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Co-opetition among dry ports for competing with seaports

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ABSTRACT

Dry ports and seaports are important facilities for global trade in the cargo service industry. The previous researchers mainly studied the competition between dry ports and seaports while this paper proposes a co-opetition model based on standardized pricing with centralized distribution for competing dry ports for attracting cargoes from seaports. A simple and effective Nash equilibrium calculation method is developed to allocate profit between dry ports under the co-opetition model. Further, a case study is conducted by using practical data collected from two China-Europe Railway Express (CRE) routes as dry ports and a seaport. This paper verifies that the co-opetition model significantly enhances the temporal competitiveness of dry ports, leading to higher profits when competing with the seaport. Furthermore, the co-opetition model enables cost-efficient dry port to achieve higher absolute profits and less cost-efficient dry port to realize a greater marginal gain. Besides, subsidy harms sustainable development of dry ports, which provides evidence for subsidy phase-out policies. The above results have significant implications for both governments and dry port operators on subsidy policy, cost reduction and the implementation of cooperation.

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1. Introduction

1.1. Background and motivation

Usually, there are many transportation routes connecting Asian sourcing locations to European demand centres, particularly for bulky cargo shipments. Dominant modal options include maritime transportation (Liu et al. 2024) and rail transportation (Li et al. 2023), and each exhibit distinct operational characteristics. Specifically, maritime transportation serves as the backbone of global trade, leveraging its high-volume capacity and cost efficiency (Feng et al. 2025; Li and Yin 2025; Mahmud, Chowdhury, and Shaheen 2024). However, stemming from diverse factors like geopolitical and legal disputes, adverse weather, and technical failures, maritime transportation faces mounting pressures from chronic delays, which is significantly amplified since the COVID-19 pandemic (Gao et al. 2023; Peng et al. 2025). This chronic unreliability poses a severe time pressure for global supply chains. For instance, the

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ongoing safety disruption in the Red Sea, which handles approximately 12% of global trade and serves as a primary artery between Asia and Europe, forced four of the world's top five shipping companies to suspend this critical route, injecting massive delays and uncertainty into maritime schedules. In the context of heightened time sensitivity and schedule disruption, railway transportation has surged as a compelling alternative recently, prized for its greater predictability and shorter, more controllable transit times.

A dry port, also called an inland port, connects to the seaport by road or railway and inland waterway transport (Wei, Sheng, and Lee 2018). As intermodal logistics hubs, dry ports fundamentally facilitate cargo consolidation for associated seaports, thereby optimizing maritime transportation efficiency. With the development of the Belt and Road Initiative, some of the dry ports in China are directly transporting cargoes from inland hinterland to European countries by the CRE. Compared to maritime transportation, railway transportation demonstrates superior reliability and punctuality. Illustratively, despite similar exposure to armed conflicts between the Ukraine and Russian forces, the overall cargo volumes of the CRE are still steadily growing. More specifically, according to data released by China Railway, the number of CRE freight trains in operation reached 19,000, which represents a 10.4-fold increase with a 35% compound annual growth rate compared to the baseline of 1,702 trains in 2016.[1]

The dry ports with CRE capability have the same functionality as sea ports for transporting cargoes from inland hinterland to European destinations. This development facilitates a bimodal transport selection, wherein consignors select between maritime and railway transportation for European-bound freight. That is, the post-CRE era has catalysed strategic competition between dry ports and seaports (Jeevan, Chen, and Cahoon 2018; Zhou and Kim 2020a, 2020b), which injects new impetus into global economic

Figure 1. The competition among Chengdu, Chongqing dry ports and Ningbo seaport.

connectivity. Figure 1 shows the competition among Chengdu, Chongqing dry ports, and Ningbo seaport.

In the early stage of CRE operations, local governments often leverage fiscal subsidies to bridge the cost gap with maritime transportation (Chen et al. 2023). With the subsidies supported by the local governments, the competitiveness of dry ports dramatically increases. The China-Europe railway freight transport market has been rapidly growing since the beginning of the CRE launch in 2011. However, affected by huge financial pressure, a growing number of governments begin to implement subsidy phase-out policies over time. For example, according to policy on standardizing CRE subsidies imposed by the Ministry of Finance of the People's Republic of China, subsidies provided by local governments are no more than 30% of the total transportation cost in 2021 and no more than 20% in 2022,[2] and local governments should lower or even cancel subsidies according to actual situations. In a word, subsidies obtained from local governments are decreasing. Therefore, considering the subsidy phase-out policies, dry port operators must urgently develop innovative solutions to compete strategically with seaports.

In light of this background, this paper proposes a novel collaborative model between competing dry ports, referred to as the co-opetition model for simplify. Furthermore, this paper verifies the effectiveness of the co-opetition model and investigates how it enhances dry port operators' competitiveness with the subsidy phase-out policies. Based on the foregoing analysis, this paper aims to establish a foundation for future research on dry port operators' collaboration to enhance competitiveness with maritime transportation. To this end, the study addresses the following questions:

(1) What are the equilibrium decisions of dry port and seaport operators under the co-opetition model?
(2) How do dry port operators allocate their profit obtained from the co-opetition model?
(3) How the co-opetition model help competing dry ports enhance competitiveness for competing with seaports in the real world?
(4) How do key factors influence equilibrium decisions and profits of different operators under the co-opetition model?

To solve the above research questions, this paper develops several game theoretical models considering the impact of transportation cost, timeliness, and subsidies, and studies the equilibrium service price of dry port and seaport operators under the benchmark and co-opetition models, respectively. Furthermore, a profit allocation model is developed under the co-opetition model, which is solved by an effective Nash equilibrium calculation method. Based on real operational data of two CRE routes and a seaport, a case study is conducted to verify the effectiveness of the co-opetition model. Finally, managerial implications for both dry port operators and governments are discussed.

1.2. Contribution to the literature

The contributions of this paper to the literature are two-fold.

First, some of the existing literature focuses on the competition between CRE and maritime transportation (Chen et al. 2020; Feng and Liu 2022; Gong and Li 2022; Jiang et al. 2018; Yin et al. 2021; Zhang, Zhang, and Lee 2020), and some of them only focus on the relationship within the CRE operators, such as competition within the CRE operators (Li et al. 2021; Ma et al. 2021; Zhang and Xu 2021) and cooperation within the CRE operators (Li et al. 2021; Zhang and Xu 2021). Different from the above literature, this paper not only considers the competition between dry port and seaport operators, but also proposes a new co-opetition model for competing dry port operators. The results verify the model's efficacy, which establishes a foundational paradigm for theoretical development in cooperation mechanisms among competing dry port operators.

Second, some scholars also investigate how to set the optimal subsidy with the competition between railway transportation and maritime transportation (Chen et al. 2020; Feng and Liu 2022; Gong and Li 2022; Yin et al. 2021). Differently, this paper takes into consideration that subsidies obtained from local governments are decreasing until to zero. From the perspective of subsidy phase-out policies, this paper points out new means for dry port operators to enhance competitiveness.

The remainder of this paper is organised as follows. Section 2 introduces the literature review. Section 3 presents the mathematical model setup and preliminaries of the studied problem. The profit allocation between dry port operators is shown in Section 4. A case study is conducted in Section 5. Section 6 shows sensitive analysis under different models. Finally, conclusions are given in Section 7.

2. Literature review

The advent of CRE elevates dry ports to a viable competitive position against seaports in the Asia-Europe cargo service market. Thus, an increasing stream of literature focus on the operations of CRE, which can be divided into operations of CRE without and with competition from maritime transportation.

Without the competition with maritime transportation, scholars mainly examined the operations of CRE from two aspects: without internal competition among CRE operators (Du, Zhou, and Lian 2022; Li et al. 2020; Liu and Meng 2024; Sun et al. 2020; Wu, Lin, and Huang 2019; Yin et al. 2020; Zhao et al. 2018, 2019); with internal competition among CRE operators (Li et al. 2021; Zhang and Xu 2021), and the second aspect is more relevant to our paper. From the second aspect, scholars considered the heterogeneous competition among CRE operators. For instance, Li et al. (2021) introduced a Hotelling model to explore the coexistence of competition and cooperation among CRE operators, and found the conditions for collaboration among CRE operators. Further, considering the significant impact of subsidies on the early development of CRE, some scholars took subsidies into consideration. For example, Zhang and Xu (2021) formulated the competition and cooperation relationship between governments and platforms by considering the government subsidy strategy. Ma et al. (2021) developed a game model to formulate the competition between railway transportation operators in the duopoly market by considering the impact of subsidy, and a case study about two CRE routes in Chengdu and

Chongqing was conducted. However, the above literature needs to further consider the competition from maritime transportation, which is our paper's main difference.

In the second stream of literature, scholars mainly explored three aspects: without the subsidy (Jiang et al. 2018; Yang, Sun, and Lee 2020; Zhang, Zhang, and Lee 2020), with the homogenous subsidy (Chen et al. 2020; Gong and Li 2022; Yin et al. 2021), and with the differentiated subsidies (Feng and Liu 2022; Xu et al. 2023). The last two aspects are more relevant. With the homogenous subsidy, Chen et al. (2020) developed a two-stage game-theoretic model to determine the optimal service price and subsidy for CRE and liner shipping, considering the departure interval. Yin et al. (2021) explored the CRE freight subsidy mechanism by considering the impact of different costs of various models of transportation including operating costs, external costs, and transhipment costs. Gong and Li (2022) considered the competition between CRE and maritime transportation and proposed two social welfare maximisation models to optimise subsidy and emission control coverage simultaneously. The above studies considered that different cargoes obtained homogenous subsidies from local governments. Differently, Feng and Liu (2022) proposed differentiated subsidy rules for different cargo categories according to the value and time sensitivity. The results of Feng and Liu (2022) showed that social welfare would increase when the differentiated subsidy rules were adopted. Xu et al. (2023) developed a three-stage game with three players, including government, operating platforms, and heterogeneous shippers with high- and low-value cargoes, and compared two types of subsidies including subsidising shippers' freight rates and platforms' operating costs. The above literature mainly focused on how to set optimal subsidies (Chen et al. 2020; Gong and Li 2022; Xu et al. 2023; Yin et al. 2021) and the impact of subsidies (Feng and Liu 2022). Differently, this paper considers subsidy phase-out policies and proposes a new co-opetition model for competing dry port operators to grab a new competitive edge.

In summary, cooperation among dry port operators is essential from the above previous studies. Based on this background, this paper explores the coordinated service price decision-making between dry port operators to attract cargoes from a seaport operator. Besides, the competition between dry port operators is studied for profit allocation. The above two parts are the main innovations of this paper. Table 1 summarises the most relevant studies to this paper.

3. Problem statement

In the cargo service market from Asia to Europe, two dry port operators (A and B) contest cargo services against a single seaport operator (S). To seek new opportunities for achieving sustainable development, this paper proposes the co-opetition model for competing dry port operators. To verify its efficacy, we also present a competition model as a benchmark. Let superscripts C and N to denote the two scenarios. Before introducing the studied problem under different models, the notations and their definitions used in this section are summarised in Table 2.

3.1. Co-opetition model (C)

Under the co-opetition model, the two competing dry port operators form a strategic alliance R with standardized pricing and consolidated distribution networks. The service

Table 1. Summary of the previous studies related to this paper.

	Factors			
Papers	Cooperation among CRE operators	Competition among CRE operators	Competition between CRE and shipping	Government subsidy
Zhang, Zhang, and Lee (2020)			√	
Jiang et al. (2018)			√	
Yang, Sun, and Lee (2020)			√	
Chen et al. (2020)			√	√
Yin et al. (2021)			√	√
Gong and Li (2022)			√	√
Feng and Liu (2022)			√	√
Ma et al. (2021)		√		√
Li et al. (2021)	√	√		
Zhang and Xu (2021)	√	√		√
This paper	√	√	√	√

Table 2. Notations and their definitions in section 3.

Index	
S	The seaport operator
A, B	The dry port operators under the competition model
R	The dry port alliance operator under the co-opetition model
N	Competition model
C	Co-opetition model
NB	Competition model without subsidy
CB	Co-opetition model without subsidy
Parameters	
ρ_i	Unit subsidy from the government to operator i for $i = A, B, R$
a_i	Potential demand of operator i for $i = A, B, R, S$
c_i	Unit transportation cost of operator i for $i = A, B, R, S$
L_R	Transportation time for the dry ports
L_S	Transportation time for the seaport
β_R	Price sensitivity of the dry port's demand to its own service price
β_S	Price sensitivity of the seaport's demand to its own service price
γ_R^R	Competition intensity between the dry port operators
γ_R^S	Cross price sensitivity of the dry port's demand to the seaport's service price
γ_S^R	Cross price sensitivity of the seaport's demand to the dry port's service price
λ_R	Sensitivity of the dry port's demand to the transportation time gap
λ_S	Sensitivity of the seaport's demand to the transportation time gap
Decision variables	
p_i	Service price of operator i for $i = A, B, R, S$
D_i	Demand of operator i for $i = A, B, R, S$
π_i	Profit of operator i for $i = A, B, R, S$

prices of the dry port alliance and seaport operators are p_R and p_S. When delivering unit cargo, they pay a unit cost c_i and obtain subsidy ρ_i from local governments, where $i = R, S$. The corresponding transportation process of cargo service is given in Figure 2.

Under the co-opetition model, consumer demands are affected by both prices and transportation time. Linear demand functions are adopted in this paper, which are widely accepted in the existing literature, including port competition-related papers (Lu et al. 2024; Zheng et al. 2022) and other game theory papers published in top-tier journals (Ha, Luo, and Shang 2022; Zhang, Chen, and Raghunathan 2022). Considering that the time spent from the two dry ports to destinations is similar, we ignore the impact of the

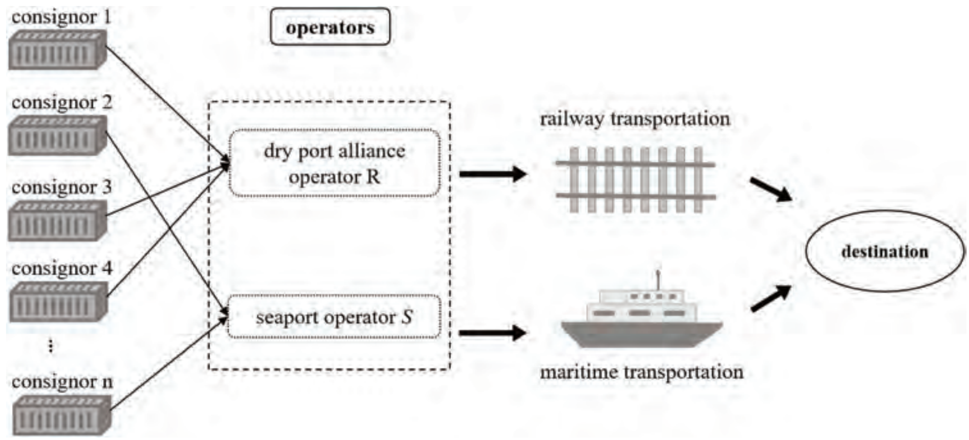


Figure 2. Transportation process of cargo service under the co-opetition model.

transportation time gap between dry port operators. Let L_R and L_S denote transportation time for the dry ports and seaport, respectively. Based on the above assumptions, we have demand of dry port alliance operator R and seaport operator S:

$$D_R^C = \alpha_R - \beta_R(p_R - \rho_R) + \gamma_R^S p_S + \lambda_R(L_S - L_R) \quad (1)$$

$$D_S^C = \alpha_S - \beta_S p_S + \gamma_S^R(p_R - \rho_R) - \lambda_S(L_S - L_R) \quad (2)$$

Where α_i for $i = A, B, R, S$ denotes potential demand of operator i, and $\alpha_R = \alpha_A + \alpha_B$; β_R (β_S) denotes price sensitivity of the dry ports' (seaport's) demand to its own service price; γ_R^S (γ_S^R) denotes cross price sensitivity of the dry ports' (seaport's) demand to the seaport's (dry ports') service price; λ_R (λ_S) denotes sensitivity of the dry ports' (seaport's) demand to the transportation time gap between the seaport and dry ports.

Besides, to avoid meaningless discussion, following assumptions are given.

Assumption 1: $\beta_R > \gamma_R^S > 0$, and $\beta_S > \gamma_S^R > 0$, which indicate that the demand of operator i is more sensitive to its own service price than the competitors.'

Assumption 2: $\beta_S > \beta_R > 0$, and $\lambda_R > \lambda_S > 0$, which indicate that demand for the seaport is more sensitive to the service price than the dry ports, and demand for the dry ports is more sensitive to the transportation time than the seaport.

Assumption 3: The cargo service capacities of the dry ports and seaport are larger than the actual total demand.

Under the co-opetition model, the dry port alliance operator R and the seaport operator S make service price decisions simultaneously based on profit maximisation. Their optimisation problems are:

$$\max \pi_R^C = (p_R - c_R)\left[\alpha_R - \beta_R(p_R - \rho_R) + \gamma_R^S p_S + \lambda_R(L_S - L_R)\right] \quad (3)$$

$$\max \pi_S^C = (p_S - c_S)\left[\alpha_S - \beta_S p_S + \gamma_S^R (p_R - \rho_R) - \lambda_S (L_S - L_R)\right] \tag{4}$$

According to $\partial^2 \pi_R^C / \partial p_R^2 = -2\beta_R < 0$ and $\partial^2 \pi_S^C / \partial p_S^2 = -2\beta_S < 0$, the optimisation problems in Equations (3)-(4) have the optimal solutions. Let $\partial \pi_i^C / \partial p_i = 0$ $(i = R, S)$, we have the equilibrium decisions in theorem 1.

Theorem 1. The equilibrium decisions of the dry port alliance and seaport operators under the co-opetition model are:

$$p_R^{C*} = \frac{2\beta_S(\alpha_R + \beta_R c_R) + \gamma_R^S(\alpha_S + \beta_S c_S) + \rho_R(2\beta_R\beta_S - \gamma_R^S\gamma_S^R) + (L_S - L_R)(2\beta_S\lambda_R - \gamma_R^S\lambda_S)}{4\beta_R\beta_S - \gamma_R^S\gamma_S^R}$$

$$p_S^{C*} = \frac{2\beta_R(\alpha_S + \beta_S c_S) + \gamma_S^R(\alpha_R + \beta_R c_R) - \rho_R\beta_R\gamma_S^R - (L_S - L_R)(2\beta_R\lambda_S - \gamma_S^R\lambda_R)}{4\beta_R\beta_S - \gamma_R^S\gamma_S^R}$$

3.2. Benchmark model (N)

Under the benchmark model, the dry port operators and the seaport operator compete in the cargo service market by setting their service price as p_i for $i = A, B, S$. When delivering unit cargo, they pay a unit cost c_i and obtain subsidy ρ_i from local governments, respectively. The corresponding transportation process of cargo service is given in Figure 3.

Based on the above assumptions, we have demand of operator i for $i = A, B, S$ as:

$$D_A^N = \alpha_A - \beta_R(p_A - \rho_A) + \gamma_R^R(p_B - \rho_B) + \gamma_R^S p_S + \lambda_R(L_S - L_R) \tag{5}$$

$$D_B^N = \alpha_B - \beta_R(p_B - \rho_B) + \gamma_R^R(p_A - \rho_A) + \gamma_R^S p_S + \lambda_R(L_S - L_R) \tag{6}$$

$$D_S^N = \alpha_S - \beta_S p_S + \gamma_S^R(p_A - \rho_A + p_B - \rho_B) - \lambda_S(L_S - L_R) \tag{7}$$

where γ_R^R denotes competition intensity between dry ports.

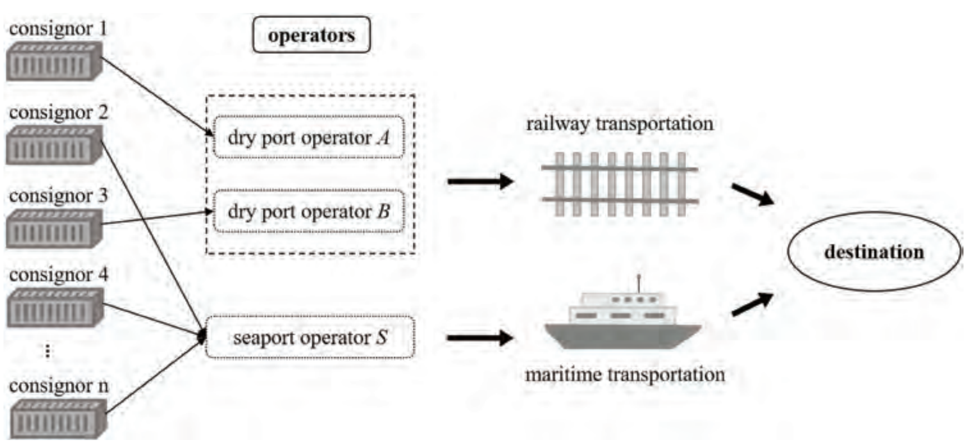


Figure 3. Transportation process of cargo service under the benchmark model.

Under the benchmark model, operator i for $i = A, B, S$ simultaneously makes service price decisions based on profit maximisation. Optimisation problems of the dry port and seaport operators are given:

$$\max \pi_A^N = (p_A - c_A)\left[\alpha_A - \beta_R\left(p_A - \rho_A\right) + \gamma_R^R\left(p_B - \rho_B\right) + \gamma_R^S p_S + \lambda_R(L_S - L_R)\right] \tag{8}$$

$$\max \pi_B^N = (p_B - c_B)\left[\alpha_B - \beta_R\left(p_B - \rho_B\right) + \gamma_R^R\left(p_A - \rho_A\right) + \gamma_R^S p_S + \lambda_R(L_S - L_R)\right] \tag{9}$$

$$\max \pi_S^N = (p_S - c_S)\left[\alpha_S - \beta_S p_S + \gamma_S^R\left(p_A - \rho_A + p_B - \rho_B\right) - \lambda_S(L_S - L_R)\right] \tag{10}$$

According to $\partial^2\pi_i^N/\partial p_i{}^2 = -2\beta_R < 0$ $(i = A, B)$ and $\partial^2\pi_S^N/\partial p_S{}^2 = -2\beta_S < 0$, the optimisation problems in Equations (8)-(10) have the optimal solutions. Let $\partial\pi_i^N/\partial p_i = 0$ $(i = A, B, S)$, we have the equilibrium decisions of the dry port and seaport operators, which is given in theorem 2.

Theorem 2. *The equilibrium decisions of the dry port and seaport operators under the benchmark model are*:

$$p_A^{N*} = \frac{2\beta_R\beta_S\left[2\alpha_A + 2\beta_R\left(c_A + \rho_A\right) + \gamma_R^R\left(c_B - \rho_B\right)\right] + X_1 + X_2}{2\left(2\beta_R + \gamma_R^R\right)\left(2\beta_R\beta_S - \beta_S\gamma_R^R - \gamma_R^S\gamma_S^R\right)}$$

$$p_B^{N*} = \frac{2\beta_R\beta_S\left[2\alpha_B + 2\beta_R\left(c_B + \rho_B\right) + \gamma_R^R\left(c_A - \rho_A\right)\right] + X_1 + X_3}{2\left(2\beta_R + \gamma_R^R\right)\left(2\beta_R\beta_S - \beta_S\gamma_R^R - \gamma_R^S\gamma_S^R\right)}$$

$$p_S^{N*} = \frac{\left(2\beta_S - \gamma_R^R\right)\left(\alpha_S + \beta_S c_S\right) + \gamma_S^R(\alpha_A + \alpha_B) + \beta_R\gamma_S^R\left(c_A - \rho_A + c_B - \rho_B\right) + X_4}{2\left(2\beta_R\beta_S - \beta_S\gamma_R^R - \gamma_R^S\gamma_S^R\right)}$$

where
$X_1 = (L_S - L_R)\left(4\beta_R\beta_S\lambda_R + 2\beta_S\gamma_R^R\lambda_R - 2\beta_R\gamma_R^S\lambda_S - \gamma_R^S\gamma_R^R\lambda_S\right) + \left(2\beta_R + \gamma_R^R\right)\left(\gamma_R^S\alpha_S + \beta_S\gamma_R^S c_S\right)$
, $X_2 = \gamma_R^S\gamma_S^R S\left[\alpha_A - \alpha_B + \beta_R\left(c_B - \rho_B - c_A - 3\rho_A\right) - 2\gamma_R^R\rho_A\right] + 2\beta_S\gamma_R^R\left(\alpha_B - \gamma_R^R\rho_A\right)$,
$X_2 = \gamma_R^S\gamma_S^R S\left[\alpha_A - \alpha_B + \beta_R\left(c_B - \rho_B - c_A - 3\rho_A\right) - 2\gamma_R^R\rho_A\right] + 2\beta_S\gamma_R^R\left(\alpha_B - \gamma_R^R\rho_A\right)$
$X_3 = \gamma_R^S\gamma_S^R\left[\alpha_A - \alpha_B + \beta_R\left(c_A - \rho_A - c_B - 3\rho_B\right) - 2\gamma_R^R\rho_B\right] + 2\beta_S\gamma_R^R\left(\alpha_A - \gamma_R^R\rho_B\right)$,
$X_4 = (L_S - L_R)\left(2\gamma_S^R\lambda_R + \gamma_R^R\lambda_S - 2\beta_R\lambda_S\right)$.
where $X_1 = (L_S - L_R)\left(4\beta_R\beta_S\lambda_R + 2\beta_S\gamma_R^R\lambda_R - 2\beta_R\gamma_R^S\lambda_S - \gamma_R^S\gamma_R^R\lambda_S\right) + \left(2\beta_R + \gamma_R^R\right)$ $\left(\gamma_R^S\alpha_S + \beta_S\gamma_R^S c_S\right)$, $X_2 = \gamma_R^S\gamma_S^{RS}\left[\alpha_A - \alpha_B + \beta_R\left(c_B - \rho_B - c_A - 3\rho_A\right) - 2\gamma_R^R\rho_A\right] + 2\beta_S\gamma_R^R$ $\left(\alpha_B - \gamma_R^R\rho_A\right)$, $X_3 = \gamma_R^S\gamma_S^R\left[\alpha_A - \alpha_B + \beta_R\left(c_A - \rho_A - c_B - 3\rho_B\right) - 2\gamma_R^R\rho_B\right] + 2\beta_S\gamma_R^R$ $\left(\alpha_A - \gamma_R^R\rho_B\right)$, $X_4 = (L_S - L_R)\left(2\gamma_S^R\lambda_R + \gamma_R^R\lambda_S - 2\beta_R\lambda_S\right)$.

4. Profit allocation under the co-opetition model

This section mainly analyses how the two dry port operators allocate the profit obtained from the co-opetition model. A profit consistent constraint is proposed in allocating the profit, that is, the total demands and profits of the two dry port operators after allocation are consistent with the equilibrium demand and profit of the dry port alliance operator under the co-opetition model.

4.1. Problem description

There are many consignors located between the two dry ports. All consignors have a unit demand for the container, and their freight destinations are the same. If a consignor's demand for the container exceeds 1, we normalise the consignor as several consignors. The consignors choose one of the dry port operators to finish its cargo service. Thus, we introduce the Hotelling model to characterise competition between the two dry port operators. Namely, there is a linear city with length D_R^{C*}, the consignors are uniformly distributed between the interval $\left[0, D_R^{C*}\right]$, and dry port operators A and B locate at point 0 and point D_R^{C*}, respectively.

After choosing one of the operators, the consignors must deliver their goods to the dry port selected through highway transportation. Thus, they suffer highway transportation costs proportionate to the transportation distance. Let d and t denote the distance between the dry ports and the highway transportation fee rate. Thus, we have the utility of the consignor located at point x for choosing dry port operators A and B.

$$U_A = U_0 - \frac{dt}{D_R^{C*}}|x-0| - \left(p_R^A - \rho_A\right) \tag{11}$$

$$U_B = U_0 - \frac{dt}{D_R^{C*}}\left|D_R^{C*} - x\right| - \left(p_R^B - \rho_B\right) \tag{12}$$

where U_0 denotes the basic utility of the consignors for finishing unit container cargo transportation; p_R^A and p_R^B denote the service prices of the two dry port operators under the co-opetition model; the second parts of Equations (11)-(12) denote highway transportation cost of dry port operator i for shipping unit container cargo, $i = A, B$. To avoid uninteresting discussion, we assume U_0 is sufficiently large, i.e. consignors located at any location in the linear city will purchase cargo service from one of the two dry port operators.

All the consignors make decisions based on utility maximisation $\max\{U_A, U_B\}$, which is also shown in Figure 4. That is, when $U_A \geq U_B$, i.e. $x \geq x_0 = D_R^{C*}\left(dt - p_R^A + \rho_A + p_R^B - \rho_B\right)$, the consignor will choose dry port operator A. When $U_A < U_B$, i.e. $x < x_0$, the consignor will choose dry port operator B.

Based on the above analysis, we have demands of the dry port operators A and B:

$$D_R^A = \int_0^{x_0} dx = \frac{D_R^{C*}\left(dt - p_R^A + \rho_A + p_R^B - \rho_B\right)}{2dt} \tag{13}$$

$$D_R^B = D_R^{C*} - \int_0^{x_0} dx = \frac{D_R^{C*}\left(dt - p_R^B + \rho_B + p_R^A - \rho_A\right)}{2dt} \tag{14}$$

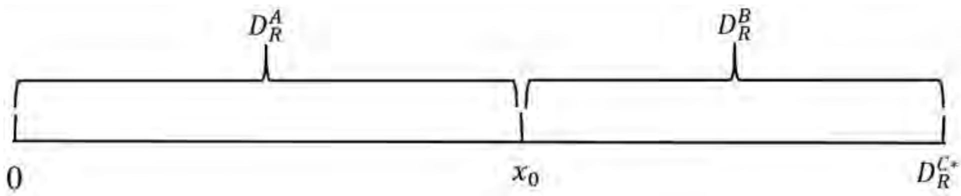


Figure 4. Consignors' purchasing behaviour.

To make sure that the total profits of the two competing dry port operators are consistent with the equilibrium profit of the dry port alliance operator, we add a constraint in the optimisation problems of the dry port operators:

$$\max \pi_A = \left(p_R^A - c_A\right)D_R^A \tag{15}$$

$$\max \pi_B = \left(p_R^B - c_B\right)D_R^B \tag{16}$$

$$\left(p_R^{C*} - c_R\right)D_R^{C*} = \left(p_R^A - c_A\right)D_R^A + \left(p_R^B - c_B\right)D_R^B \tag{17}$$

All the new notations and their definitions used in this section are summarised in Table 3.

4.2. A simple and effective Nash equilibrium calculation method

We solve optimisation problems of the dry port operators in Equations (15)-(17) based on Lagrange function, which can be rewritten as:

$$\min \pi_A = -\left(p_R^A - c_A\right)D_R^A \tag{18}$$

$$\min \pi_B = -\left(p_R^B - c_B\right)D_R^B \tag{19}$$

Optimisation problems of dry port operators turn out to be optimisation problems with non-linear constraint, which can be solved by Karush–Kuhn–Tucker (KKT) condition. Introducing Lagrangian multipliers λ_1 and λ_2, we have:

$$L\left(p_R^A, \lambda_1\right) = -\left(p_R^A - c_A\right)D_R^A + \lambda_1\left[\left(p_R^A - c_A\right)D_R^A + \left(p_R^B - c_B\right)D_R^B - \left(p_R^{C*} - c_R\right)D_R^{C*}\right] \tag{20}$$

Table 3. New notations and their definitions in section 4.

Parameters	
x	The location of a consignor
d	Transportation distance between the two dry ports
t	Highway transportation fee rate
U_0	Basic utility of the consignors for finishing unit container cargo transportation
U_i	Utility of the consignors for choosing dry port operator i for $i = A, B$
Decision variables	
p_R^i	Service price of operator i under the co-opetition model for $i = A, B$
D_R^i	Demand of operator i under the co-opetition model for $i = A, B$

$$L(p_R^B, \lambda_2) = -(p_R^B - c_B)D_R^B + \lambda_2\left[(p_R^A - c_A)D_R^A + (p_R^B - c_B)D_R^B - (p_R^{C*} - c_R)D_R^{C*}\right] \quad (21)$$

According to KKT conditions, let the first-order derivative of Equations (20)-(21) equal to 0, we have the following non-linear equations:

$$\begin{cases} \frac{D_R^{C*}\left(dt+c_A-2p_R^A+p_R^B+\rho_A-\rho_B\right)+\lambda_1 D_R^{C*}\left(2p_R^A-2p_R^B-dt-c_A+c_B-\rho_A+\rho_B\right)}{2dt} = 0 \\ \frac{D_R^{C*}\left(dt+c_B-2p_R^B+p_R^A+\rho_B-\rho_A\right)+\lambda_2 D_R^{C*}\left(2p_R^B-2p_R^A-dt-c_B+c_A-\rho_B+\rho_A\right)}{2dt} = 0 \\ \frac{D_R^{C*}\left[\left(p_R^A-p_R^B-\rho_A+\rho_B\right)\left(p_R^B-p_R^A-c_B+c_A\right)-dt\left(p_R^A+p_R^B-2p_R^{C*}+c_R\right)\right]}{2dt} = 0 \end{cases} \quad (22)$$

The above nonlinear equations have no analytical solutions. To solve this kind of nonlinear equations, we transform them into new optimisation problems and utilise a nonlinear optimisation algorithm provided by MATLAB. By inputting corresponding equations and parameters, we can create numerical solutions through iteration. The transformation is given:

$$\begin{cases} f_1(x) = 0 \\ \quad\cdots \\ f_n(x) = 0 \end{cases} \quad (23)$$

where $x \in S = [a_1, b_1] \cdot [a_2, b_2] \cdot \ldots \cdot [a_n, b_n] \subset R^n$, and $f_1, f_2, \ldots, f_n$ are non-linear real-valued continuous functions in S.

Introduce a new function:

$$F_0(x) = \sum_{i=1}^{n} |f_i(x)|^y, y > 0 \quad (24)$$

According to $F_0(x) \geq 0$, only when $F_0(x^*) = 0$, $x^* \in N(x)$ is the solution of Equation (24). In other words, x^* is the global minimum of $F_0(x)$ in S. The value of y usually are 1 and 2. Take $y = 2$ as an example, Equation (24) can be rewritten as:

$$\min_x F_0(x) = \sum_{i=1}^{n} |f_i(x)|^2 \quad (25)$$

Then Equation (22) can be rewritten as the following optimisation function:

$$\min f(x) = \begin{cases} \left[dt + c_A - 2p_R^A + p_R^B + \rho_A - \rho_B + \lambda_1\left(2p_R^A - 2p_R^B - dt - c_A + c_B - \rho_A + \rho_B\right)\right]^2 \\ +\left[dt + c_B - 2p_R^B + p_R^A + \rho_B - \rho_A + \lambda_2\left(2p_R^B - 2p_R^A - dt - c_B + c_A - \rho_B + \rho_A\right)\right]^2 \\ +\left[\left(p_R^A - p_R^B - \rho_A + \rho_B\right)\left(p_R^B - p_R^A - c_B + c_A\right) - dt\left(p_R^A + p_R^B - 2p_R^{C*} + c_R\right)\right]^2 \end{cases} \quad (26)$$

Then, we utilise the Fminsearch algorithm offered by MATLAB to solve the minimum value problem of unconstrained multivariate nonlinear functions, which is given in Equation 26. Based on the Nelder-Mead Simplex method, the Fminsearch algorithm cannot ensure convergence to the minimum value of the function when solving functions of two or more variables. In other words, the validity of the solution obtained by the Fminsearch algorithm cannot be guaranteed resulting from that Equation (22) has four variables. To cope with this issue, this paper proposes a simple and effective Nash

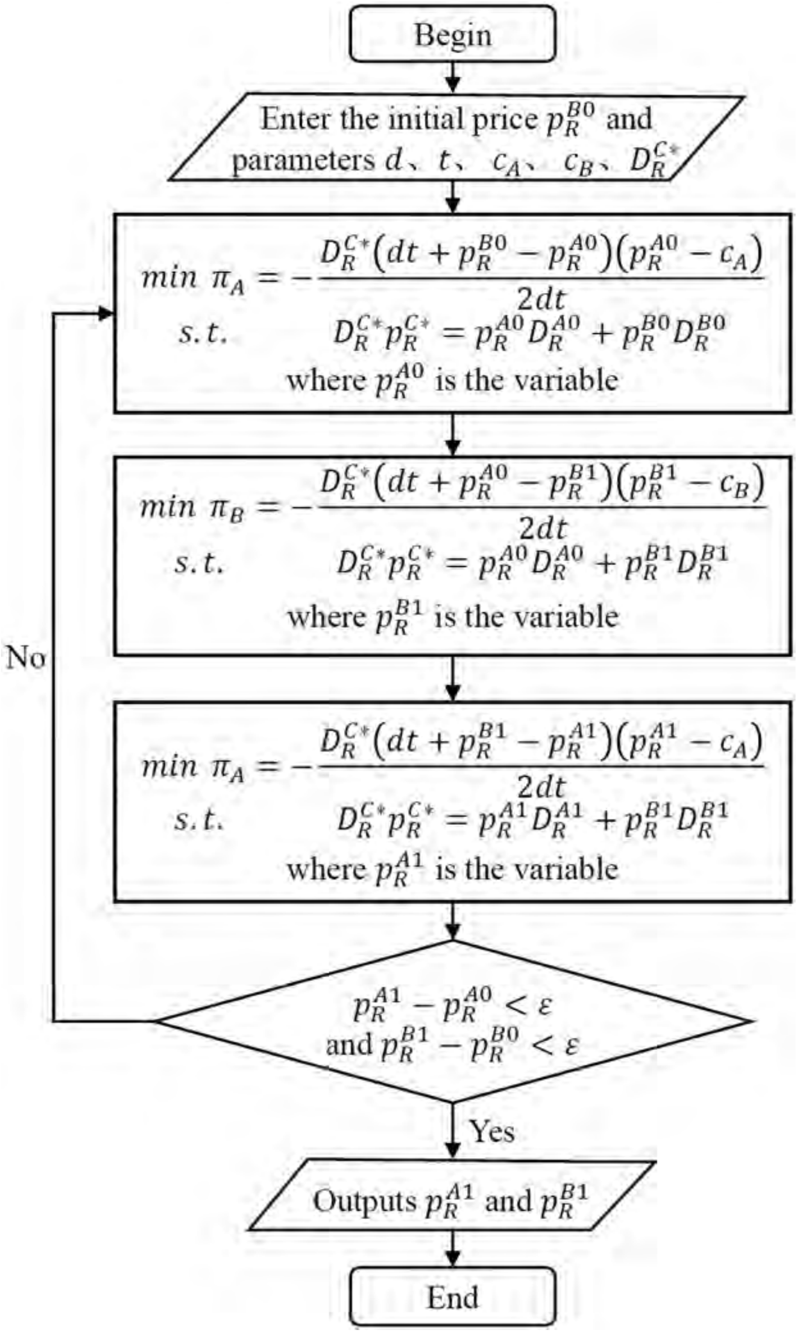


Figure 5. Solution procedure of the Nash equilibrium calculation method.

equilibrium calculation, which derives equilibrium prices of the operator i for $i = A, B$ under profit-consistent constraint based on the basic principle of Nash equilibrium. The detailed solution procedure of this method is given in the following, which is also summarised in Figure 5.

(1) Input the initial price of dry port operator B (p_R^{B0}) and other known parameters.
(2) Given p_R^{B0}, derive the corresponding p_R^{A0} of dry port operator A, which maximises its profit and satisfies profit consistent constraint, i.e. p_R^{A0} is the optimal solution of Equation (18) when satisfies the constraint in Equation (17). At present, Equation (18) only incorporates variable p_R^{A0}, and other parameters are known.
(3) Given p_R^{A0}, derive the corresponding p_R^{B1} of dry port operator B, which maximises its profit and satisfies profit consistent constraint, i.e. p_R^{B1} is the optimal solution of Equation (19) when satisfies the constraint in Equation (17). Equation (19) only incorporates variable p_R^{B1}, and other parameters are known.
(4) Given p_R^{B1}, derive the corresponding p_R^{A1} of dry port operator A which maximises its profit and satisfies profit consistent constraint, i.e. p_R^{A1} is the optimal solution of Equation (18) when satisfies the constraint in Equation (17). Equation (18) only incorporates variable p_R^{A1}, and other parameters are known.
(5) Comparing p_R^{A0} with p_R^{A1}, and comparing p_R^{B0} with p_R^{B1}, output p_R^{A1} and p_R^{B1} when the termination condition is satisfied, i.e. the difference between p_R^{A0} and p_R^{A1} and the difference between p_R^{B0} with p_R^{B1} are smaller than the given error ε simultaneously.
(6) If the termination condition is not satisfied, we assign the value of p_R^{B1} to p_R^{B0} and assign the value of p_R^{A1} to p_R^{A0}. Then, repeat steps (2–5) until the termination condition is satisfied, and then output p_R^{A1} and p_R^{B1}.

5. Case study

In the real world, plenty of dry ports strategically pursue collaboration to achieve synergistic integration and then enhance market competitiveness. For example, Chengdu and Chongqing, two main departure cities of the CRE, have jointly built a brand named ‘ChengYu Hao’ to explore how to cooperate with each other. Thus, this section selects the ‘Chongqing to Duisburg’ route and the ‘Chengdu to Duisburg’ route and conduct a case study based on the operational data of the two CRE routes and related maritime operational data.

5.1. Parameter settings

5.1.1. Transportation cost

Transportation costs for dry port operators are structurally segregated into domestic transportation costs and overseas transportation costs. According to Railway Freight Pricing Rules (2005 Edition), transportation costs mainly comprise transportation fees, railway electrification surcharges, railway construction funds, and other fees. According to transportation mileage in the Freight Rate Odometer, transportation fees are affected by basic price 1 and basic price 2. Thus, we have the transportation cost of dry port operator i for $i = A, B$:

$$c_i = c_i^E + c_i^F \tag{27}$$

$$c_i^E = c_1 + c_{2i}^E d_i^E + c_3 d_i^E + c_4 \tag{28}$$

$$c_i^F = c_{2i}^F d_i^F \tag{29}$$

where superscripts E, F denote domestic transportation and overseas transportation; c_1 denotes basic price 1 of railway freight; c_{2i}^j denotes basic price 2 of dry port operator i in j part transportation, $i = A, B$, $j = E, F$; c_3 denotes the sum of railway electrification surcharge rate, railway construction fund rate, and railway new price sharing rate; c_4 denotes other fees.

According to Silk Road Express,[3] we identify transportation mileages of the two routes, which is given in Table 4.

According to Notice on Adjusting Railway Freight Transport Prices (Development and Reform Price [2015] No.183), we learn basic price 1 of railway freight (c_1) and basic price 2 of dry port operator i in domestic transportation (c_{2i}^E). According to the freight rate of the New Eurasian Land Bridge, we learn the basic price 2 of dry port operator i in overseas transportation (c_{2i}^F). The above three basic prices are given in Table 5. Note that FEU means Forty-foot Equivalent Unit (the container with a length of 40 feet), and the exchange rate conversion is based on $1\text{USD}(\$) = 6.7\text{RMB}$.

According to Railway Freight Pricing Rules (2005 Edition), we learn railway transportation miscellaneous fees and surcharges of 40-inch container (c_3), which is given in Table 6, and railway station operation fee (c_4), which is given in Table 7.

According to the information shown in Tables 4-7, we can calculate the total transportation cost of the two dry port operators, which is given in Table 8.

5.1.2. Other parameters

Given transportation costs and service prices of the dry port operators, the actual operational data, and the relative literature, we set the subsidy to Chongqing dry port and Chengdu dry port as 3000 \$/FEU and 3500 \$/FEU, respectively. When allocating

Table 4. Transportation mileage of the two transportation routes (km).

Transportation routes	Entry-exit port	Domestic mileage	Overseas mileage	Total
Chongqing to Duisburg	Alashankou	4137	7042	11179
Chengdu to Duisburg	Alashankou	3511	7042	10553

Table 5. Basic prices of dry port operators (\$/FEU).

Items	Prices
Basic price 1 (c_1)	101.493
Basic price 2 in domestic (c_{2i}^E)	0.411
Basic price 2 in New Eurasian Land Bridge (c_{2i}^F)	0.697

Table 6. Railway transportation miscellaneous fees and surcharges (\$/FEU*km).

Items	Fee for loaded containers	Formula
Electrification surcharge	0.061	Rate*charged weight*electrification mileage
Construction fund	0.167	Rate*charged weight*charged mileage
New price sharing fee	0.0056	Rate*charged weight*charged mileage
Sum (c_3)	0.2336	

profit under the co-opetition model, profits of the dry port operators are also affected by highway transportation costs and transportation time for the dry ports and seaport. Searching starting stations of the two CRE routes in Baidu Maps, 'Railway Container Centre Station in Tuanjie Village, Shapingba District, Chongqing' and 'Railway Container Centre Station in Qingbaijiang District, Chengdu,' we have the relative distance as $d = 300\text{km}$. According to the pricing of highway containers announced by the National Development and Reform Commission, $t = 1.3971\$/\text{FEU} \cdot \text{km}$. The actual

Table 7. Railway station operation fee ($/FEU).

Items	Comprehensive operation fee
Loading and unloading	43.66
Unpacking	44.77
Sum (c_4)	88.41

Table 8. Transportation cost of the two dry port operators ($/FEU).

Transportation routes	Transportation cost
Chongqing to Duisburg (c_A)	7767
Chengdu to Duisburg (c_B)	7363

Table 9. The values of the important parameters.

Parameters	Values
ρ_A, ρ_B	3000, 3500 ($/FEU)
a_A, a_B, a_S	30000, 30000, 240000 ($/FEU)
c_A, c_B, c_R, c_S	7767, 7363, 7565, 2650 ($/FEU)
L_R, L_S	2.04, 6.7 (weeks)
β_R, β_S	5.9, 23
$\gamma_R^R, \gamma_R^S, \gamma_S^R$	0.5, 0.4, 0.5
λ_R, λ_S	0.3, 0.2
p_R^{B0}	0
ε	10^{-6}

values of other parameters are also set due to operational data of the CRE and maritime transportation and the relevant literature, which is given in Table 9. Note that $c_R = (c_A + c_B)/2$.

5.2. Results analysis

Based on the values of parameters in subsection 5.1 and the proposed calculation method in subsection 4.2, we get the equilibrium results of different operators under different models. To investigate the impact of the subsidy, we also give the equilibrium results without the subsidy, i.e. $\rho_i = 0$ for $i = A, B, R$. Let CB and NB denote the co-opetition and benchmark models without the subsidy, respectively. Equilibrium results under different models are summarised in Table 10.

Table 10. Equilibrium results under different models.

Models	Operators	Subsidy	Service prices ($)	Demands (FEU)	Profits (million$)
Benchmark model	A	×	8169	2374	0.96
		√	9591	10762	19.63
	B	×	7976	3615	2.21
		√	9658	13538	31.06
	S	×	6515	88901	343.63
		√	6478	88052	337.09
Co-opetition model	R	×	10271	15964	43.19
		√	11895	25548	110.62
	S	×	6451	87433	332.37
		√	6434	87026	329.29
Co-opetition model after profit allocation	A	×	10271	7830	19.61
		√	11653	8599	33.41
	B	×	10263	8134	23.59
		√	12016	16949	78.87

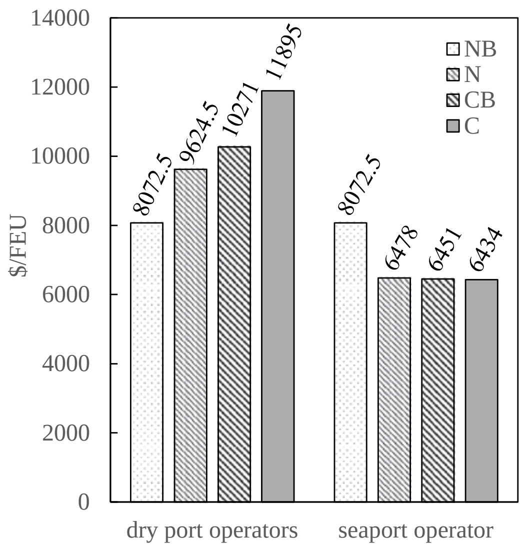


Figure 6. The service prices under different models.

5.2.1. The impact of the co-opetition model on decisions

To illustrate the impact of the co-opetition model on the service prices vividly, we draw Figure 6, in which the service prices of dry port operators under the benchmark model equals the average price of dry port operators A and B.

As illustrated in Figure 6, both the co-opetition model and the subsidy prompt dry port operators to raise service prices, enabling higher profit margins. More specifically, based on the service price under the *NB* model, the subsidy and the co-opetition model induce a 19.2% and 27.2% price uplifts, respectively. This result indicates that the co-opetition model is more capable of helping dry port operators to obtain higher margins. Furthermore, the service price under the *C* model increases by 43.8%, which is lower than 46.4%. That is, the interaction of the subsidy and the co-opetition model weakens the separate impact of subsidies and the co-opetition model on the service prices. This result also provides a quick glance at how to enhance competitiveness for dry port operators with subsidy phase-out policies.

For the seaport operator, the subsidy and the co-opetition model have similar negative impacts on the service price compared with that under the *NB* model. Furthermore, the service price of seaport operator exhibits only marginal declines under the *C* model, presenting a stark contrast to the pronounced upward trajectory in the service prices of the dry port operators under the *C* model. It indicates that the interaction of the co-opetition and the subsidy merely influences the service price of the seaport operator. In other words, under the co-opetition model, the dry port operators have to take measures except subsidies to enhance competitiveness. This result gives evidence for subsidy phase-out policies.

5.2.2. The effectiveness of the co-opetition model

To present the effectiveness of the co-opetition model vividly, we draw Figure 7 in which the demands and profits of dry port operators under the benchmark model equals the sum of the demands and profits of dry port operators *A* and *B*.

From Figure 7, the total demands and profits of the dry port operators only account for 6.7% and 0.9% of the seaport operator's demand and profit under the *NB* model, which results from the relatively high-cost advantage of maritime transportation. It indicates that despite outperforming seaports in timeliness, dry ports still trail in market share and profitability due to unmonetized advantages. After acquiring a subsidy from the local government, the dry port operators raise the service prices up while the service prices with subsidies are lower than those without subsidies for consignors. As a result, increasing consignors choose dry ports for their cargo service, leading to a significant increase in the demands and profits of dry port operators. More specifically, the total demands and profits of the dry port operators account for 27.6% and 15% of the seaport operator's demand and profit under the *N* model, increasing by 20.9% and 14.1% compared with the *NB* model.

Furthermore, Figure 7 demonstrates that regardless of subsidy provision, both total demand and profits for dry port operators under the co-opetition model consistently

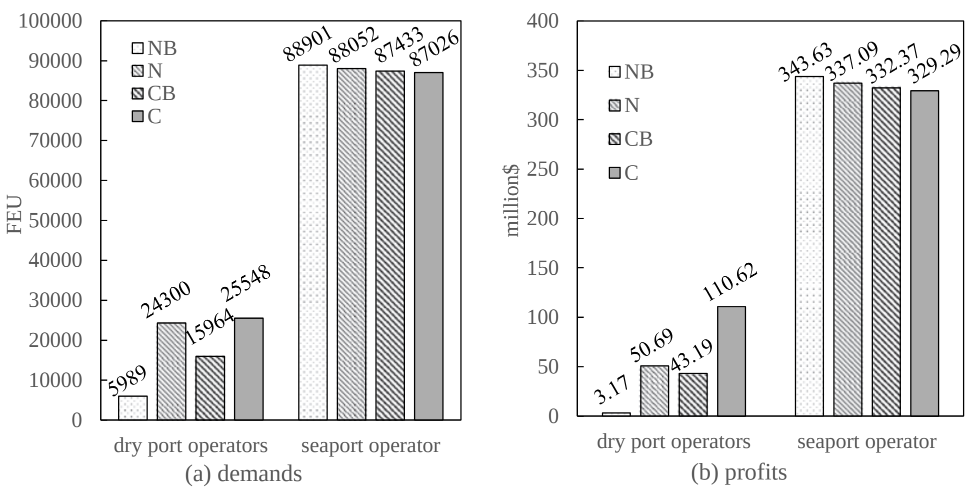


Figure 7. Equilibrium results of the operators under different models.

exceed those under the benchmark model, with substantial growth margins. This indicates that the co-opetition model significantly enhances the timeliness advantage of dry ports, thereby driving a marked increase in their market demand and profitability. More specifically, the demand and profit of the dry port alliance operator under the *CB* model account for 18.3% and 13.0% of the seaport operator respectively, increasing by 11.6% and 12.1% compared with the *NB* model. This increase is lower than that affected by the subsidy, which indicates that the subsidy does have a significant impact for dry port operators to compete with seaport operators in the early stage.

Further, the demand and profit of the dry port alliance operator under the *C* model account for 29.4% and 33.6% of the seaport operator, respectively, increasing by 1.8% and 18.6% compared with the *N* model. The slight demand uplift implies minimal subsidy impact under the co-opetition model. Notwithstanding substantial profit gains, these improvements entail disproportionate fiscal burdens for local governments, indicating suboptimal policy efficiency.

5.2.3. The analysis after profit allocation under the co-opetition model

Subsection 5.2.2 proves the effectiveness of the co-opetition model on dry port operators. Based on this, this subsection further analyses the impact of the co-opetition model on heterogeneous dry port operators. Figure 8 is drawn by comparing the equilibrium results of dry port operators among different models.

From Figure 8, compared with the results under the benchmark model, the profits of dry port operators *A* and *B* are higher under the co-opetition model, whether with or without the subsidy. This validates that the profit allocation model proposed in section 4 effectively facilitates cooperation between competing dry ports. Specifically, two rival dry ports may collaborate through standardized pricing with centralized distribution, while their respective cargo volumes are divided by equilibrium demands derived from inner competition.

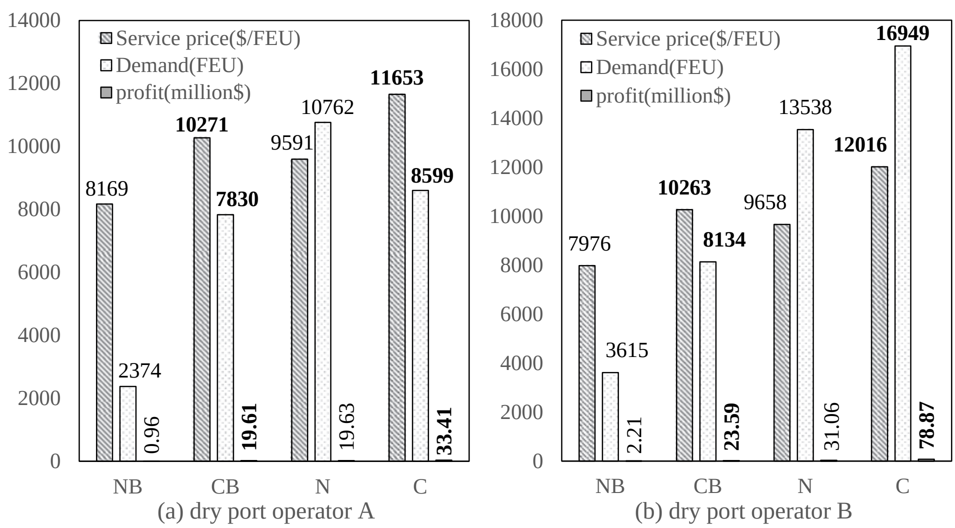


Figure 8. Equilibrium comparison of dry port operators.

Figure 8 shows that the service prices of dry port operator A under the NB and CB models are higher than that of dry port operator B due to higher transportation cost. Nevertheless, dry port operator B achieves both higher demand and greater profitability. Specifically, the profits of dry port operator B are 2.3 and 1.2 times that of A under the NB and CB models, respectively. This implies that cost advantage plays a critical role in dry port profitability. Counterintuitively, this competitive edge is diminished by the co-opetition model, which enables less cost-competitive dry port operator A to capture larger marginal profit increments under the CB model than the efficient dry port operator B. In other words, the co-opetition model leads efficient dry port operator B to superior profit levels and less cost-efficient dry port operator A to a greater marginal gain. This holds significant operational implications for different dry port operators. That is, efficiency-driven dry ports give top priority to optimize absolute profits, such as employing AI-driven optimization, while cost-disadvantaged dry ports leverage co-opetition model for accelerated growth, such as implementing differentiated service-product designs to facilitate strategic collaboration with dominant dry ports.

6. Sensitive analysis

6.1. The impact of the transportation time gap between the seaport and dry ports

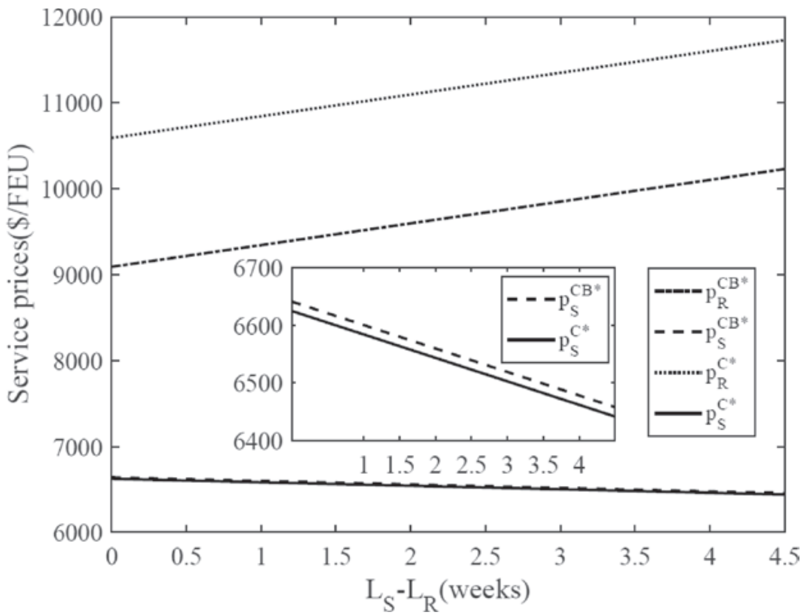
Section 5 identifies that the co-opetition model contributes to the timeliness advantage of the dry ports. Therefore, this subsection further explores the impact of the transportation time gap between the seaport and dry ports on the service prices and profits of dry port operators, which is illustrated in Figure 9.

According to Figure 9(a), with or without the subsidy, the service prices of the dry port alliance operator increase with a higher transportation time gap between the seaport and dry ports ($L_S - L_R$). It verifies that the co-opetition model makes higher margins possible for dry port operators. After receiving subsidies, the realised service prices of dry port operators are equal to the equilibrium prices minus subsidies. That is, for the consignors in the cargo service market, the service prices with subsidies are lower than those without subsidies. Therefore, to avoid the loss of market share, the seaport operator lowers its service price with higher values of $L_S - L_R$. Furthermore, the impact of $L_S - L_R$ on the dry port alliance operator is more obvious than that on the seaport operator.

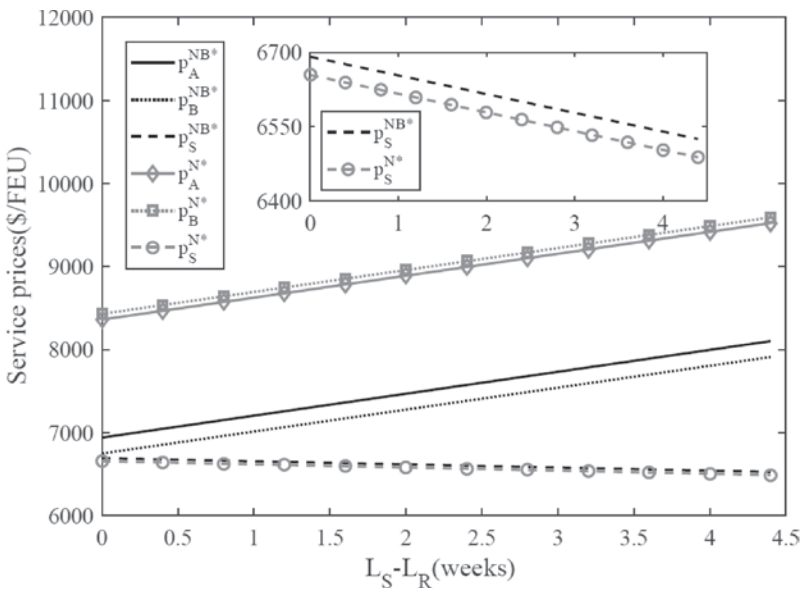
Comparing Figure 9(a) with 9(b), with or without the subsidy, the service prices of the dry port operators under the co-opetition model are higher than that under the benchmark model while the service prices of the seaport operator under the co-opetition model are lower than that under the benchmark model. This demonstrates that the co-opetition model effectively enables dry port operators to secure competitive leverage against seaport operators.

Figure 10 illustrates the impact of $L_S - L_R$ on total profits of the dry port operators under different models.

Under the co-opetition model, no matter whether with or without the subsidy, the dry port alliance operator obtains more profits as $L_S - L_R$ increases. Differently, the total profits of the two dry port operators first decrease and then increase under the NB model with higher values of $L_S - L_R$. Furthermore, the growth rate under the benchmark model is lower than that under the co-



(a) under the co-opetition model



(b) under the benchmark model

Figure 9. The impact of the transportation time gap on the service prices.

opetition model. Besides, the total profit of the dry port operator under the co-opetition model is always larger than that under the benchmark model. This demonstrates that the co-opetition model significantly enhances the timeliness advantage for dry port operators.

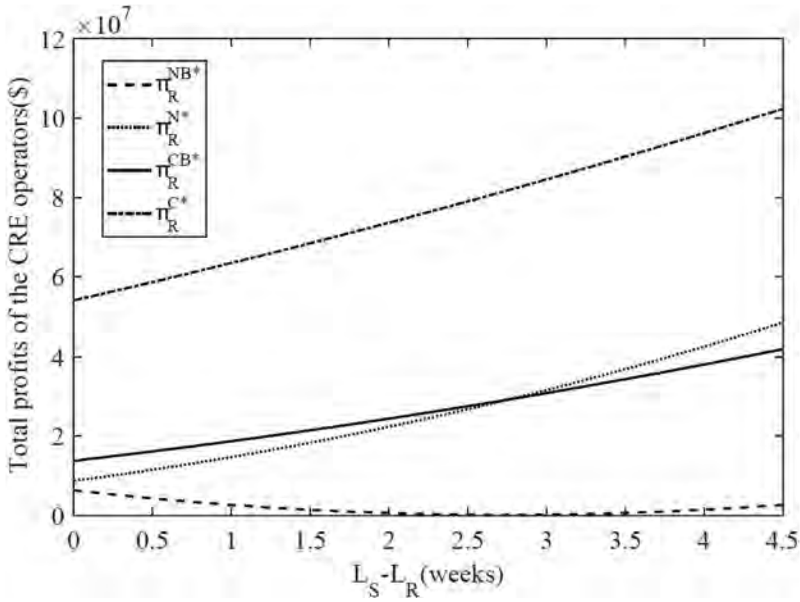


Figure 10. The impact of the transportation time gap on total profits of dry port operators.

6.2. The impact of the subsidy on realised profit of dry port operators

Section 5 shows that local governments pay for the dry port operators' profit increase with the subsidy. Thus, this subsection illustrates the impact of the subsidy on realised profit of dry port operators, which equals the profit of dry port operators minus subsidies obtained from governments, which is given in Figure 11.

Figure 11 illustrates that the realised profits of dry port operators with the subsidy are lower than those without the subsidy. From Figure 11(a), with the increase of ρ_A, the realised profit of dry port operator A decreases, and the decrement is higher with higher values of ρ_A. With the increase of ρ_B, the realised profit of dry port operator A decreases as well, but the decrement is not significant. As evidenced in Figures 11 (c,d), dry port operators' total profits decline with increasing subsidy levels under both benchmark and co-opetition models, while the rate of decline diminishes at higher subsidies.

Figure 12 further compares the realised profit decrement of dry port operators between the benchmark and the co-opetition models. With different subsidy strategies, dry port operators experience greater profit erosion under the benchmark model than that under the co-opetition model. Besides, with the increase in subsidies, the gap between the realised profit decrement of dry port operators under the two models becomes larger. This result indicates that although the subsidy can enlarge the market share of dry port operators, it has a negative impact on the profits of dry port operators. In other words, the subsidy goes against the long-term development of dry port operators. Meanwhile, compared with the benchmark model, the co-opetition model can mitigate the ill effect of the subsidy on the realised profits of dry port operators, leading to the sustainable development of dry port operators.

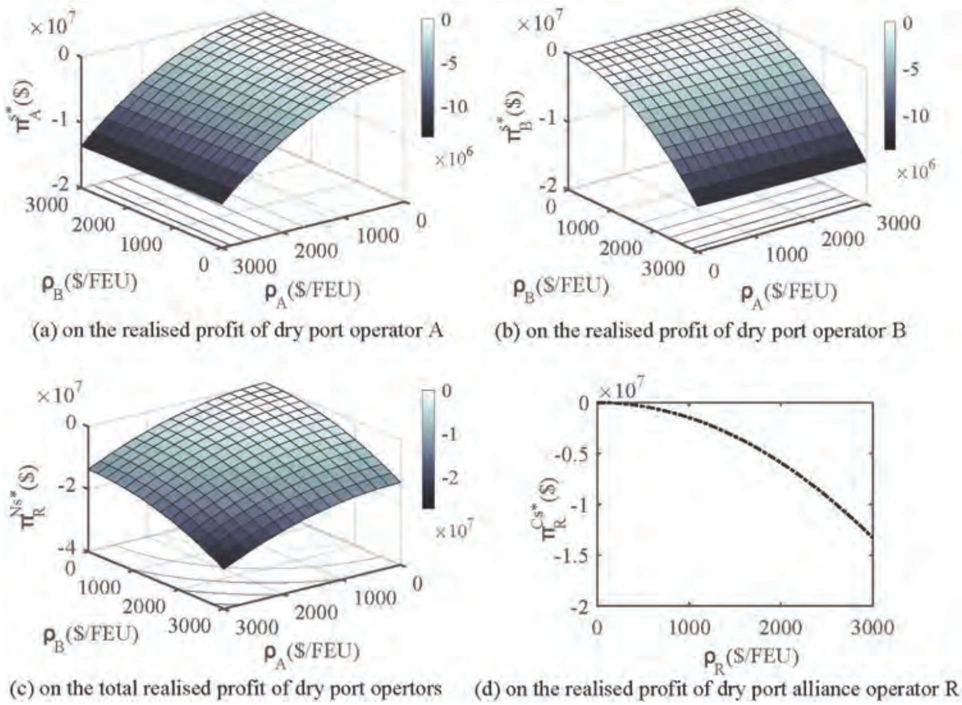


Figure 11. The impact of the subsidy on realised profit of dry port operators.

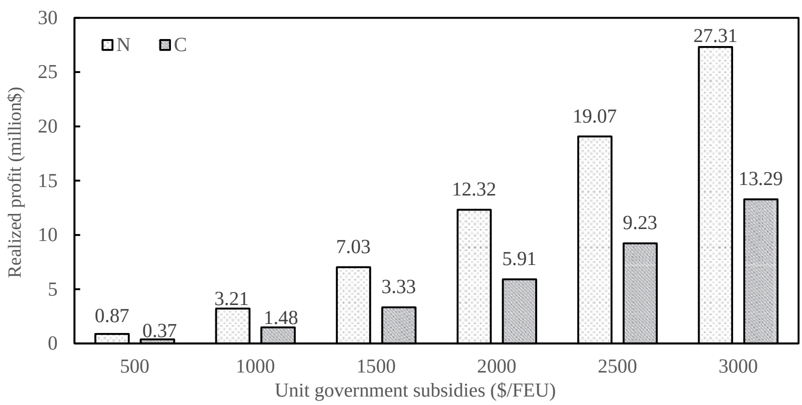


Figure 12. Realised profit decrement of dry port operators between different models.

7. Conclusions

Amid unpredictable transit times and suboptimal delivery performance in seaports, dry ports are gaining significant attractions in the cargo service market due to their demonstrable reliability and transit time consistency. Furthermore, ongoing fiscal subsidies have further catalysed the development of dry ports. However, confronting the reality of subsidy phase-outs ploicies, dry ports must urgently identify new competitive drivers to rival maritime transportation. Under such circumstances, this paper proposed a novel co-opetition model between dry ports for competing with maritime transportation, and investigated how this model enhances dry port operators' competitiveness. A simple and effective Nash equilibrium calculation method was developed for profit allocation between two dry port routes. This paper conducted a case study considering two Silk Road Express routes from Chongqing and Chengdu to Duisburg for competing with a seaport.

7.1. Main findings

We found the following results.

(1) Compared with the benchmark, the co-opetition model significantly enhances the timeliness advantage of dry ports alliance operator and empowers it to capture increased equilibrium freight volumes and higher profit margins against seaport rivals. (2) After profit allocation, the equilibrium profits of dry port operators under the co-opetition model have been dramatically improved, which demonstrates the efficacy of the co-opetition model proposed in this paper. (3) The subsidy indeed improves the demands and profits of dry port operators when competing with maritime transportation. However, the actual revenue which equals profit minus subsidies obtained from local governments has declined, which harms the long-term stable development of dry port. (4) Without the presence of subsidy, the co-opetition model enables cost-efficient dry port to achieve higher absolute profits while helping less efficient operator realize greater profit increments.

7.2. Managerial implication

The above results have notable implications for both local governments and dry port operators.

The first is for local governments. This paper examines that the subsidy is not conducive to the long-term stable development of dry port operators, which provides evidence for subsidy phase-out policies. Furthermore, we also find that the profit decrement under the co-opetition model proposed by this paper is lower than that under the benchmark model. It indicates that the co-opetition model can mitigate the adverse impact of the subsidy on dry port operators. This result suggests that local governments should encourage cooperation between competing dry port operators with subsidy phase-out policies. This suggestion is proved by the practice of many dry port joint brands launched by local governments, such as 'ChengYuHao' (the cooperation between Chengdu and Chongqing), and 'ZhongYuHao' (the cooperation among different cities of Henan province, which is referred to as 'Yu').

The second is for dry port operators. This paper proposes a co-opetition model based on standardized pricing with centralized distribution for dry port operators. The case study of Chongqing and Chengdu dry ports provides empirical validation that the co-opetition model significantly enhances the temporal competitiveness of dry ports, which leads to a significant profit increase for dry port operators. That is, the co-opetition model provides an efficient and practicable means for dry port operators to compete with seaport operators. Moreover, the differential benefits of the co-opetition model for heterogeneous dry ports necessitate strategic adaptation based on individual competitive positioning. For instances, efficiency-driven dry ports can employ AI-driven strategy to optimize absolute profits while cost-disadvantaged dry ports implement differentiated service-product designs to improve cooperation opportunities with dominant dry ports.

7.3. Future research

Our study develops a game-theoretic model to analyse the effectiveness of the co-opetition model. Given the computational complexity inherent in solving multi-agent games, we propose a simple and effective Nash equilibrium calculation method to derive feasible solutions. While this approach enables tractable analysis (as demonstrated in section 5 through a case study), it trades off theoretical optimality for practical implementability. Consequently, the primary limitation of this work lies in the suboptimal nature of our algorithm's solutions. Future studies could enhance robustness through the following extensions.

First, this study primarily considered the influence of fundamental factors including price, transportation time and transportation cost to examine how cooperation between dry port enhances their competitiveness relatively to seaports. Future research can further consider the combined effects of more factors to test the robustness of the proposed model. For example, multimodal transport connectivity, automated and AI-enabled logistics infrastructure and the carbon cap-and-trade policy (Xu et al. 2023) can be explored to increase the applicability of the co-opetition model proposed in this paper.

Second, future research could also explore alternative modelling approaches and in-depth equilibrium analysis. For example, non-linear demand function can be considered to capture variability of actual operations. Besides, comparing with the benchmark model, the co-opetition model does not consider the fixed total demand of different dry ports operators. Thus, the future research can adopt the total aggregate demand function to limit the change of latent demands. Meanwhile, in-depth equilibrium analysis can be conducted to achieve the theoretical optimality.

Third, this paper verified that the co-opetition model with standardized pricing with centralized distribution can exert the timeliness advantage of dry ports. Based on these results, future research can investigate how to implement standardized pricing with centralized distribution. For example, future research can investigate how optimise door-to-door service capacity among co-opetitive dry port operators to reduce marginal costs and improve service stability.

Notes

1. http://www.china-railway.com.cn/xwzx/mtjj/rmrbhwb/rmrbhwb/202506/t20250611_145957.html.
2. https://commerce.ah.gov.cn/public/21711/120541421.html.
3. More details of Silk Road Express are shown in this link https://www.imsilkroad.com/z/160525-4/.

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Data availability statement

The data that support the findings of this study are openly available at https://www.imsilkroad.com/z/160525-4/.

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