[1]Yuhao Cheng
[2,*]Bo Lin
[3]Qinchang Li
[4]Mengyue Huang

Enhancing Transshipment Decision-making in Transportation Companies through Computational Intelligence: A Bayesian Game Model with Data-Driven Simulations at Guangzhou Port

Journal of Electrical Systems

Abstract: - The challenge of port congestion significantly impedes the efficiency of global trade flows and the economic vitality of hinterland regions. Addressing this issue, our study harnesses computational intelligence to construct a sophisticated Bayesian game model between the government and multiple transportation companies, where the transshipment costs, considered as private information to the companies, play a pivotal role. This research integrates data analytics and machine learning techniques to analyze the strategic decision-making processes of transportation companies, which decide on transshipment based on a critical cost threshold influenced by government subsidies and a probabilistic assessment of transshipment costs. Utilizing backward induction, the study outlines how the government can leverage computational models to devise an optimal subsidy strategy for transshipment, taking into account the anticipated responses of the transportation companies. The Bayesian Nash equilibrium identified through our model suggests that companies with costs below a predefined threshold are incentivized by government subsidies to opt for transshipment. This conclusion is further validated through evolutionary game theory analysis, enriched by data-driven simulations. Employing real-world data from Guangzhou Port, we conducted extensive computational simulations to quantify the impact of transshipment subsidies. The findings reveal a substantial alleviation in port congestion, with a 33.7% reduction in congestion levels and a 35% decrease in congestion-related costs, alongside a notable 1.9% increase in government revenue. These simulations, powered by advanced computational algorithms and data analytics, not only underscore the effectiveness of informed subsidy strategies in mitigating port congestion but also demonstrate the potential of integrating computational approaches in logistical and transportation decision-making. This study contributes a novel computational framework to the logistics and transportation literature, offering practical insights for policymakers to tackle the enduring problem of port congestion through data-driven strategies.

Keywords: Port Congestion, Transshipment Decisions, Bayesian Game, Computational Simulation, Data Analytics, Machine Learning.

I. INTRODUCTION

In an era where the transportation of international trade is predominantly sea-based, with over 85% of goods relying on maritime routes [1], the critical role of ports within the global trade network becomes undeniable. China, as one of the world's leading trading nations, boasts a vast and varied port system, essential for the country's trade and economic development. The efficiency and functionality of these ports are significantly influenced by the economic dynamics of the surrounding hinterland and the accessibility of terrestrial transport systems, factors that collectively fuel the vitality of port operations [2]. Recent data reveals that from January to July 2023, China's ports collectively processed a staggering 9.62 billion tons of cargo, with the top ten ports accounting for a majority share. This immense throughput underscores the challenge of cargo congestion in high-activity ports, leading to increased waiting times and freight costs, which in turn reflect the critical strain on port resources [3, 4]. The economic repercussion of freight congestion on China's export trade, which accounts for nearly 2% of its exports, or an estimated loss of US$15.6 billion [4], alongside the inefficiency gap highlighted by DEA model analyses [5, 6], further emphasizes the urgent need to optimize port resource utilization to foster smoother trade operations and sustainable economic growth [7, 8].

Addressing port congestion involves two predominant strategies: enhancing the capacity of congested ports [9] and leveraging underutilized ports for cargo transshipment [10, 11]. Each approach presents its own set of complexities. Expanding congested ports demands significant infrastructure investments and grapples with environmental concerns [12], whereas transshipment introduces additional land transportation costs and

[1] Guangzhou College of Technology and Business, Guangzhou 510850, China
[2] Guangzhou College of Technology and Business, Guangzhou 510850, China
[3] Guangzhou College of Technology and Business, Guangzhou 510850, China
[4] Guangzhou College of Technology and Business, Guangzhou 510850, China
*Corresponding author: Bo Lin

operational uncertainties for freight companies [13, 14]. The reluctance of freight companies to divert from congested ports, despite the availability of idle ports, underscores the intricate balance between operational efficiency and economic viability [15-17].

Amidst these challenges, computational research emerges as a pivotal ally, offering innovative solutions to optimize port operations and transshipment decisions. This paper integrates computational methods, specifically focusing on the development of a Bayesian game model between the government and transportation companies. By leveraging computational algorithms and data analytics [18], the study delves into the strategic interactions dictated by transshipment costs, government subsidies, and the probabilistic nature of these variables. This computational approach facilitates a nuanced understanding of the decision-making processes inherent in port congestion management, highlighting the potential of machine learning and big data analytics in refining subsidy strategies and enhancing port efficiency. Furthermore, the use of real-world data from Guangzhou Port, coupled with advanced simulation techniques, illustrates the tangible benefits of data-driven policy interventions. These computational simulations, grounded in empirical analysis, elucidate the capacity of transshipment subsidies to alleviate port congestion significantly, reducing congestion levels and associated costs, while concurrently bolstering government revenue. By embracing computational science, this research transcends traditional analytical frameworks, offering a comprehensive strategy for mitigating port congestion through informed policy-making and strategic collaboration among ports, shipping companies, and governmental bodies.

The integration of computational methodologies in addressing the logistical challenges of port operations marks a significant advancement in the field. Through the application of Bayesian game models, data analytics, and simulation techniques, this study not only addresses the immediate concerns of port congestion but also sets the foundation for a more resilient, efficient, and sustainable global trade infrastructure. This computational perspective not only enriches the discourse on port management and transshipment strategies but also underscores the transformative potential of technology in navigating the complexities of international trade logistics.

II. MODEL CONSTRUCTION

This paper develops a dynamic Bayesian game model that intricately involves the government and multiple transportation companies, leveraging computational intelligence to enhance the model's realism and strategic depth [19, 20]. Within this framework, the government acts as a game participant with complete transparency, devoid of any private information. Conversely, the land transportation costs, integral to each transportation company's strategic considerations, are treated as private information. Given the diverse array of transportation companies utilizing the port at any given time, and the variability in their participation across different periods, the model incorporates several key assumptions to maintain its alignment with realistic operational dynamics:

Information Asymmetry and Computational Privacy: Each transportation company possesses exclusive access to its own cost data, with no direct insight into the confidential information of its peers. This assumption underscores the role of computational privacy mechanisms in safeguarding sensitive operational data, a principle central to the integrity of strategic decision-making within the model.

Government's Computational Constraints: Despite its comprehensive oversight, the government is modeled to respect the confidentiality of the transportation companies' private information, thereby acknowledging the computational limitations in accessing and processing protected data. This scenario emphasizes the importance of secure data environments and the ethical considerations in computational data analysis.

Distributed Information and Predictive Analytics: The assumption that the private information of each transportation company follows an independent and identical distribution, a fact known to all participants, leverages the concept of predictive analytics. By acknowledging the statistical properties of transportation costs, the model integrates computational methodologies to infer patterns and optimize subsidy strategies accordingly.

At the game's inception, the government's decision to offer a subsidy amount, S, for transshipment activities sets the stage for a nuanced interaction. In response, transportation companies evaluate whether to engage in transshipment through alternative ports, considering both the government's subsidy and their specific land transshipment costs, θ. This decision-making process is intricately modeled as a static sub-game involving N transportation companies, characterized by incomplete information. Here, computational simulation techniques come to the fore, enabling the exploration of various strategic outcomes based on the complex interplay of government subsidies, individual costs, and the collective behavior of transportation entities. The utilization of advanced computational models and algorithms facilitates a deeper understanding of each company's decision-making process under conditions of uncertainty. By employing machine learning algorithms, the model can predict

potential decision outcomes, enhancing the strategic foresight of both the government and transportation companies.

The government's profits come from the economic benefits brought by port throughput and the tariff revenue collected when goods are imported. This paper sets the maximum carrying capacity of congested ports as B. When n (0<n<N) transportation companies choose to transship, the total number of transportation companies accommodated by all ports in unit time is B+n. The revenue that the government can obtain through the transportation of these shipping companies is G(B+n). According to the law of diminishing marginal returns, can further restrict the government revenue function G^' (B+n)>0, G''(B+n)<0, and it is assumed that the income function satisfies the Inada condition. When n shipping companies choose transshipment, the government's profit function is:

$$\pi_1 = \mathrm{G}(\mathrm{B}+\mathrm{n}) - \mathrm{S}\cdot\mathrm{n} \tag{1}$$

When considering the subsidy S set by the government, the transportation company makes two choices based on its transshipment cost θ. a_1 represents choosing transshipment, and a_2 represents choosing not to transship. If the transportation company chooses to transship through other ports, they must pay the land transshipment fee θ and can receive a government subsidy S. On the other hand, if the transportation company chooses not to transship when the port is idle. Namely, when the number of transportation companies that choose not to transship is less than the port's capacity limit ($\mathrm{N}-\mathrm{n}\leq\mathrm{B}$), the transportation company does not need to pay additional fees. However, if the port is congested, that is, the number of shipping companies that choose not to transship is greater than the port's capacity limit ($\mathrm{N}-\mathrm{n}>\mathrm{B}$), the shipping company will face fuel costs lost due to queuing and losses due to increased loading and unloading costs $\mathrm{L}(\mathrm{N}-\mathrm{n}-\mathrm{B})$, based on the principle of increasing marginal cost, this paper further assumes that $\mathrm{L}'(\mathrm{N}-\mathrm{n}-\mathrm{B})>0, \mathrm{L}''(\mathrm{N}-\mathrm{n}-\mathrm{B})>0$. The profit function of transportation company i is:

$$\pi_{2,i} = \begin{cases} S-\theta_i\ , & A_i = a_1 \\ -c_i(n)\ , & A_i = a_2 \end{cases} \tag{2}$$

$$c_i(n) = \begin{cases} 0 & , \mathrm{n}\geq\mathrm{N}-\mathrm{B} \\ \mathrm{L}(\mathrm{N}-\mathrm{n}-\mathrm{B}) & , \mathrm{n}<\mathrm{N}-\mathrm{B} \end{cases} \tag{3}$$

Given that all transportation companies have similar characteristics, the second-stage sub-game can be viewed as a symmetric game. This paper is based on the following assumption: Each transportation company adopts a linear decision-making strategy, that is, when the transshipment cost θ is greater than the critical value M, the expected profit of the transportation company when it chooses not to transship is greater than the profit of choosing transshipment, so the transportation company chooses not to transship. On the contrary, when θ is less than the critical value M, the transportation company chooses transshipment. This assumption is also consistent with realistic decision-making situations. The relevant parameters are shown in Table 1.

Table 1: Parameters Related to Game Participants

Participants	Parameter	Explanation
Government	π_1	Government profit function
	G	Government revenue from port cargo handling
	S	Subsidy of transshipment set by government
Transportation Company	$\pi_{2,i}$	Profit of transportation company i
	θ_i	Transshipment cost of transport company i
	A_i	Actions that the transport company i take
	M	Critical value of transshipment cost when the transportation company determines that the benefits of the two options are equal
	c_i	Cost when transport company i chooses not to transship
	L	Costs for transportation companies when port congestion occurs
Others	N	Total number of transportation companies
	n	Number of transportation companies who took transshipment action
	B	The maximum number of transport companies that a congested port can accommodate per unit time
	a_1	The transportation company's action is to transship
	a_2	The transportation company's action is stay rather than transshipment

This paper uses backward induction to solve dynamic Bayesian games. In the second stage, it is assumed that the transshipment cost of each transportation company satisfies the independent and identical exponential distribution with parameter λ, that is, the probability density of the transshipment cost of transportation company i is:

$$f(\theta_i) = \lambda e^{-\lambda\theta_i} \tag{4}$$

Based on the above assumption, when the transportation company's transshipment cost is greater than the critical value M, the transportation company will choose not to transship, and when it is less than M, the transportation company will choose transshipment. The transshipment probabilities of transportation company i are:

$$p \equiv Pr(A_i = a_1) = \int_0^M f(\theta_i) d\,\theta_i \tag{5}$$

$$\bar{p} \equiv Pr(A_i = a_2) = 1 - Pr(A_i = a_1) \tag{6}$$

At this time, the number of transportation companies that choose transshipment obeys the binomial distribution. The number of selected transshipment companies and the corresponding probabilities are shown in Table 2.

Table 2: Probability for Transportation Company to Transship

Number of the transportation company	1	2	…	i	…
Probability	$C_N^1(p)^1(\bar{p})^N$	$C_N^2(p)^2(\bar{p})^N$	…	$C_N^i(p)^i(\bar{p})^N$	…

There are currently a large number of transportation companies in crowded ports, so the number of transportation companies that choose to transship can be approximated as obeying the Poisson distribution with parameter γ, and $\gamma \equiv pN$. The probability that the number of transportation companies selected for transshipment is n is as follows:

$$Q(n) = \frac{\gamma^n}{n!} e^{-\gamma} \tag{7}$$

When there is congestion at the port, the cost required by the transportation company i is $L(N - n - B)$. The expected cost of the transportation company i choose not to transship is:

$$E(c_i) = \sum_{n=0}^{N-B} Q(n) L(N - n - B) \tag{8}$$

According to the assumption, M is the critical value of the transshipment cost. It means that when the transshipment cost θ_i is M, the cost of choosing transshipment is equal to the expected cost of choosing not to transship. It can be expressed as:

$$S - M = -E(c_i) \tag{9}$$

Substitute (4) to (8) into (9) to get:

$$S \equiv F(M) = M - \sum_{n=0}^{N-B} \left(\frac{(N \int_0^M \lambda e^{-\lambda\theta_i} d\theta_i)^n}{n!} exp(-N \int_0^M \lambda e^{-\lambda\theta_i} d\,\theta_i) \right) L(N - n - B) \tag{10}$$

It can be concluded that in the second stage of the game, the optimal strategy of each transportation company is:

$$A_i = \begin{cases} a_1, \theta_i \le M \\ a_2, \theta_i > M \end{cases} ; M \equiv D(S) = F^{-1}(S) \tag{11}$$

In the first stage of government decision-making, the transshipment subsidy S set by the government will cause the transportation company to generate a critical value judgment for transshipment costs. Transport companies with transshipment costs lower than M will choose transshipment. From this, it can be concluded that the number of companies choosing transshipment is:

$$n = N \int_0^{D(S)} \lambda e^{-\lambda\theta} d\,\theta \tag{12}$$

Substitute (12) into (1) can get the government's profit function and first-order conditions:

$$\pi_1 = G\left(B + N \int_0^{D(S)} \lambda e^{-\lambda\theta} d\,\theta\right) - S \cdot N \int_0^{D(S)} \lambda e^{-\lambda\theta} d\,\theta \tag{13}$$

$$\frac{\partial \pi_1}{\partial S} = \left(\frac{\partial G\left(B + N \int_0^{D(S)} \lambda e^{-\lambda\theta} d\theta\right)}{\partial S} - S \right) N\lambda e^{-\lambda D(S)} \frac{\partial D(S)}{\partial S} - N \int_0^{D(S)} \lambda e^{-\lambda\theta} d\,\theta = 0 \tag{14}$$

The government subsidy S^* that satisfies equation (14) represents the optimal solution for government decision-making. Equations (14) and (11) reveal the equilibrium strategy of this dynamic Bayesian game. That is, after the government selects the optimal transshipment subsidy S, each transportation company will make a decision based on its own transshipment cost. When the transshipment cost is lower than the threshold $D(S^*)$, the transportation company chooses to transship; when the transshipment cost is higher than the threshold $D(S^*)$, they choose not to transship. The result that some transport companies choose transshipment has effectively alleviated the port congestion problem. More berth resources can be used per unit time, and the increase in trade volume also creates more revenue for the government.

III. Evolutionary Game Analysis

Since many transportation companies are involved, it is difficult to achieve equilibrium in a one-time game. Moreover, both the government and transportation companies can adjust their strategies through previous game

records, which accord with the prerequisites of evolutionary games. To better explore the relationship between government transshipment subsidies and transportation company transshipment choices, this paper uses evolutionary game analysis to analyze different equilibrium paths to gain a deeper understanding of this issue.

To facilitate research, this paper sorts transportation companies by transshipment costs from low to high. Assume that the probability of each transshipment company choosing transshipment is x. In this case, the expected number of transportation companies other than transportation company i that chooses to transship is $\sum_{j\neq i} x_j$, and the expected number of transportation companies that choose not to transship is $N-\sum_{j\neq i} x_j$. The profit when choosing transshipment for transportation formula i is $S-\theta_i$; the expected profit when choosing not to transship is $E_i \equiv -Pr\left(\sum_{j\neq i} x_j < N-B\right)L(N-n-B)$. The dynamic replication equation of transportation company i is:

$$W_i(x_1,\cdots,x_i,\cdots,x_N) = x_i(1-x_i)(S-\theta_i-E_i) \tag{15}$$

The first-order condition of transportation company i is:

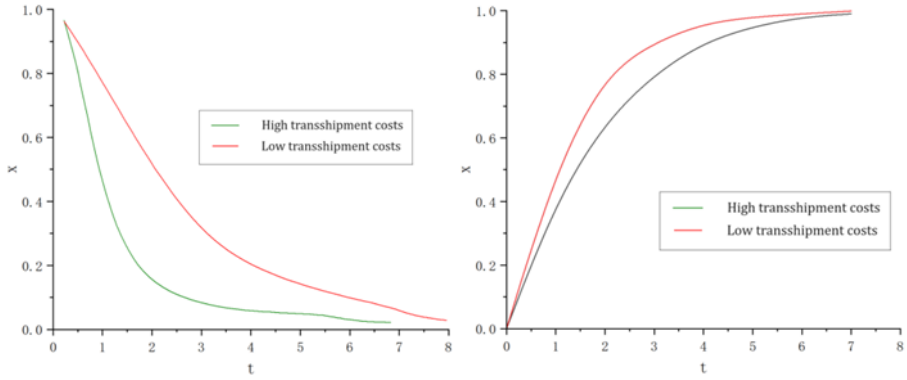
$$\frac{\partial W_i}{\partial x_i} = (1-2x_i)(S-\theta_i-E_i) \tag{16}$$

$$\frac{\partial W_i}{\partial x_j} = -x_i(1-x_i)\frac{\partial E_i}{\partial x_j} \tag{17}$$

Construct the Jacobian matrix as follows:

$$\Sigma = \begin{bmatrix} \frac{\partial W_1}{\partial x_1} & \cdots & \frac{\partial W_1}{\partial x_N} \\ \vdots & \ddots & \vdots \\ \frac{\partial W_N}{\partial x_1} & \cdots & \frac{\partial W_N}{\partial x_N} \end{bmatrix} = \begin{bmatrix} (1-2x_1)(S-\theta_1-E_1) & \cdots & -x_1(1-x_1)\frac{\partial E_1}{\partial x_N} \\ \vdots & \ddots & \vdots \\ -x_N(1-x_N)\frac{\partial E_N}{\partial x_1} & \cdots & (1-2x_N)(S-\theta_N-E_N) \end{bmatrix}$$

From the results of the above analysis, it can be seen that the stability of the evolution result depends on the government subsidy amount S and the transshipment cost θ of each transportation company. When $S < \theta_1 + L(N-B)$, the result of the evolutionary game is $x_i = 0, \forall i = 1,2\cdots N$, that is, all transportation companies choose not to transship. When $S > \theta_N$, the result of the evolutionary game is$x_i = 1, \forall i = 1,2\cdots N$, that is, all transportation companies choose transshipment. The evolution path is shown in Figure 1. When $\theta_1 + L(N-B) < S < \theta_N$, some transportation companies choose to transship, while others choose not to transship. This paper used Jacobian to further prove this conclusion.



(1) Low transshipment subsidy (2) High transshipment subsidy

Figure 1: Evolution Path When the Government's Transshipment Subsidy is Too High/Low

Since $L(N-n-B)$ is a monotonically increasing function, as the number of transportation companies choosing transshipment increases, $L(N-n-B)$ gradually decreases. As transshipment companies are more inclined to choose transshipment, the probability of port congestion gradually decreases, that is, the value of $Pr\left(\sum_{j\neq i} x_j < N-B\right)$ decreases. Then there must be a result that makes the expected profit of a certain transportation company's choice of whether to transship equal, that is, $S-\theta-E=0$. Assume that the expected profit of transportation company r is in a critical state, that is, $S-\theta_r-E_r>0, S-\theta_{r+1}-E_{r+1}<0$. When $xx_1 = x_2 = \cdots x_r = 1, x_{r+1} = \cdots x_n = 0$, the Jacobian matrix transformation is as follows:

$$\Sigma = \begin{bmatrix} -(S-\theta_1-E_1) & \cdots & 0 & 0 & \cdots & 0 \\ \vdots & \ddots & \vdots & \vdots & & \vdots \\ 0 & \cdots & -(S-\theta_r-E_r) & 0 & \cdots & 0 \\ 0 & \cdots & 0 & S-\theta_{r+1}-E_{r+1} & \cdots & 0 \\ \vdots & & \vdots & \vdots & \ddots & \vdots \\ 0 & \cdots & 0 & 0 & \cdots & S-\theta_N-E_N \end{bmatrix}$$

In the above Jacobian matrix, the values on the diagonal are all negative, and the remaining values are zero. This means that the outcome of the evolutionary game at this time is stable. The evolution path is shown in Figure 2. All transportation companies with transshipment costs less than or equal to θ_r will choose transshipment, while transportation companies with transshipment costs greater than θ_r will choose not to transship. The results of this evolutionary game are consistent with the Bayesian Nash equilibrium in the theoretical analysis section.

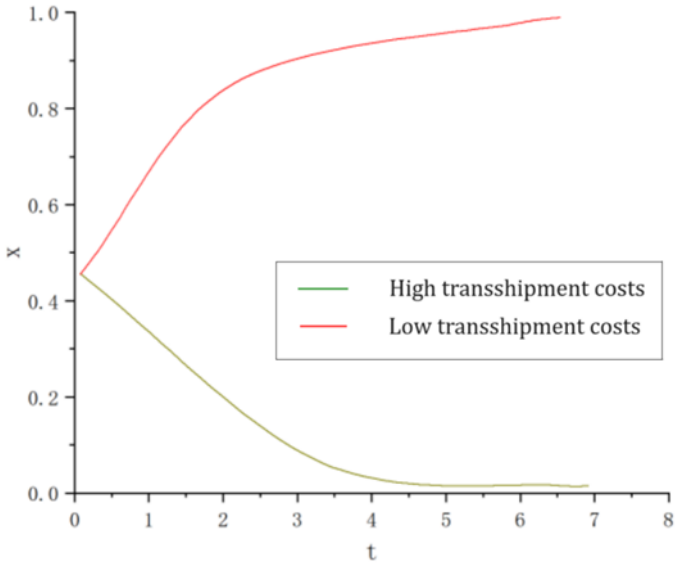


Figure 2: Evolution Path of Moderate Transshipment Subsidy

This paper uses the same method to analyze the evolutionary path of government decision-making in the first stage of the game. After the government formulates the transshipment subsidy S, the expected number of transportation companies that choose transshipment is $\sum_{i=1}^{N} x_i$, and the government's expected profit is $E\pi_1 = G\left(B + \sum_{i=1}^{N} x_i\right) - S \cdot \sum_{i=1}^{N} x_i$. According to the backward induction method, the government's evolutionary game replication equation can be obtained by merging the transportation company's evolutionary strategy.

$$V = (G' - S)\left(\sum_{i=1}^{N} x_i(1 - x_i)\right) - \sum_{i=1}^{N} x_i \tag{18}$$

Function (18) shows that there exists an evolutionary result S*, and the evolutionary path converges towards S*. If the government income function satisfies the Inada conditions, the optimal decision S* can be obtained through the first-order conditions, and the sign of the two-stage conditions is negative. At this time, the evolution result of the government is stable. The evolutionary path is shown in Figure 3.

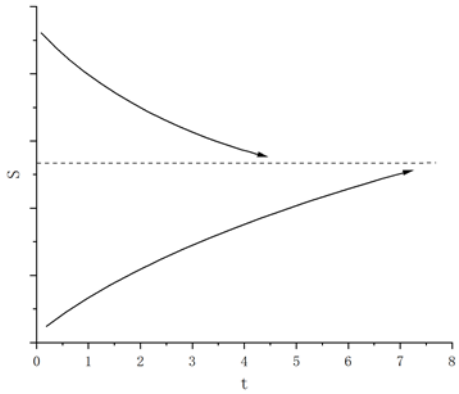


Figure 3: Evolution Path of Government Decision-making

Through evolutionary analysis, this paper draws the following conclusions: (1) Transportation companies adjust their decisions when considering the amount of government transshipment subsidies. Transportation companies use their transshipment costs as a benchmark and refer to the subsidy amount set by the government to decide whether to transship. At the end of the evolutionary game, companies with lower transshipment costs choose transshipment, while companies with higher transshipment costs choose not to transship. (2) The government can adjust the amount of subsidies based on the number of transshipment companies. In this process, there is an optimal subsidy amount, and all evolutionary paths will tend to this optimal amount. The evolution results of transportation companies and governments are consistent with the Bayesian Nash equilibrium conclusion in game theory, further verifying the rationality and accuracy of the model.

IV. CALCULATION EXAMPLE ANALYSIS

To make the conclusion more practical, this study conducted simulations using actual data from Guangzhou Port. According to data published in the Port Statistical Yearbook, Guangzhou Port had 208 berths in 2021, with a designed annual throughput capacity of 298.86 million tons, and a designed annual throughput capacity of each berth of 1.4368 million tons. The actual cargo throughput of Guangzhou Port in 2021 is 551.494 million tons. Calculated proportionally, the demand for berths is 384. According to the previous research, port capacity utilization, and transportation costs show a significant positive correlation, that is, for every 1% increase in utilization, transportation costs increase by approximately 0.19% [4]. Setting the baseline transportation cost as 1, it can derive the extra cost function paid by the transportation company during congestion as:

$$L(N-n-B) = 0.19\% \times \frac{N-n-B}{B} \times 100 \tag{19}$$

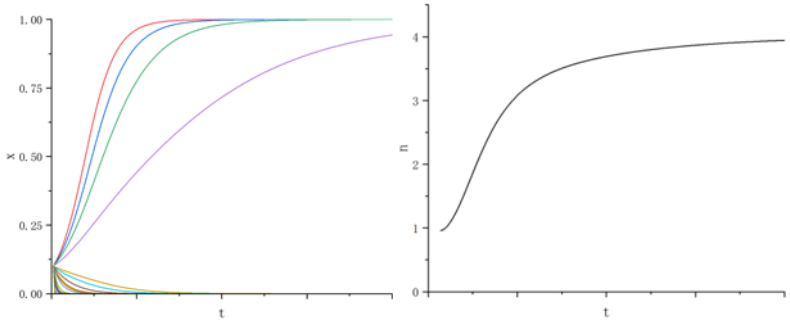
This paper refers to the prior research convention and assumes that the government's revenue function is a Cobb-Douglas type function. Then the government's profit function can be obtained as:

$$\pi_1 = \sqrt{B+n} - S \cdot n \tag{20}$$

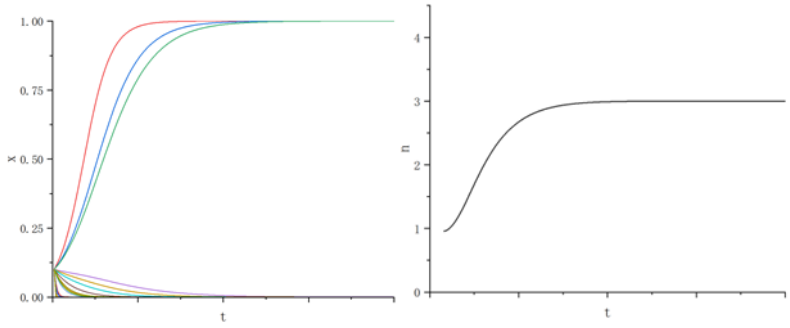
Additionally, the main cargo handled by Guangzhou Port mainly includes bulk commodities, automobiles machinery, and equipment, while the main mode of land transport is through railway transport. The quotation for rail transportation is 0.2 yuan per ton per kilometer. This paper estimates the transshipment cost per ship to be 787 yuan per kilometer and normalizes it to 1 unit cost. This paper treats the transshipment cost as a probability distribution to consider its randomness and also to eliminate the influence of observation error and other random errors. This paper assumes that transshipment costs follow an exponential distribution with mean 1:

$$f(\theta) = e^{-\theta} \tag{21}$$

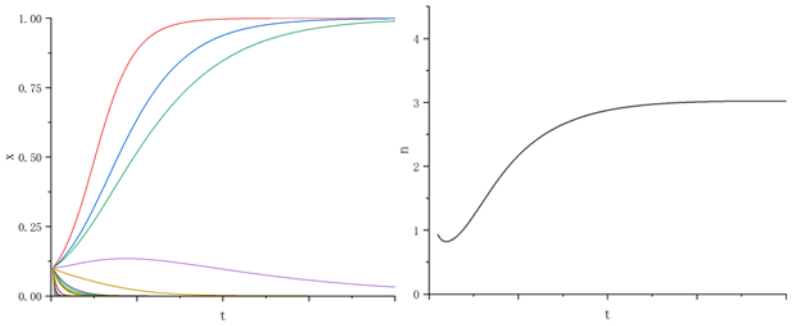
To facilitate calculation, this paper reduces the port data and divides the original data value by 20 before entering into the calculation, that is, N=20, B=10. This means that each number represents 20 ships. Multiple sets of 20 transshipment cost data obeying the above exponential distribution are randomly generated for simulation. The evolution results of the transportation company are shown in Figure 4. Sub-figures (1) - (4) represent the evolution results of the strategy and the number of transportation companies selecting transshipment under four different randomly generated transshipment costs. The results show that the critical value of transportation companies' transshipment cost is between 0.12 and 0.16, and the transportation company's decision-making shows obvious differentiation. When the transshipment cost is greater than the critical value, the transportation company is more likely to choose not to transship; when the transshipment cost is less than the critical value, the transportation company is more likely to choose transshipment. During the simulation process, an average of about 3.5 observations finally converged to 1, that is, about 70 shipping companies chose to use other ports for transshipment. The results of digital simulation show the phenomenon of separation equilibrium. This conclusion is consistent with the previous theoretical analysis and once again verifies the reliability of the model.



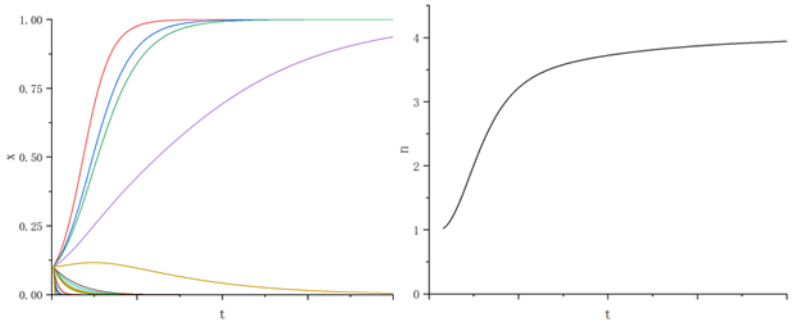
(1)



(2)



(3)



(4)

Figure 4: Evolution Path of Transportation Company's Decision-making

The evolutionary path of government is presented in Figure 5. Observing the evolution results of different groups, it can be seen that when the government subsidy amount starts to evolve from a smaller amount, it finally converges to 0.128. This means that the subsidy provided by the government is about 12.8% of the unit transshipment cost, which is equivalent to a transshipment subsidy of 100 yuan per kilometer.

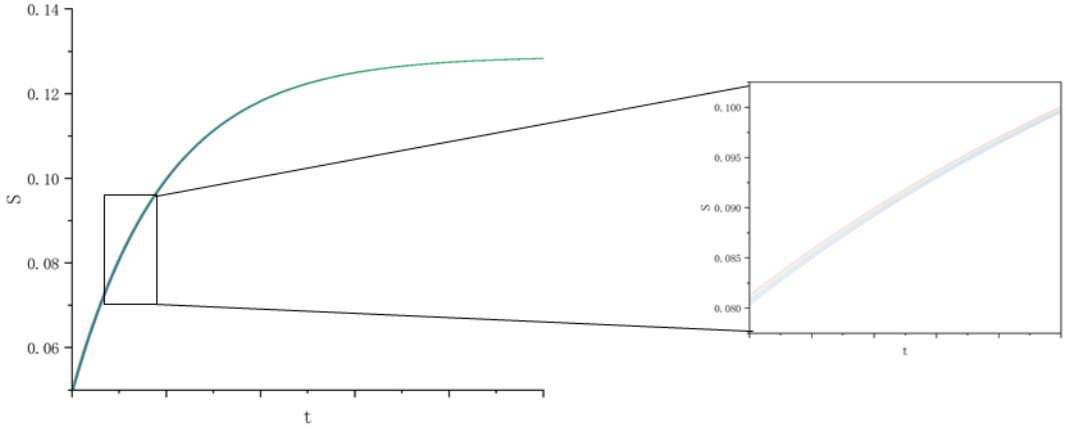


Figure 5: Evolution Path of Government's Subsidy

In the above simulation, a win-win equilibrium state can be obtained. When the government subsidy amount stabilized at 100 yuan per kilometer, about 70 transportation companies chose transshipment. In this case, the port congestion problem has been alleviated, and congestion has dropped by approximately 33.7%. At the same time, the growth rate of freight increases due to congestion has slowed down by 6.65%, reducing costs caused by congestion by 35%. In addition, increased cargo throughput means increased trade, and the government's total revenue increases by 1.9% compared to before in the stable equilibrium state. This result shows that under the guidance of government subsidies, transportation companies' transshipment decisions, and port congestion problems have been effectively alleviated, creating good conditions for the continued growth of the economy and trade.

V. CONCLUSION

Port congestion stands as a formidable barrier in the realm of international trade, impeding the seamless flow of commerce and hampering economic progress. This study delves into the intricacies of transportation companies' transshipment decisions, employing a Bayesian Game framework to dissect the nuanced interplay between government subsidies and the transshipment activities of these companies. Through a comprehensive blend of

theoretical insights and computational simulations, this paper elucidates several pivotal conclusions that underscore the transformative potential of computational methodologies in resolving port congestion challenges.

Firstly, the research demonstrates that government subsidies allocated for transshipment significantly influence the decision-making processes of transportation companies. By calculating a critical transshipment cost threshold, informed by the subsidy amount, transportation companies can strategically determine their transshipment engagements. This decision critically hinges on the juxtaposition of their individual transshipment costs against this derived threshold, highlighting the utility of computational analysis in optimizing transshipment strategies.

Secondly, the application of computational simulations to a representative scenario reveals a mutually beneficial equilibrium within this game model. The inclination of more transportation companies towards transshipment, driven by the subsidy incentive, notably mitigates port congestion. This, in turn, curtails both the cargo transportation and waiting costs at ports, fostering a more efficient logistical environment. Furthermore, the resultant increase in port throughput and foreign trade tariff revenue accrues additional economic advantages to the government. This outcome accentuates the role of computational models and simulations in forecasting and analyzing the economic impacts of policy measures on port operations.

Finally, acknowledging the probabilistic nature of transportation companies' transshipment costs and the inherent randomness in the game's evolutionary path, the study advocates for a dynamic policy-making approach. Transportation companies and government bodies are urged to employ computational analytics to adapt their strategies in response to real-time data on congestion levels and the operational landscape of the transportation sector. The determination of subsidy amounts, thus, should be dynamically aligned with prevailing port conditions and the transshipment cost profiles of transportation companies, enhancing the policy's efficacy and adaptability.

While the analysis presented in this paper primarily draws upon averaged data and extant research findings, due to the challenges in accessing specific real-world data, the proposed methodological framework is not confined to Guangzhou Port. Its applicability extends to various ports, where real data can be leveraged to tailor more nuanced policy interventions and validate the model's universal applicability. The fusion of Bayesian game theory with advanced computational techniques, including data analytics and simulations, provides a novel lens through which the complexities of port congestion and transshipment decisions can be navigated. This computational approach not only offers strategic insights for policymakers and transportation companies but also heralds a new era of data-driven decision-making in the optimization of port resources and the facilitation of global trade.

ACKNOWLEDGMENT

The research is funded by the National Natural Science Foundation of China (No.72073018, No.72261147705 and No.T2241025), the Philosophy and Social Science Foundation of China (key project, No.20&ZD129), the Liaoning Revitalization Talents Program (No.XLYC2007191), Guangdong University Characteristic Innovation Foundation (No.2021WTSCX109), Guangdong Key Discipline Construction Foundation of Scientific Research Capacity Improvement (No.2022ZDJS144), the Doctoral Workstation Planning Foundation of Guangzhou College of Business and Technology (No.KABS202101), Guangzhou Philosophy and Social Science Foundation (No.2021GZGJ25). The Featured Innovation Project of Guangdong Provincial Education Department in 2022 (2022WTSCX139).

REFERENCES

[1] K. Peters, "Deep routeing and the making of 'maritime motorways': Beyond surficial geographies of connection for governing global shipping". Geopolitics, vol. 25, no. 2020, pp. 43-64.

[2] S. E. Hanson and R. J. Nicholls, "Demand for ports to 2050: Climate policy, growing trade and the impacts of sea‐level rise," Earth's Future, vol. 8, no. 8, 2020, pp. e2020EF001543.

[3] M. Takebayashi and S. Hanaoka, "Efficient inter-port cooperation considering port congestion and port charge," Maritime Transport Research, vol. 2, 2021, pp.100011.

[4] Y. Wang and L. Yang, "Port congestion, endogenous trade costs and China's foreign trade interests," The World Economy, vol. 46, no. 9, 2023, pp. 52-81.

[5] Y. Deng and J. Qin, "Smart port efficiency evaluation based on super-efficiency DEA and DEA-Malmquist index models," Journal of Shanghai Maritime University, vol. 43, no. 4, 2022, pp. 83-90.

[6] E. Krmac and M. Mansouri Kaleibar, "A comprehensive review of data envelopment analysis (DEA) methodology in port efficiency evaluation," Maritime Economics & Logistics, 2022, pp. 1-65.

[7] Y. Zheng and M. Xu, "Study on the evaluation of port logistics efficiency based on the DEA model," Journal of Chongqing University of Technology (Natural Science), vol. 34, no. 10, 2020, pp. 266-272.

[8] S. Steinbach, "Port congestion, container shortages, and US foreign trade," Economics Letters, vol. 213, 2022, pp.110392.

[9] Q. Lei and C. Bachmann, “Assessing the role of port efficiency as a determinant of maritime transport costs: Evidence from Canada,” Maritime Economics & Logistics, vol. 22, 2020, pp. 562-584.
[10] S. Başтuğ, S. Esmer, and E. Eminoglu, “Port Competitiveness Criteria for Transshipment Container Market: A Turkish Port Industry Application,” Acta Nat.Sci, vol. 4, no. 1, 2023, pp. 27-46.
[11] X. Ren, C. Zhou, S. Zhu, et al., “Development ideas and construction measures of Ningbo Zhoushan Port Container Port Area,” Water Transport Engineering, no. 06, 2023pp. 68-73 + 95,.
[12] B. Noguera-Alguero, “Growth in the docks: Ports, metabolic flows and socio-environmental impacts,” Sustainability Science, vol. 15, no. 1, 2020, pp. 11-30.
[13] H. Tagawa, T. Kawasaki, and S. Hanaoka, “Conditions influencing the choice between direct shipment and transshipment in maritime shipping network,” Journal of Shipping and Trade, vol. 6, no. 1, 2021, pp. 1-15.
[14] N. Shramenko, D. Muzylyov, and V. Shramenko, “Model for choosing rational technology of containers transshipment in multimodal cargo delivery systems,” in New Technologies, Development and Application III, vol. 6, Springer International Publishing, pp. 621-629, 2020.
[15] M. Bergmann, M. K. Msakni, A. Hemmati, et al., “An adaptive heuristic for Feeder Network Design with optional transshipment,” Transportation Research Part E: Logistics and Transportation Review, vol. 176, 2023, pp.103153.
[16] B. Ji, H. Sun, X. Yuan, et al., “Coordinated optimized scheduling of locks and transshipment in inland waterway transportation using binary NSGA‐II,” International Transactions in Operational Research, vol. 27, no. 3, 2020, pp. 1501-1525.
[17] L. Jiang and G. Dong, “Research on the Stability of Dynamic Game Theory of Differentiated Port Conspiracy,” China Navigation, vol. 46, no. 03, 2023, pp. 72-79.
[18] S. B. Atitallah, M. Driss, W. Boulila, and H. B. Ghézala, “Leveraging Deep Learning and IoT big data analytics to support the smart cities development: Review and future directions,” Computer Science Review, vol. 38, 2020, pp.100303.
[19] S. Shamshirband, N. B. Anuar, M. L. M. Kiah, and A. Patel, “An appraisal and design of a multi-agent system based cooperative wireless intrusion detection computational intelligence technique,” Engineering Applications of Artificial Intelligence, vol. 26, no. 9, 2013, pp. 2105-2127.
[20] H. Alqahtani and G. Kumar, “Machine learning for enhancing transportation security: A comprehensive analysis of electric and flying vehicle systems,” Engineering Applications of Artificial Intelligence, vol. 129, 2024, pp.107667.