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Data-Driven Strategies in the Evolutionary Game of Green Port Construction: Analyzing Policy Incentives for Shore Power Adoption

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Abstract: - This study addresses the critical challenge of green port construction in China, with a focus on the underutilized potential of shore power technology, through a computational lens. By establishing an evolutionary game model that captures the intricate dynamics among ports, shipping companies, and government agencies, we introduce a computational framework that utilizes advanced data analytics, network simulations, and optimization algorithms to evaluate policy incentives and their efficacy. The heart of our analysis lies in the deployment of network simulation tools and predictive analytics, which facilitate a deep dive into the operational dynamics and strategy adaptations within the tripartite system. Our findings underscore the pivotal role of government subsidies, quantitatively determined through optimization algorithms, in influencing the evolutionary path towards sustainable port operations. The research demonstrates that a carefully calibrated subsidy regime, informed by simulation outcomes and data-driven insights, can significantly boost the adoption of shore power technologies among ports and shipping companies, nurturing a symbiotic relationship that accelerates green construction efforts. Furthermore, the study leverages computational algorithms to simulate initial game scenarios, revealing how the presence of shore power infrastructure and technology-ready ships can catalyze a cooperative push towards environmental goals. Through a comprehensive computational approach, including the use of mathematical modeling and the analysis of vast datasets, the paper highlights the transformative power of policy interventions guided by computational intelligence. The conclusions drawn not only emphasize the necessity for targeted government action but also showcase the potential of computer science methodologies in crafting and implementing effective environmental policies, offering a novel pathway to expedite the green transformation of China’s maritime infrastructure.

Keywords: Green Port Construction, Shore Power Technology, Evolutionary Game, Simulation, Computational Algorithms, Data Analysis

I. INTRODUCTION

In an era where global environmental issues are becoming increasingly pronounced, the role of ports, especially the emissions from ships docked at these ports, has been identified as a significant contributor to overall pollution levels. Statistically, emissions from ships in coastal port cities are responsible for 20% to 40% of total pollution emissions[1], a fact that has catalyzed an urgent call for enhanced environmental governance in ports and their associated sectors. Urban centers, in particular, are grappling with the adverse effects of sulfur oxides (SOx), nitrogen oxides (NOx), and particulate matter emitted by ships, which have been pinpointed as primary sources of air pollution[2-4]. The considerable scale of this energy consumption and emission poses a dire threat to public health and the urban living environment[4,5], thereby underscoring the necessity for an accelerated shift towards green port construction within the broader context of global environmental protection efforts.

As China edges closer to its ambitious "double-carbon" targets, the imperative to mitigate port pollution and emissions has become more pronounced. This has been reflected in a series of pivotal policy initiatives, such as The Measures for the Administration of Shore Power at Ports and Ships, introduced by the Ministry of Transport in 2019, and The 14th Five-Year Development Plan for Green Transport, launched in 2021[6]. These legislative frameworks have set stringent benchmarks for the energy consumption and emissions of ports and ships, underscoring a nationwide commitment to fostering sustainable port operations. Within the spectrum of solutions aimed at green port construction, shore power technology emerges as a focal point due to its potential to cut down major pollutant emissions from ships by 40% to 70%[7-9]. However, despite the clear environmental benefits, the penetration of shore power technology in China's ports was recorded at less than 7% in 2019[10-11], highlighting a conspicuous gap between potential and actual adoption. This discrepancy can primarily be attributed to the high capital and operational costs associated with the deployment of shore power infrastructure[12-13], which poses a substantial financial burden on both ports and shipping companies, deterring widespread adoption. Moreover, the collaborative dimension of implementing shore power technology,

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necessitating concerted efforts between ports and shipping companies for system compatibility and efficiency[14-15], introduces additional challenges to its proliferation.

Past scholarly endeavors have predominantly centered on two pivotal mechanisms to bolster green port construction: the imposition of carbon taxes or punitive measures[16-20], and the provision of subsidies or preferential policies[21-25]. While the former strategy leverages economic disincentives to nudge ports and shipping companies towards environmentally friendly practices, the latter approach focuses on financial incentives to foster the adoption of green technologies, including shore power. The application of game theory has proven instrumental in dissecting the dynamic interplay between governmental policy interventions and port green construction efforts[18-20]. This analytical approach has not only illuminated the barriers impeding the progression of green construction initiatives but has also explored the efficacy of various policy instruments in promoting sustainable practices[23,26]. Recognizing the tripartite nature of the green construction endeavor, encompassing the government, ports, and shipping companies[27-29], this paper seeks to advance the discourse by integrating computational techniques to refine the analysis of these interactions.

This study propels the discussion forward by constructing a sophisticated computational model that simulates the complex dynamics of the tripartite game involving ports, shipping companies, and the government. By leveraging the capabilities of computational science, including data analytics, network simulations, and algorithmic optimizations[30-31], this paper offers a granular exploration of the strategic choices confronting each stakeholder under varying subsidy schemes and operational conditions. These computational methodologies enable a nuanced understanding of the ecosystem, facilitating a precise articulation of how different policy incentives might influence the adoption rates of shore power technology and, by extension, the green construction of ports.

The integration of computational techniques allows for the simulation of diverse scenarios, where the introduction of shore power technology and its acceptance by the maritime community can be forecasted with greater accuracy. By employing mathematical modeling to predict the outcomes of specific policy measures, this research underscores the transformative potential of computational insights in enhancing the decision-making process. Through algorithmic analysis, the study elucidates the conditions under which ports and shipping companies are more likely to embrace green technologies, thereby contributing to the collective effort of achieving sustainable development goals. By marrying the disciplines of environmental science and computational research, this investigation not only adheres to the immediate objective of promoting green port construction but also pioneers a novel approach to environmental policy analysis. The use of computational models and data-driven simulations represents a leap forward in the quest to reconcile economic viability with environmental stewardship, offering a blueprint for leveraging technological advancements in the service of ecological sustainability.

II. Model Construction

Shore power technology requires the joint construction of port, shipping company, and government. When shore power equipment is introduced to the port, the shipping company needs to install the corresponding interface equipment on the ship to achieve the emission-reducing effect of using shore power. At the same time, previous researches have strongly proved the efficiency of government subsidies in effectively promoting the application of shore power technology and the necessity of government policies for the green construction of port. To this end, the three-party standard game of port, shipping company, and government was hereby taken as the limited rational subject. Among them, the port can choose two strategies of green construction and no construction, the shipping company can choose emission reduction transformation and no transformation, and the government can choose construction subsidy and operation subsidy. The payoff obtained by the three game players after the adoption of different strategies are shown in Table 1, in which the upper section is the port payoff, the middle section is the shipping company payoff, and the lower section is the government payoff. s_{ij} indicates the j-th strategy of the game participant i.

Table 1: The Tripartite Game Payoff Matrix

Port / Shipping company / Government	Construction subsidies (s_{31})		Operating subsidies (s_{32})	
	Emission reduction transformation(s_{21})	No transformation (s_{22})	Emission reduction transformation (s_{21})	No transformation (s_{22})
Green construction (s_{11})	$\pi_1 - F_1 - C_{11} + B$ $\pi_2 - F_2 - C_{21}$ $\pi_3 - B$	$-F_1 + B$ 0 $-B$	$\pi_1 - F_1 - C_{11}$ $+ M_1$ $\pi_2 - F_2 - C_{21}$ $+ M_2$ $\pi_3 - M_1 - M_2$	$-F_1$ 0 0
No construction (s_{12})	$\pi_1 - C_{12}$ $\pi_2 - F_2 - C_{22}$ 0	$\pi_1 - C_{12}$ $\pi_2 - C_{22}$ 0	$\pi_1 - C_{12}$ $\pi_2 - F_2 - C_{22}$ 0	$\pi_1 - C_{12}$ $\pi_2 - C_{22}$ 0

When the results of the game is (s_{11}, s_{21}), the port and shipping company can complete the green construction and normal operation, achieving the benefits of π_1 and π_2, respectively. The port and the shipping company purchase equipment and introduce technology for green construction and emission reduction transformation. The costs are F_1 and F_2, respectively. and the daily operating costs are C_{11} and C_{21}. When the result is (s_{11}, s_{22}), because the shore power equipment at the port does not match the shipping company, the port and the shipping company can not operate normally, and both of them lose the profits, and do not generate daily operation costs of C_{11} and C_{21}. When the result of the game is (s_{12}, s_{21}) and (s_{12}, s_{22}), the port and shipping company can operate in traditional energy-intensive ways to generate revenue, and the operating costs are C_{12} and C_{22}. When the government chooses the construction subsidy strategy, it will give the subsidy of B to the port for green construction. When the government chooses the strategy of operating subsidies, it gives subsidies of M_1 and M_2 to the port and shipping company under the green operation mode. Only when the port and shipping company complete the green operation model, the government can gain revenue of π_3 through credibility. The specific parameters are shown in Table 2.

Table 2: Game-related Parameters

Player	Parameter	Explanation
Port	π_1	Proceeds from the normal operation of the port
	F_1	Port green construction cost
	C_{11}	Port green operation costs
	C_{12}	Traditional port operating costs
Shipping company	π_2	Income from the normal operation of the shipping company
	F_2	Emission reduction and transformation cost of the shipping company
	C_{21}	Green operating costs of the shipping company
	C_{22}	Traditional operating costs of the shipping company
Government	π_3	Green operation of the government's credibility benefits
	B	Government transfer payments to the port during the construction subsidies
	M_1	Government transfer payments to the port during the operating subsidies
	M_2	Government transfer payments to the shipping company during the operating subsidies

In order to make the model more realistic and reasonable, the following assumptions were hereby made on the parameters. The amount of government subsidies for port construction is not less than the sum of operating subsidies for the port and the shipping company, and is not greater than the green construction cost of the port, namely, $M_1 + M_2 \leq B$. The port and shipping company have a positive income in the traditional operating model, namely, $\pi_1 - C_{12} > 0, \pi_2 - C_{22} > 0$. According to the basic principle of shore power, the green operating costs are less than the traditional operating costs, namely, $C_{12} > C_{11}, C_{22} > C_{21}$. According to the current situation of the lack of power for shore power construction, the income of the green port construction is less than that of the traditional model when the government subsidy is 0, that is $\pi_1 - F_1 - C_{11} < \pi_1 - C_{12}$ and $0 < \pi_2 - C_{22}$. The profit of the government after achieving the green construction is positive, that is $\pi_3 - B > 0, \pi_3 - M_1 - M_2 > 0$.

III. EVOLUTION GAME

According to the basic assumptions of the parameters in the model, there are three pure strategy Nash equilibrium in the game, $(s_{11}\ s_{21}, s_{32})$, (s_{12}, s_{22}, s_{31}), and (s_{12}, s_{22}, s_{32}) when the conditions of $\pi_1 - F_1 - C_{11} + M_1 > \pi_1 - C_{12}$ are met. Only (s_{11}, s_{21}, s_{32}) can complete the green port construction, to achieve the results of energy conservation and emission reduction. If the above condition is not met, the two pure strategy Nash equilibrium of (s_{12}, s_{22}, s_{31}) and (s_{12}, s_{22}, s_{32}) cannot realize the green port construction. Since the participants in the game are incomplete rational subjects, the way of the evolutionary game was hereby adopted to explore the path leading to equilibrium in various situations.

It is assumed that the port, shipping company, and government adopt the probability of strategy of s_{11}, s_{21}, and s_{31} is x, y,z. The possibility of adopting s_{12}, s_{22}, and s_{32} is $1-x$, $1-y$, and $1-z$. The expected payoff of the port, shipping company, and government are as follows:

$$U_1(x,y,z) = x(y\pi_1 - yC_{11} + yM_1 - yzM_1 + zB - F_1) + (1-x)(\pi_1 - C_{12}) \tag{1}$$

$$U_2(x,y,z) = y(xC_{22} - xC_{21} + \pi_2 - F_2 - C_{22} + xM_2 - xzM_2) + (1-y)(1-x)(\pi_2 - C_{22}) \tag{2}$$

$$U_3(x,y,z) = z(xy\pi_3 - xB) + (1-z)(xy\pi_3 - xyM_1 - xyM_2) \tag{3}$$

The dynamic replication equations of the port, shipping company, and government are:

$$F(x,y,z) = x(1-x)(y\pi_1 - yC_{11} + yM_1 - yzM_1 + zB - F_1 - \pi_1 + C_{12}) \tag{4}$$

$$G(x,y,z) = y(1-y)(-xC_{21} - F_2 + xM_2 - xzM_2 + x\pi_2) \tag{5}$$

$$L(x,y,z) = z(1-z)(xyM_1 + xyM_2 - xB) \tag{6}$$

The stability of each game result could be analyzed by using the Jacobian matrix, and the Jacobian matrix was constructed as follows:

$$\Sigma = \begin{bmatrix} \frac{\partial F(x,y,z)}{\partial x} & \frac{\partial F(x,y,z)}{\partial y} & \frac{\partial F(x,y,z)}{\partial z} \\ \frac{\partial G(x,y,z)}{\partial x} & \frac{\partial G(x,y,z)}{\partial y} & \frac{\partial G(x,y,z)}{\partial z} \\ \frac{\partial L(x,y,z)}{\partial x} & \frac{\partial L(x,y,z)}{\partial y} & \frac{\partial L(x,y,z)}{\partial z} \end{bmatrix}$$

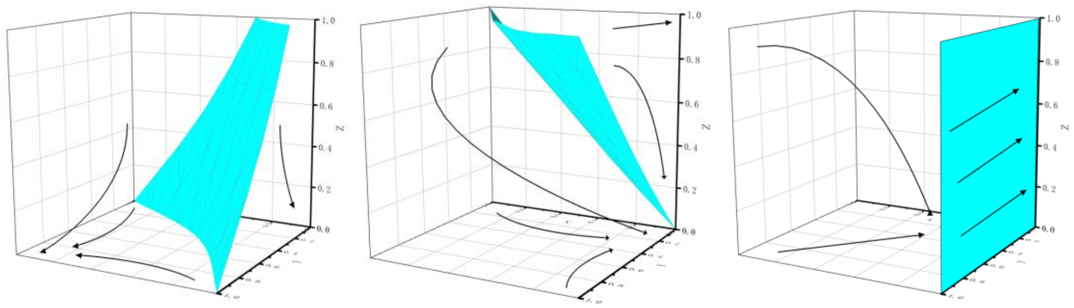
The equilibrium analysis across the results is shown in Table 3.

Table 3: Equilibrium Analysis Table of All Results

Bear fruit	$\frac{\partial F(x,y)}{\partial x}$	$\frac{\partial G(x,y)}{\partial y}$	$\frac{\partial L(x,y)}{\partial z}$	Conclusion
$(x=1, y=1, z=1)$	±	±	+	Saddle point or non-equilibrium point
$(x=0, y=1, z=1)$	±	+	0	Saddle point or non-equilibrium point
$(x=1, y=0, z=1)$	+	+	+	Non-equilibrium point
$(x=0, y=0, z=1)$	-	-	0	Equilibrium point
$(x=1, y=1, z=0)$	±	±	-	Saddle point or equilibrium point
$(x=0, y=1, z=0)$	±	+	0	Saddle point or non-equilibrium point
$(x=1, y=0, z=0)$	+	+	-	Saddle point
$(x=0, y=0, z=0)$	-	-	0	Equilibrium point

The outcome and the evolution path of the game depend on the amount of the government construction subsidy B and the amount of operation subsidy M_1 and M_2. When the condition $B > F_1 + C_{11} + C_{12}$ is met, government can adopt the construction subsidy strategy (s_{31}) to endow the port with the power of green construction. But the result $(x=1, y=1, z=1)$ is a saddle point, government will change its strategy. When the conditions $M_1 > F_1 + C_{11} - C_{12}$ and $M_2 > F_2 + C_{21} - \pi_2$ are met, the government can adopt the operation subsidy strategy (s_{32}) to make the port have the power of green construction, and $(x=1, y=1, z=0)$is an equilibrium point of the evolutionary game. When the condition $M_1 < F_1 + C_{11} + C_{12}$ or $M_2 < F_2 + C_{21} - \pi_2$ is met, the results of the evolutionary game are $(x=0, y=0, z=1)$ and $(x=0, y=0, z=0)$. The operation subsidy strategy (s_{32}) is the weak dominant strategy of the government. However, when the port chooses the green construction strategy (s_{11}) and the shipping company chooses the emission reduction transformation strategy (s_{21}), the government strictly prefers the operation subsidy strategy (s_{32}). The evolution path of whether the shipping company carry out emission reduction transformation is similar to the port evolution path.

As shown in the Figure 1. When the conditions $M_1 > F_1 + C_{11} - C_{12}$ and $M_2 > F_2 + C_{21} - \pi_2$ are met, the evolution path is Evolution Path (1). when the condition $M_1 < F_1 + C_{11} - C_{12}$ or $M_2 < F_2 + C_{21} - \pi_2$ is met, the evolution path is Evolution Path (2). When the conditions $M_1 < F_1 + C_{11} - C_{12}$ and $M_2 < F_2 + C_{21} - \pi_2$ are met, the evolution path is Evolution Path (3).



Evolution Path(1) Evolution Path(2) Evolution Path (3)

Figure 1: Diagram of Game Evolution Path

The evolution path of the port depends on the amount of government subsidies and the strategy of the shipping company. When the benefits of successful green construction are greater than those of the traditional model, and the shipping company can cooperate with the emission reduction transformation, the port enterprises will adopt the green construction strategy. When the condition cannot be met, the port tends not to carry out green construction. The evolution path of the shipping company depends on the strategy of the port. When the port has a high probability of choosing the green construction strategy, the emission reduction transformation strategy will be chosen by the shipping company. In the case of a low probability of the port choosing the green construction strategy, the shipping company tends not to carry out the emission reduction transformation. Meanwhile, the government evolution path depends on the port strategy. When the port chooses the green construction, the operation subsidy strategy is strictly better than the construction subsidy strategy. When the port does not choose the green construction, two kinds of subsidy will receive the same benefits, and the government will have no incentive to change its strategy.

To sum up, the amount of government subsidies will affect the choice of the port and shipping company and impose a crucial impact on the outcome and evolutionary path of the game. At the same time, different game starting points will also lead to different evolutionary results. The government gives high subsidy amounts, and in the early stage of the game, both the port and the shipping company have a certain probability of choosing the corresponding strategy of green construction (s_{31}, s_{21}). The result of the evolutionary game can achieve the goal of green construction and emission reduction. This paper simulated the evolution path under different starting positions of the game and different subsidy amounts of the government.

IV. SIMULATION

In order to better elucidate the impact of varying game starting points and different government subsidies on the evolutionary path and outcomes, we employed advanced simulation techniques, incorporating computational algorithms and data analytics. This approach enabled the intuitive visualization of the tripartite game's evolution across diverse scenarios, utilizing machine learning models to predict and analyze the complex dynamics and strategic interactions among the port, shipping company, and government. Through the integration of network simulations and predictive analytics, we could precisely capture the nuanced effects of initial conditions and subsidy strategies on the game's trajectory, offering a comprehensive computational perspective on the decision-making processes and potential policy implications. The parameter values in this paper were set as benefits during normal operation of port, $\pi_1 = 50$; cost of active green construction of port, $F_1 = 20$; cost of green operation cost of port, $C_{11} = 10$; traditional operation cost of port, $C_{12} = 20$; income from normal operation of shipping company, $\pi_2 = 30$; emission reduction cost of shipping company, $F_2 = 20$; cost of green operation cost of shipping company, $C_{21} = 15$; and traditional operation cost of shipping company, $C_{22} = 25$. The government benefits by completing the green construction, $\pi_3 = 100$. First, this paper simulated the evolution path at a low subsidy amount. $B = 20, M_1 = 5, M_2 = 0$, which meet the conditions $M_1 < F_1 + C_{11} - C_{12}$ and $M_2 < F_2 + C_{21} - \pi_2$. Upon the completion of green construction and government subsidies, the income of the port is less than that of the traditional model, or the income of the shipping company is negative. Figure 2 shows that the path converges to $(x = 0, y = 0, z = a)$ in various initial states.

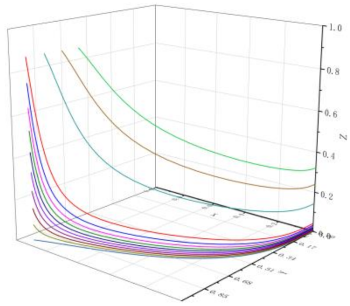
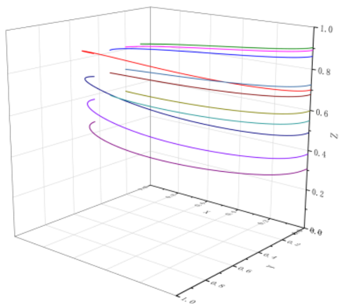
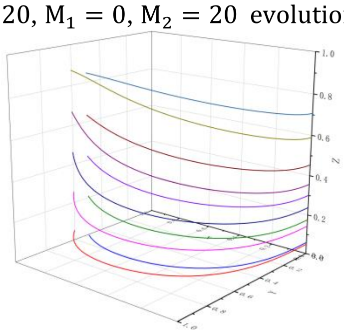


Figure 2: Evolution Path Diagram under Low Grant

As shown in Figure 2, when the government subsidy is not enough to support the operation of the port or shipping company, the results of the evolutionary game will converge to the state of $(x = 0, y = 0, z = a)$. At this time, the port green construction fails. However, increasing the operating subsidies for port or shipping company alone cannot change the outcome of the evolutionary game. Figure 3 shows the evolution path when $B = 20$, $M_1 = 0$, $M_2 = 20$ and when $B = 40$, $M_1 = 15$, $M_2 = 0$. The condition meets either $M_1 > F_1 + C_{11} + C_{12}$ or $M_2 > F_2 + C_{21} - \pi_2$.



(1)$B = 20$, $M_1 = 0$, $M_2 = 20$ evolution path



(2)$B = 40$, $M_1 = 15$, $M_2 = 0$ evolution path

Figure 3: Evolutionary Path Diagram under High Subsidies Individually

As can be seen from Figure 3, when giving a high operation subsidy to the port or the shipping company alone, the power of green construction can be improved. When the port receives sufficient subsidy, meanwhile the shipping company has a high probability of choosing the emission reduction transformation strategy, and the port will have a higher probability of choosing the green construction strategy. When the shipping company reduces the probability of choosing the emission reduction transformation strategy, the port will have a lower probability of choosing the green construction strategy. Similarly, when the shipping company receives sufficient subsidies and the port has a high probability of choosing a green construction strategy, the shipping company will have a higher probability of choosing an emission reduction transformation strategy. When the port reduces the probability of choosing the green construction strategy, the shipping company will have a lower probability of choosing the emission reduction transformation strategy. High subsidies to the port and shipping company alone fail to achieve the result of successful green construction. The game participant not receiving the high operation subsidy will give up the green construction, thereby affecting the enthusiasm of the another game participant. The result of the game is $(x = 0, y = 0, z = a)$.

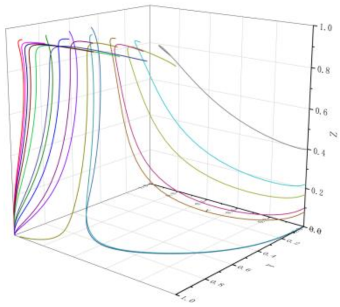


Figure 4: Evolutionary Path Diagram under High Subsidies Simultaneously

Figure 4 shows that the government grants high operating subsidies to the port and shipping company at the same time, and both the port and shipping company achieve positive profits in the process of green construction and operation. The relevant parameters were set to $B = 40$,$M_1 = 15$, $M_2 = 20$. The conditions meet $M_1 > F_1 + C_{11} - C_{12}$ and $M_2 > F_2 + C_{21} - \pi_2$. At this time, two types of equilibrium points $(x = 0, y = 0, z = a)$ and $(x = 1, y = 1, z = 0)$ appear. From Figure 4, the evolution path depends on the initial position. When the evolution begins, both the port and the shipping company have a certain probability of choosing the green construction strategy and emission reduction transformation strategy, the port and the shipping company will promote the green construction of each other. The evolution result is $(x = 1, y = 1, z = 0)$. At this time, the port green construction can be completed. When the evolution begins, the probability of the port and shipping company choosing the green construction strategy and the emission reduction transformation strategy is low, the game participants will gradually reduce the value of x and y, and the result of the game is $(x = 0, y = 0, z = a)$. At this time, the green construction of the port failed.

V. Conclusion and Outlook

A. Conclusion

Herein, the green construction of shore power facilities was introduced through the tripartite game of the port, the shipping company, and the government. The evolution path was simulated under different conditions and different initial states. Through the analysis of the evolutionary path, the following conclusions were drawn:

Conclusion 1: When conditions $M_1 < F_1 + C_{11} - C_{12}$ and $M_2 < F_2 + C_{21} - \pi_2$ are met, operating subsidies granted by the government do not guarantee the profitability of the port and the shipping company. Whatever the initial state of the port and shipping company, these subsidies may not provide enough impetus to promote green construction, eventually leading to the failure of the green construction.

Conclusion 2: When the condition meets either $M_1 > F_1 + C_{11} - C_{12}$ or $M_2 > F_2 + C_{21} - \pi_2$, high operating subsidies will be granted by the government to the port or shipping company. When the government provides high operating subsidies to the port, it temporarily improves the impetus for green port construction of the port. For shipping company, the losses in green construction will reduce the probability of choosing the emission reduction transformation strategy. The port and the shipping company will influence the strategy choosing of each other. When the probability of choosing emission reduction transformation strategy is reduced, the port will reduce the probability of choosing green construction strategy, and eventually, neither game participants will carry out emission reduction transformation or green construction. Similarly, the government gives high operating subsidies to the shipping company alone leading to the same result. So the operating subsidies to a participant alone cannot change the status quo of green port construction.

Conclusion 3: When conditions met $M_1 > F_1 + C_{11} - C_{12}$ and $M_2 > F_2 + C_{21} - \pi_2$, the operating subsidies granted by the government can ensure the profitability of the port and the shipping company. The outcome of the game depends on the initial state. (1) When the game begins, both the port and the shipping company have a high probability of implementing the green construction strategy and emission reduction transformation strategy, and both game participants can obtain greater expected benefits by increasing the corresponding probability. In this way, the port and the shipping company can promote the green construction of each other, and successfully complete the green construction, energy conservation and emission reduction targets. (2) When the game begins, there is a small probability of the port and shipping company choosing green construction strategy and emission reduction transformation strategy, and game participants continuing green construction will lead to losses. The port and shipping company hinder the green development of each other, and ultimately fail to complete the green construction. Therefore, the initial state is crucial to the success of green construction.

Conclusion 4: The integration of computational models and data analytics plays a pivotal role in enhancing the strategic decision-making process for green port construction. By applying sophisticated computational algorithms and leveraging the power of big data, this study has been able to simulate complex scenarios and predict outcomes with a higher degree of accuracy. This computational approach not only facilitates a deeper understanding of the dynamics within the tripartite game but also offers valuable insights into optimizing government subsidies and collaborative strategies. Therefore, future efforts in green port construction should increasingly rely on computational intelligence to refine policy interventions, streamline operations, and ensure the sustainability of environmental initiatives. The use of machine learning and data mining techniques can further improve the precision of simulations, enabling stakeholders to anticipate challenges and adjust strategies proactively. Hence, the marriage of computational science with environmental policy-making emerges as a critical frontier in the quest for sustainable port development.

B. Outlook

According to the above conclusions, the following suggestions were put forward. First, continuous profits should be guaranteed. Government subsidy policy should ensure that the port and the shipping company can continue to be profitable in green construction. In addition to providing operating subsidies, other incentives such as preferential taxes and low-interest loans can also be considered by the government to reduce the cost of investment and increase the return on green projects. By providing a sustainable profit guarantee, enterprises will be more motivated to actively participate in green construction, energy conservation and emission reduction. Second, both the port and shipping company should be considered at the same time. The government should take into account the interests of both the port and shipping company, rather than subsidizing one party alone. Ensuring the cooperation between the port and shipping company will help to achieve the success of green construction. Government could set up a policy coordination mechanism to promote the cooperation between the port and shipping companies, jointly formulate and implement green strategies, and maximize the efficiency and effect of green construction. Third, the publicity and demonstration effect should be strengthened. The government is suggested to increase the importance of publicizing green construction, highlight the leading role of large ports and shipping companies in this area, and improve the probability of the society as a whole choosing the green strategy. Through public education and information exchange among enterprises, the cognition and awareness of green construction should be enhanced. At the same time, large ports and shipping companies should be encouraged by the government to actively share the successful experience of green construction, drive the green development of the whole industry, and attract more port and shipping company to get involved. Fourth, AI and Machine Learning for Strategy Optimization: The use of artificial intelligence (AI) and machine learning algorithms can optimize green construction strategies and operations. AI can help in predicting the outcomes of different green construction strategies, identifying the most cost-effective measures, and optimizing resource allocation. Additionally, machine learning algorithms can analyze vast datasets to uncover patterns and insights that can inform policy decisions, strategy formulation, and operational improvements in green port construction. Fifth, IoT for Monitoring and Compliance: Utilizing the Internet of Things (IoT) technology can enhance the monitoring of green construction projects and compliance with environmental standards. IoT devices can provide real-time data on pollution levels, energy consumption, and the effectiveness of green construction measures. This real-time monitoring enables proactive adjustments to strategies and operations, ensuring that green construction goals are met efficiently.

Due to the rapid development of research on green port construction in China, coupled with the situation of the port in the early stage of green development, the relevant government subsidy data and green operation cost data are limited. Future researchers can consider taking a specific port as a study object, using real port data for simulation, so as to obtain more accurate and targeted conclusions.

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