small differences. In addition, β represents the impact of corporate sponsorship, which involves collaboration between corporations and the media, making adjustments to the value of β more difficult to implement. In summary, the analysis concluded that priority should be given to increasing the value of α over adjusting β .

Conclusions, Policy Implications, Limitations, and Future Work

Conclusions

The strategic decisions made by the tripartite media regarding the discharge of nuclear wastewater in Japan have important practical implications for the protection of the marine environment and the promotion of sustainable human development. This study establishes a stochastic evolutionary game model involving Japanese media, SDM, and LDM. It determines the payoff matrices for these parties and introduces Gaussian white noise into the dynamic equations. We then use stochastic Taylor expansion for numerical approximation and analyze the three-party dynamics through numerical simulations. Finally, we examine the impact of key variables on the stochastic evolution of the tripartite system to provide guidance to stakeholders in choosing strategies for marine environmental protection and sustainable development. The main findings of this study are summarized below.

The main conclusions can be summarized as follows: 1) In the current scenario, Japanese

media are gradually tending to choose the non-positive strategy, while LDM shows consistent oscillation between strategies, gradually tending to choose the non-positive strategy. In contrast, SDM remains steadfast in adopting the active strategy. 2) The introduction of Gaussian white noise causes the evolutionary paths of the participants to fluctuate around a smooth curve. However, excessive Gaussian white noise leads to a bias in the equilibrium strategy. 3) Essential parameters, such as the coefficient of public opinion influence, economic impact intensity, synergy fees paid by LDM, sponsorship loss by Japanese media, political influence, and prestige, significantly impact the evolutionary trajectory and result. In particular, the sponsorship gained by SDM and the synergy fees paid by LDM have minimal impact on the strategic decisions of Japanese media. 4) Parameters related to the ratio, such as the public opinion influence coefficient, have a greater impact on the degree and speed of change in the strategic decisions of decision-makers. Meanwhile, the economic influence intensity has more impact on the stability of these strategic decisions. Notably, adjusting the opinion influence coefficient is more important than changing the economic influence intensity.

In summary, this study uses the tripartite stochastic evolutionary game model to analyze the media coverage strategies of Japan's nuclear wastewater discharge incident. It contributes to the emerging theories of time dissemination and provides practical insights for promoting marine environmental protection and sustainability. The research explores media reporting strategies during current high-profile emergencies and provides valuable guidance for environmental protection organizations, such as international environmental organizations. In addition, the inclusion of Gaussian white noise captures environmental uncertainty and extends the application of stochastic theory in the analysis of hotspot event coverage. This study also highlights

the effectiveness and operational difficulties of control methods, thereby enhancing the validity of the research findings.

Policy Implications

Based on the above analysis, this paper outlines several policy implications for the Japanese media, the SDM, the LDM, and relevant international organizations. The goal is to strengthen the LDM's inclination toward positive reporting and facilitate the Japanese media's transition to a positive reporting strategy regarding the nuclear wastewater incident. Advocating for positive reporting by the LDM, especially if Japan refrains from adopting such a stance, could attract increased global attention to Japan's nuclear wastewater discharge. This attention could further efforts to protect the marine environment and promote sustainable development of the earth.

The choice of reporting strategies by the Japanese media requires careful consideration of political pressures, corporate sponsorship, public opinion, and their financial position and reputation. To minimize the influence of adverse factors, they should strive to present relevant events in a positive light. Maintaining a serious and impartial image while adhering to media ethics and standards is paramount. Emphasizing investigative journalism, especially in-depth reporting, leveraging local strengths, and providing detailed, comprehensive coverage can enhance credibility and attract support and funding from other media outlets. To manage political pressure, a multi-pronged approach that seeks information from a variety of perspectives, including interviews with business experts, technologists, and the public, can mitigate the impact of such pressure on reporting.

For the SDM, LDM, and relevant international organizations, it is important to positively report on relevant events to reap benefits such as increased traffic and prestige, while at the same

time rallying global efforts to protect the marine environment and achieve sustainable development. First and foremost, it is crucial to strengthen public opinion monitoring and exert pressure to draw international attention to Japan's nuclear wastewater discharge incident and the role of Japanese media. This pressure is aimed at encouraging the Japanese media to take positive reporting strategies. In addition, it is essential to establish appropriate regulatory frameworks to ensure accuracy and impartiality in reporting on nuclear wastewater issues. Monitoring press freedom and independence in media coverage is crucial. Adjusting the strength of public opinion's influence on the Japanese media is proving to be a highly effective approach. External organizations can increase this influence by publishing relevant reports and raising public awareness, thereby encouraging the Japanese media to adopt positive strategies. Assisting with the Japanese media is another avenue to explore. International assistance and security protection can safeguard their press freedom while establishing global cooperation and financial support can incentivize the provision of valuable information by Japanese media. Collective efforts are aimed at improving media coverage of the nuclear wastewater discharge incident and realizing sustainable development goals. Furthermore, if the Japanese media persist in inadequate or biased reporting, other media outlets should choose positive reporting strategies to promote their interests and attract global attention, thereby contributing to marine environmental protection and sustainable development goals.

Limitations

This paper has several limitations. First, we have categorized the media outside of Japan into only two groups, which may warrant further subdivision to include a wider range of actors, taking into account the different national contexts of different countries. In addition, our analysis focuses only on Japanese media, SDM, and LDM,

incorporating Gaussian white noise. However, other entities outside of the media, but relevant to the coverage of the nuclear wastewater incident, may have influence. Expanding the scope of participants in the game could lead to more realistic conclusions. In addition, since the nuclear wastewater discharge incident in Japan is relatively recent, its full impact remains uncertain. Continued observation and analysis of this incident are necessary to fully understand its impact.

Future Work

Future research goals include exploring the creation of a more comprehensive model that takes into account the diverse interests of multiple stakeholders in complicated real-world scenarios. In addition, as Japan's nuclear wastewater discharge incident is a first-of-its-kind event in the world, numerous new issues continue to emerge, making the construction of a real-time simulation model challenging. Therefore, the future research direction will emphasize the ongoing development of a real-time system that integrates data mining, machine learning, and related techniques to address this complexity. In addition, the influence of various factors such as social culture, religious beliefs, and environmental aspects in different countries significantly shape media coverage strategies. Subsequent research can broaden the focus to thoroughly explore the impact of these factors.

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

ZiDu Chen: Data collation, visualization, writing-original draft. PD Song: investigation, methodology, visualization, writing-review and editing. CM Li: Conceptualization, formal analysis, methodology, visualization, writing-original draft, writing-re-

view and editing.

Declaration of competing interest

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

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