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Yitong, M, Johnson, D orcid.org/0000-0002-1188-8610, Wang, JYT orcid.org/0000-0002-3361-6413 et al. (1 more author) (2021) Competition for rail transport services in duopoly market: Case study of China Railway(CR) Express in Chengdu and Chongqinq. Research in Transportation Business and Management, 38. 100529. ISSN 2210-5395

https://doi.org/10.1016/j.rtbm.2020.100529

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Competition for rail transport services in duopoly market: Case study of China Railway(CR) Express in Chengdu and Chongqing

Abstract

Known as the Belt and Road Initiative, China Railway(CR) Express is driving China's efforts to boost connectivity and explore regional cooperation with Eurasian markets. In order to investigate the fierce hinterland competition between two neighbouring CR Express lines, this paper first formulates a non-cooperative game model to explore strategic decisions on pricing accounting for competition in a spatial setting, given frequency, government subsidy, local road infrastructure investment, and operation costs. We then extend the model to analyze decisions on frequency and pricing together, and the implications for social welfare, profits and market share as well. Based on a case study of CR Express lines originated from Chengdu and Chongqing to Hamburg, we verify our model and conclude some findings. The results show that government subsidy is the major factor that influences operators pricing strategy. Also, frequency and local road infrastructure investment have effects on operators' decisions. For the government, giving more freedom to operators, that is letting operators decide their frequency, is a good way to bring benefits for both social welfare and operator profits.

Keywords: the Belt and Road Initiative, China Railway Express, rail transport, spatial duopoly competition, game theory

1. Introduction

The "B&R" Initiative, involving a few of new trade and development initiatives, is a blueprint for China to explore good cooperation with new trade partners and to boost regional economic prosperity. There are two main routes, i.e. the land-based "Silk Road Economic Belt" and the sea-going "Twenty-First-Century Maritime Silk Road", which are driving China's efforts to boost connectivity with Eurasia markets, as shown in Fig. 1. As for the infrastructure and strategy development for the "B&R" initiative, improving and reconfiguring logistics and transport networks along the trade corridors and connectivity among participating countries are primary goals of the initiative (Sheu and Kundu, 2018). In order to increase the transport and trade connectivity with surrounding countries by land, the Chinese government has strongly supported the cross-continent rail transport, which is known as China Railway Express (hereinafter referred to as CR Express).

CR Express has been a crucial component for "Silk Road Economic Belt". In 2011, the first CR Express (Chongqing-Duisburg) started to operate. Currently, generating the west, the middle, and the east three transport channels (Fig. 2) relying on the Siberia Continental Bridge and the new Eurasian Continental Bridge, CR Express lines origin from 59 cities in China and reach 49 cities of 15 European countries, respectively. Featuring the shorter transport time and the reasonable fee, CR Express have attracted a group of customers. For example, it takes about 50 days to transport a cargo from Guangzhou, the most southeast port of China, to a German port by shipping. However, a cargo from China's midwestern inland city Chongqing can reach Germany only in 14-16 days. The time saving helps cargo owners respond to market uncertainty better and accelerate cash flow. Also, subsidies given by local governments could offset the gap between CR Express price and the maritime transport fee to some degree. CR Express, therefore, has developed dramatically and has run 6,373 trains in total in 2018, which is greater than the sum of trains of the last few years (Fig. 3). As a result, CR Express has reached cumulatively 14,000 trains by the end of February, 2019 (Official "B&R" initiative website, 2019), with a good balance of westbound (China to Europe) and eastbound (Europe to China) transport as well.

There are nonetheless some challenges for CR Express operators and governments at this initial and nurturing stage, although the development prospects are bright. From operators' prospects, price competition

Figure 1: The Belt and Road Initiative sketch map. *Source:* Xinhua News Agency

is the main means to attract customers in the CR Express transport market because there is no obvious difference in transport services provided by different operators. That is to say, CR Express operators have a strong substitutability. Optimal pricing competition strategy, therefore, is necessary and significant for operators to obtain more benefits. CR Express have much less transport capacity than shipping, therefore, it is an efficient way to increase running frequency to strengthen competitiveness for operators. However, in the current situation, CR Express running frequency is decided by the railway authority. Another scenario, therefore, where the government would like to let operators participate in the running frequency strategic decision, is considered in this paper. It it meaningful to explore joint decisions of operators on pricing and frequency under this scenario.

This study, therefore, attempts to give answers to the following questions: (1) How will CR Express operators design their pricing competition strategy in the present situation to reap maximum profits? (2) How could operators decide their price and frequency, respectively, if the fixed frequency constraint, currently set by the railway authority, is relaxed? (3) What are the implications for social welfare of operators' decisions in above two cases, respectively?

This paper is organized as follows. Recent and related literature are reviewed in Section 2. Section 3 shows detailed problem, a basic model and analytical solutions of equilibria. The extended model is put forward in Section 4. Section 5 presents the analytical results based on the case of CR Express from Chengdu and Chongqing, and managerial insights as well from sensitivity analysis. In Section 6, this paper is concluded and the future research is suggested.

2. Literature review

Many researchers have focused on problems with the context of "B&R" Initiative since it was put forward. At the early stage of this topic, scholars mostly used the qualitative analysis to explain the motivation, content, and framework of "B&R". Huang (2016) and Cheng (2016) conducted a quantitative assessment of "B&R" Initiative and found that it would offer opportunities to develop the world economy in terms of trade and social welfare. Specifically, Schinas and von Westarp (2017) assessed the impact of the maritime silk road and determined that it has a positive effect on economic and environmental development for "B&R" involved countries. Then, some researchers turn their attentions to problems related to trade and logistics network. Sheu and Kundu (2018) forecasted the time-varying international logistics distribution flow of a three-layer supply chain framework under the initiative induced stochastic and dynamic challenges, and they carried out the numerical analysis on two cases of an oil supply chain. Also, transport infrastructure plays an important

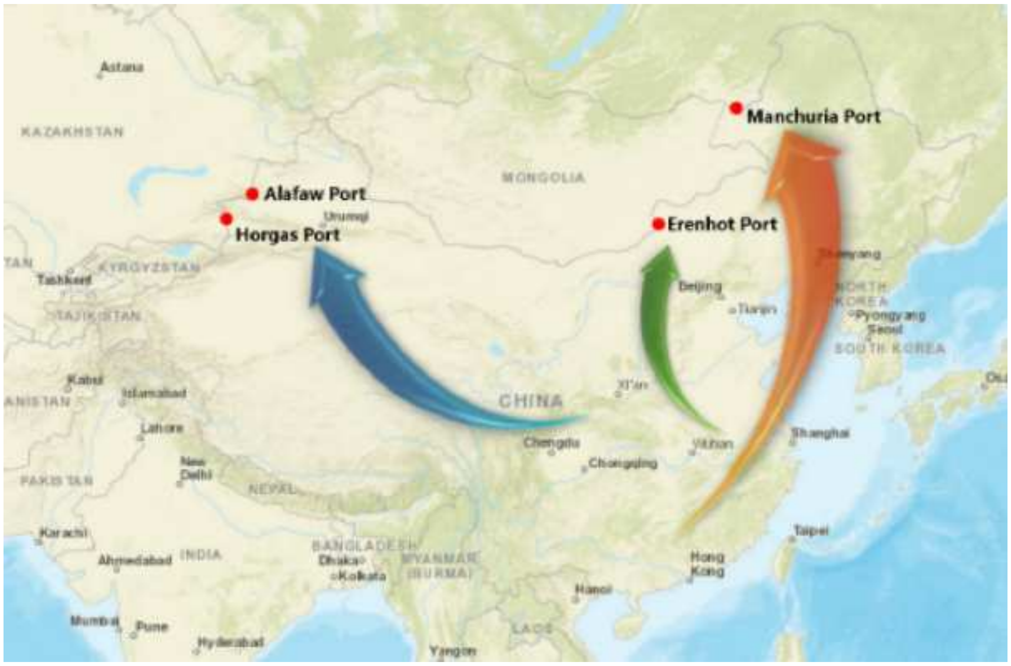

Figure 2: Three logistics channel of CR Express in China.

role in the regions' economic growth and also has a spatial spillover effect on the surrounding areas (Li et al., 2017). Therefore, scholars have explored transport infrastructure related problems, especially problems with the focus on maritime transport (Lee et al., 2018), such as transport efficiency evaluation (Shao et al., 2018), transport corridors (Zeng et al., 2018), transport network (Ruan et al., 2018; Yang et al., 2018) and marine port competition (Chen et al., 2017).

Recently, with the rapid development of CR Express, there is a trend to explore the development strategy for this new transport mode. Some earlier studies discussed the opportunities and challenges of CR Express in Chinese. Researchers have sought to analyse the specific problems, such as the government subsidy mechanism (Du and Shi, 2017), the consolidation center capacity and location evaluation (Zhao et al., 2018), and hinterland pattern (Jiang et al., 2018). Existing studies have mainly concentrated on the macroscopic strategy from the perspective of governments or the CR Express networks in the "B&R" Initiative context. However, the sustainable development of CR Express also relies heavily on the competition strategy of operators who affect the customers' choices as well as the industrial market structure, which is not considered in the literature. This paper contributes to filling this gap.

With regard to competition between transport operators, there is a rich body of literature discussing it, especially in marine port competition. Many scholars provided empirical evidence to show their points and conclusion (Veenstra and Notteboom, 2011; Ng and Ducruet, 2014; Ng et al., 2014; Li et al., 2015; Tian et al., 2015; Knatz, 2017). Game theory approaches have been widely adopted in this field. From spatial differentiation, game theory applications in competition between transport operators can be classified by two categories. A majority of works explore competition based on non-spatial game theory. Ishii et al. (2013) constructed a non-cooperative game theoretic model to examine the effects of inter-port price competition with different timing of port capacity investment, and they applied the propositions to the case of competition between the ports of Busan and Kobe. Chen and Liu (2016) set up a two-period game theoretic model to investigate the facility investment strategy of risk-averse ports with congestion and uncertain demand. Song et al. (2016) formulated a non-cooperative game model to analyse duopoly inter-port competition from the transport chain's cost perspective, and illustrated the results using a case study of Southampton and Liverpool ports. In recent years, the spatial game theory application in transport operators competition is emerging because of the more intense hinterland competition. Spatial game theory describes the links between ports and inland market with road transportation, first introduced by Hotelling (1929). Then, the modified versions and extensions of this model have been used to investigate the port spatial competition

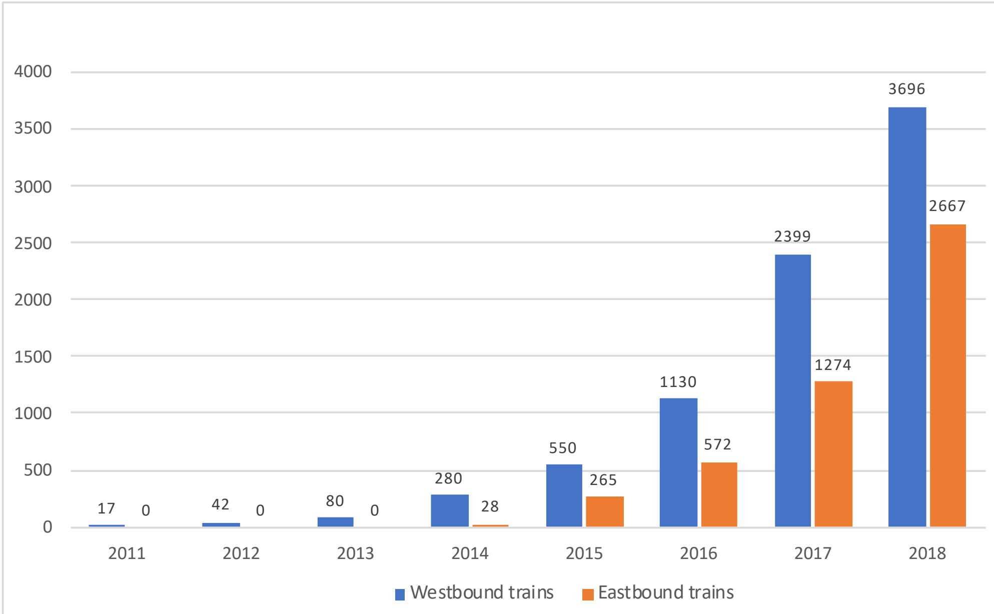

Figure 3: Total trains of CR Express transport from 2011 to 2018. *Source:* Public reports and investigations

problems. Kaselimi et al. (2011) developed a framework for Cournot competition between multi-user terminals based on the Hotelling model to explore the impact of the shift to a dedicated terminal. Álvarez-SanJaime et al. (2015) examined the economic incentives and welfare implications to the port integration with inland transport activities under inter-port competition using a Hotelling model. Lien et al. (2016) studied the Wardrop equilibrium for a transport network under social optimum scenario, price-free scenario and duopoly market scenario, respectively. Adopting the spatial game theory approach, Kuang et al. (2020) investigated and compared different structures, which are serial versus parallel, for a transport market, solved for the equilibrium, and conducted welfare analysis. Zhang et al. (2017) developed a spatial duopoly model to explore how the introduction of rail transport service affects the port competition, and found that there is a negative effect on ports' prices and profits after introducing rail transport.

As listed above, the spatial game theory model can be applied successfully to explore the hinterland competition between inter-ports/stations. Based on the observation and investigation of CR Express transport in real life, in this paper, we aim to formulate a spatial game theory model to discuss the competition strategy between two neighbouring CR Express operators from the spatial perspective, and to answer the questions mentioned in Section 1.

3. Methodology

3.1. Problem Description

In this paper, we firstly build a basic model in a regulated market (given frequency is decided by the railway authority) to consider the competition between CR Express operators with regard to cargo owners' transport choices. CR Express operators heavily depend on local government subsidy to compete on price. According to our investigation, the highest subsidy could reach up to 4000-5000 USD per FEU, 40%-50% of total cost. For this reason, government subsidy becomes an important factor in this duopoly rail transport competition. Moreover, inland accessibility, having an impact on total cost, is another aspect cargo owners consider differences of CR Express operators in this problem.

In order to make the problem more clearer, we illustrate the game in Fig. 4. The game has two players, which are neighbouring CR Express operator 1 and operator 2. They have a strong competition for attracting more customers and gaining more market share because they have an overlapping hinterland. With a given running frequency (which is decided by the railway authority) and government subsidy (which is decided by the local government), the operators will decide the CR Express transport price charged to cargo owners in order to gain maximum profits. Cargo owners are customers to CR Express operators. They will decide to choose the CR Express transport service provided by one of the two operators, considering their prices, service quality (the running frequency) and the inland transport costs.

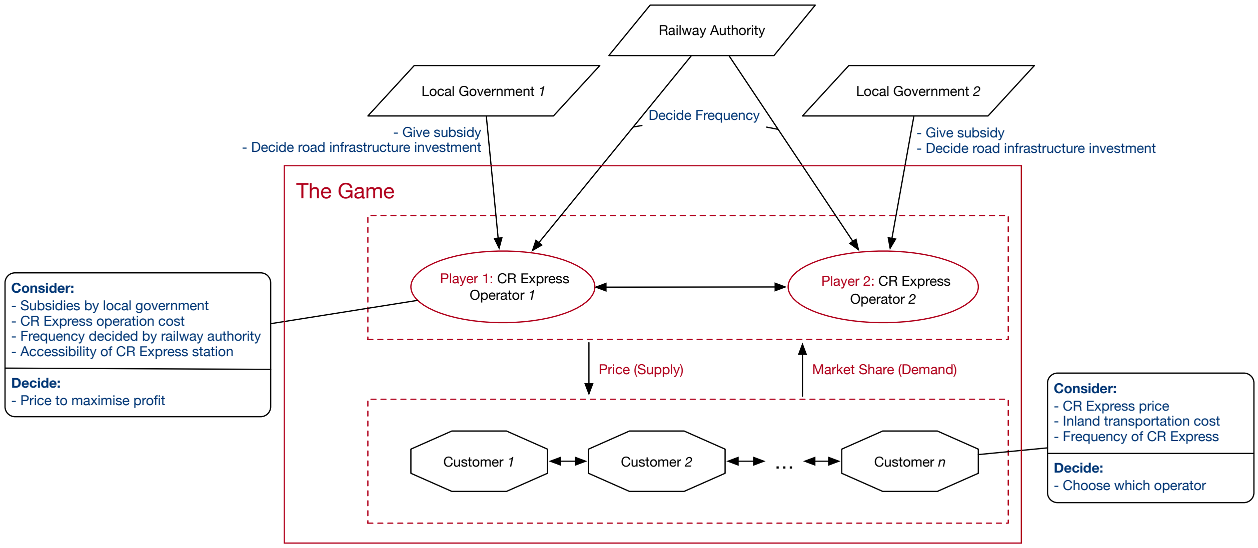

Figure 4: Explanation of the game in the basic model.

In order to solve this duopoly spatial competition problem, we construct a basic model with the following characteristics:

(1) two neighbouring CR Express operators provide homogeneous services, and their difference is their location;
(2) two neighbouring CR Express operators compete for the same hinterland market;
(3) the strategy of each operator is to determine the transport price based on different government subsidies, different running frequencies, and different inland accessibility;
(4) CR Express operators aim to maximize their profits.

Compared with marine transport, time-saving is the key benefit of CR Express, however, the capacity is the weakness. For now, adjusting running frequency is an effective way to improve capacity. We then formulate an extended model in the next section which considers the situation in which the railway authority gives operators more flexibility to decide not only their prices but also their running frequencies. In other words, frequency is endogenous and is the decision variable together with price in the extended model.

3.2. Assumption and Notation

According to the above problem description, the model assumptions are as below:

(1) there are two operators between [0,1], and their railway stations are located at zero and one, respectively;
(2) customers are uniformly distributed between [0,1], and the location is expressed as x. $D(x)$ is the distribution function of demand, and every customer has just one unit demand;
(3) customers are rational and independent;
(4) cargoes are transported to the same destination.

Table 1 shows the notation definitions for the basic model.

3.3. Function and equilibrium

We formulate customers' utility function, operators' profit function and social welfare, respectively, in the following basic model to solve the problem.

Table 1: Notation definitions.

Notation	Definition
Sets	
I	set of CR Express operators, $i, j \in I$
Parameters	
$U_i(x)$	customer's utility while choosing CR Express operator i (service provided by operator i), $i \in I$
V	maximum willingness to pay by customers to use CR Express service
t_i	unit inland transport cost from customers to rail station i, $i \in I$
x	location of customers, $x \in [0, 1]$
d	distance of two operators in reality
θ	station disutility parameter
f_i	CR Express running frequency of operator i, $i \in I$
n	total FEU carried by per CR Express train
X_i	market share of CR Express operator i, $i \in I$
D	total demand of customers
δ_i	unit government subsidy for operator i, $i \in I$
C_i	unit CR Express variable operation cost of operator i, $i \in I$
C_0	CR Express fixed operation cost per train
Decision variables	
p_i	unit price operator i charged to customers, $i \in I$

3.3.1. The basic model

CR Express operators with static location supply rail transport service to the same hinterland market in this problem. Customers in this market choose operators on the basis of the lowest "full price", and the "full price" consists of CR Express transport fee and inland transport cost. Based on the above assumptions, we express customers' utility function as Eq. (1).

$$U_i(x) = \begin{cases} V - p_i - t_i x - \theta \frac{X_i D}{f_i n} & \text{if choosing port 1, i=1} \\ V - p_i - t_i(1-x) - \theta \frac{X_i D}{f_i n} & \text{if choosing port 2, i=2} \end{cases} \quad (1)$$

where $U_i(x)$ is customers' utility while choosing CR Express service provided by operator i, x is the location of customers, and also the distance between customers and port 1 which locates at zero. V denotes the maximum willingness to pay, and is assumed to be large enough to make sure the hinterland market is fully covered. p_i is the decision variable of this basic model, and is the price of operator i. t_i denotes the unit road transport fee from customers to operator i. Time-saving is the key advantage of CR Express transport. Customers will not choose some operators when their rail terminals are too busy or too congested. In addition to monetary transport costs, therefore, we consider the rail terminal disutility with the level of rail service capacity, similar to port congestion mentioned by Álvarez-SanJaime et al. (2015). The term $\theta \frac{X_i D}{f_i n}$ measures such rail service disutility, where θ is a monetary disutility parameter; X_i denotes market share of operator i; D is the total demand of the whole market; f_i represents the given frequency of operator i and also the supply provided by operator i to the market; n is number of FEUs carried per CR Express train.

Let $h_i = \dfrac{\theta D}{f_i n}$, the formulation can be simplified to Eq. (2).

$$U_i(x) = \begin{cases} V - p_i - t_i x - h_i X_i & \text{if choosing port 1, i=1} \\ V - p_i - t_i(1-x) - h_i X_i & \text{if choosing port 2, i=2} \end{cases} \quad (2)$$

Let $D(x)$ denotes the distribution function of demand. Then, market share X_i of each operator can be derived as Eq. (3) and Eq. (4).

$$X_1 = \frac{\int_0^x D(x)\mathrm{d}x}{\int_0^1 D(x)\mathrm{d}x} = x \tag{3}$$

$$X_2 = \frac{\int_0^x D(x)\mathrm{d}x}{\int_0^{1-x} D(x)\mathrm{d}x} = 1 - x \tag{4}$$

If x^* is the indifferent location where customers have equal utility either choosing port 1 or choosing port 2; that is $U_1 = U_2$, when $x = x^*$. Therefore, market shares and the indifferent point are shown as Eq. (5) and Eq. (6).

$$X_1 = x^* = \frac{p_2 - p_1 + t_2 + h_2}{h_1 + h_2 + t_1 + t_2} \tag{5}$$

$$X_2 = 1 - x^* = \frac{p_1 - p_2 + t_1 + h_1}{h_1 + h_2 + t_1 + t_2} \tag{6}$$

From Eq. (5) and Eq. (6), we could find that when the frequency of port 1 increases through h_1, the more customers for port 1 while fewer customers for port 2.

We let π_i represent the profit of CR Express operator i. Considering revenue, costs and government subsidy, the operator's profit function is shown as Eq. (7).

$$\pi_i = (p_i + \delta_i - C_i)X_i D - C_0 f_i \tag{7}$$

3.3.2. Nash equilibrium

Operators' objective is to maximize own profits through p_i^* to give $\frac{\partial \pi_i}{\partial p_i} = 0$. Substituting Eq. (5) and Eq. (6) into Eq. (7), equilibrium price formulations are derived as Eq. (8) and Eq. (9).

$$p_1^* = \frac{t_1}{3} + \frac{2t_2}{3} + \frac{h_1}{3} + \frac{2h_2}{3} + \frac{2(C_1 - \delta_1)}{3} + \frac{C_2 - \delta_2}{3} \tag{8}$$

$$p_2^* = \frac{2t_1}{3} + \frac{t_2}{3} + \frac{2h_1}{3} + \frac{h_2}{3} + \frac{(C_1 - \delta_1)}{3} + \frac{2(C_2 - \delta_2)}{3} \tag{9}$$

The price difference is given by Eq. (10).

$$p_1^* - p_2^* = \frac{1}{3}(t_2 - t_1) + \frac{1}{3}(h_2 - h_1) + \frac{1}{3}[(C_1 - \delta_1) - (C_2 - \delta_2)] \tag{10}$$

Substituting Eq. (8) and Eq. (9) into Eq. (5) and Eq. (7), we could derive the equilibrium market share and the equilibrium profit functions as Eq. (11) and Eq. (12).

$$X_i^* = \frac{t_i + 2t_j + (\delta_i - C_i) - (\delta_j - C_j) + h_i + 2h_j}{3(h_i + h_j + t_i + t_j)} \tag{11}$$

$$\pi_i^* = \frac{D[t_i + 2t_j + (\delta_i - C_i) - (\delta_j - C_j) + h_i + 2h_j]^2}{9(h_i + h_j + t_i + t_j)} - C_0 f_i \tag{12}$$

Social welfare is equal to the sum of operator surplus, consumer surplus and government surplus, therefore, social welfare can be calculated by Eq. (13).

$$\begin{aligned} SW^* =& \pi_1^* + \pi_2^* + \int_0^{x^*} (V - p_1^* - t_1 x - h_1 X_1^*) D(x)\mathrm{d}x \\ &+ \int_{x^*}^1 (V - p_2^* - t_2(1-x) - h_2 X_2^*) D(x)\mathrm{d}x - \delta_1 X_1^* D - \delta_2 X_2^* D \end{aligned} \tag{13}$$

3.4. Sensitivity Analysis

CR Express operators need to realize how different parameters affect customers' choices and their own profits, therefore, the impacts of some parameters on the equilibria are explored using analytical method in this section. We will verify the results in the following empirical analysis as well.

3.4.1. Impacts on equlibrium price

Impact of frequency on equlibrium price.

$$\frac{\partial p_1^*}{\partial h_1} = \frac{\partial p_2^*}{\partial h_2} = \frac{1}{3} > 0 \tag{14}$$

$$\frac{\partial p_1^*}{\partial h_2} = \frac{\partial p_2^*}{\partial h_1} = \frac{2}{3} > 0 \tag{15}$$

Because $h_i = \frac{d}{f_i w}$, we can conclude that the more frequently CR Express run, the stronger the price competition. This is because total supply increases with CR Express running more frequently, therefore, operators need more efforts (lower price) to attract customers assuming total demand level does not change.

Impact of government subsidy on equlibrium price.

$$\frac{\partial p_1^*}{\partial \delta_1} = \frac{\partial p_2^*}{\partial \delta_2} = -\frac{2}{3} < 0 \tag{16}$$

$$\frac{\partial p_1^*}{\partial \delta_2} = \frac{\partial p_2^*}{\partial \delta_1} = -\frac{1}{3} < 0 \tag{17}$$

The more subsidies given by government, the stronger the price competition. This is because higher subsidy can cover more operation costs, and then operators will give more benefits to customers in order to attract more demands. This is why there is a fierce subsidized price fight in the period of early development.

Impact of inland transport cost on equlibrium price.

$$\frac{\partial p_1^*}{\partial t_1} = \frac{\partial p_2^*}{\partial t_2} = \frac{1}{3} > 0 \tag{18}$$

$$\frac{\partial p_1^*}{\partial t_2} = \frac{\partial p_2^*}{\partial t_1} = \frac{2}{3} > 0 \tag{19}$$

Equilibrium price is positively related to inland transport cost. This is because the difference between two operators become bigger when the inland transport cost increases. That is to say the high inland transport cost can decrease the price competition.

3.4.2. Impacts on equlibrium profit

Impact of frequency on equlibrium profit.

$$\frac{\partial \pi_1^*}{\partial h_1} = \frac{D(2A - A^2)}{9} + D\frac{\theta D}{n h_1} \tag{20}$$

$$\frac{\partial \pi_2^*}{\partial h_2} = \frac{D(2B - B^2)}{9} + D\frac{\theta D}{n h_2} \tag{21}$$

$$\frac{\partial \pi_1^*}{\partial h_2} = \frac{D(4A - A^2)}{9} \tag{22}$$

$$\frac{\partial \pi_2^*}{\partial h_1} = \frac{D(4B - B^2)}{9} \tag{23}$$

Where $A = \frac{t_1+2t_2+(\delta_1-C_1)-(\delta_2-C_2)+h_1+2h_2}{t_1+t_2+h_1+h_2}$, $B = \frac{2t_1+t_2+(\delta_2-C_2)-(\delta_1-C_1)+2h_1+h_2}{t_1+t_2+h_1+h_2}$. According to Eq. (20) - Eq. (23) and expressions of A and B, impacts of frequency on the equilibrium profit are very dependent on the comparative advantage of operators' government subsidy, which is the value of $(\delta_1 - C_1) - (\delta_2 - C_2)$. However, it's hard to analyze the specific impacts because there are too many cases need to consider, therefore, we analyze this part in the following empirical analysis.

Impact of government subsidy on equilibrium profit.

$$\frac{\partial \pi_1^*}{\partial \delta_1} = -\frac{\partial \pi_1^*}{\partial \delta_2} = \frac{2DA}{9} = \frac{2D(t_1 + 2t_2 + (\delta_1 - C_1) - (\delta_2 - C_2) + h_1 + 2h_2)}{9(t_1 + t_2 + h_1 + h_2)} \tag{24}$$

$$\frac{\partial \pi_2^*}{\partial \delta_2} = -\frac{\partial \pi_2^*}{\partial \delta_1} = \frac{2DB}{9} = \frac{2D(2t_1 + t_2 + (\delta_2 - C_2) - (\delta_1 - C_1) + 2h_1 + h_2)}{9(t_1 + t_2 + h_1 + h_2)} \tag{25}$$

Government subsidy plays an important role in CR Express transport competition; operators prefer to receive substantial subsidy to increase competitiveness. Therefore, we discuss in three cases. The first is operator 1 having the advantage of government subsidy, $\delta_1 - C_1 > \delta_2 - C_2$ expressed by formulation, when subsidy given to operator 1 can cover more of operation cost. Through Eq. (24) and Eq. (25), $\frac{\partial \pi_1}{\partial \delta_1} > 0$, $\frac{\partial \pi_2}{\partial \delta_1} > 0$, $\frac{\partial \pi_1}{\partial \delta_2} < 0$, and $\frac{\partial \pi_2}{\partial \delta_2} < 0$ can be derived under this case. Then, we could conclude both operators make more profits with increasing government subsidy given to operator 1, if operator 1 is in the advantageous position in terms of subsidy; similarly, both operators lose benefits with subsidy given to operator 2 going up. The second is opposite and is denoted by $\delta_1 - C_1 < \delta_2 - C_2$; consequently, $\frac{\partial \pi_1}{\partial \delta_1} < 0$, $\frac{\partial \pi_2}{\partial \delta_1} < 0$, $\frac{\partial \pi_1}{\partial \delta_2} > 0$, and $\frac{\partial \pi_2}{\partial \delta_2} > 0$ are derived, and operators' profits go in the opposite direction to the first case. The last is two operators have no difference on government subsidy level, representing $\delta_1 - C_1 = \delta_2 - C_2$. Then, we can obtain $\frac{\partial \pi_i}{\partial \delta_i} = 0$ and $\frac{\partial \pi_i}{\partial \delta_j} = 0$; as a result, profits have no relationship with any operator's subsidy.

Impact of inland transport cost on equilibrium profit.

$$\frac{\partial \pi_1^*}{\partial t_1} = \frac{D(2A - A^2)}{9} \tag{26}$$

$$\frac{\partial \pi_2^*}{\partial t_2} = \frac{D(2B - B^2)}{9} \tag{27}$$

$$\frac{\partial \pi_1^*}{\partial t_2} = \frac{D(4A - A^2)}{9} \tag{28}$$

$$\frac{\partial \pi_2^*}{\partial t_1} = \frac{D(4B - B^2)}{9} \tag{29}$$

The impacts of inland transport cost on the equilibrium profit are similar to the impacts of frequency on the equilibrium profit, that is heavily dependent on the comparative advantage of operators' government subsidy (the value of $(\delta_1 - C_1) - (\delta_2 - C_2)$). We will discuss this part in the following empirical analysis as well.

3.4.3. Impacts on equlibrium market share

Impact of frequency on equilibrium market share.

$$\frac{\partial X_1^*}{\partial h_1} = -\frac{\partial X_2^*}{\partial h_1} = -\frac{(\delta_1 - C_1) - (\delta_2 - C_2) + h_2 + t_2}{3(t_1 + t_2 + h_1 + h_2)^2} \tag{30}$$

$$\frac{\partial X_2^*}{\partial h_2} = -\frac{\partial X_1^*}{\partial h_2} = -\frac{(\delta_2 - C_2) - (\delta_1 - C_1) + h_1 + t_1}{3(t_1 + t_2 + h_1 + h_2)^2} \tag{31}$$

According to Eq. (30) and Eq. (31), we discuss the impacts of frequency on the equilibrium market share in two cases. The first case is operator 1 having the advantage of government subsidy, $\delta_1 - C_1 \leq \delta_2 - C_2$ expressed by formulation, when subsidy given to operator 1 can cover more of operation cost. Because of $h_i = \frac{d}{f_i w}$, we can derive that $\frac{\partial X_1}{\partial f_1} > 0$, $\frac{\partial X_2}{\partial f_2} > 0$, $\frac{\partial X_2}{\partial f_1} < 0$, and $\frac{\partial X_1}{\partial f_2} < 0$. Then, we can conclude that operators gain more market share with increasing running frequency and lose market share with increasing competitor's running frequency. The second is opposite and is denoted by $\delta_1 - C_1 < \delta_2 - C_2$; however, we couldn't discuss the impacts directly, and we will analyze this part in the following empirical analysis.

Impact of government subsidy on equilibrium market share.

$$\frac{\partial X_1^*}{\partial \delta_1} = \frac{\partial X_2^*}{\partial \delta_2} = 1 \tag{32}$$

$$\frac{\partial X_1^*}{\partial \delta_2} = \frac{\partial X_2^*}{\partial \delta_1} = -1 \tag{33}$$

Operators can gain more market share with increasing government subsidy, and lose market share when competitor receive more government subsidy, which could be concluded through Eq. (32) and Eq. (33). This is because operators have more competitiveness to decrease their prices with more government subsidy so that operators can attract more customers and expand the market share.

Impact of inland transport cost on equilibrium market share.

$$\frac{\partial X_1^*}{\partial t_1} = -\frac{\partial X_2^*}{\partial t_1} = -\frac{(\delta_1 - C_1) - (\delta_2 - C_2) + h_2 + t_2}{3(t_1 + t_2 + h_1 + h_2)^2} \tag{34}$$

$$\frac{\partial X_2^*}{\partial t_2} = -\frac{\partial X_1^*}{\partial t_2} = -\frac{(\delta_2 - C_2) - (\delta_1 - C_1) + h_1 + t_1}{3(t_1 + t_2 + h_1 + h_2)^2} \tag{35}$$

Through Eq. (34) and Eq. (35) we can conclude that the impacts on inland transport cost on equilibrium market share have the same pattern of the impacts on frequency on equilibrium market share.

4. Extended model

In the basic model, the frequency is exogenous; operators cannot decide their running frequencies but the railway authority decides them. In other words, the basic model describes problems of a regulated market. In order to improve competitiveness of CR Express through adjusting frequency, in this section, we consider the situation in a partially regulated market, where operators could decide their prices and frequencies together.

In this extended model, operators maximize their profits Eq. (36) through determining their prices and frequency. In this partially regulated market, running frequency is a longer-term decision compared to price while considering the logistics planning. Operators cannot change the running frequency at any time even if the railway authority could let operators decide their frequencies. In general, operators make their frequency decisions for a quarter and publish their schedules to customers first, and then make their pricing decisions more flexible considering different market conditions and customers' choices. Therefore, we adopt a sequential decision approach to analyze this extended model based on the observation of facts. In other words, this problem can be solved as a two-stage game in duopoly market. In the first stage, operators decide their frequencies and in the second stage, each operator decide their price given a frequency. As usual in such a model, the solution is derived backwards, i.e. calculating price solution first and then deriving the frequency equilibrium using this solution.

$$\pi_i = (p_i + \delta_i - C_i)X_i D - C_0 f_i \tag{36}$$

Using the profit function Eq. (36), the second stage price solution for operator i is calculated from the first order condition, which is seen as Eq. (37).

$$\frac{\partial \pi_i}{\partial p_i} = (p_i + \delta_i - C_i)\frac{\partial X_i}{\partial p_i} + X_i = 0 \tag{37}$$

Denoting the price solution as p_i^*, the first stage problem is

$$\max_{f_i} \pi_i = (p_i^* + \delta_i - C_i)X_i(p_i^*, p_j^*, f_i, f_j)D - C_0 f_i, \qquad i = 1, 2,\ j = 1, 2 \tag{38}$$

Under the Nash assumption that the competitor's price is fixed, the first order condition for this problem is

$$\frac{\partial \pi_i}{\partial f_i} = \frac{\mathrm{d}p_i^*}{\mathrm{d}f_i} X_i D + (p_i^* + \delta_i - C_i) \frac{\mathrm{d}X_i}{\mathrm{d}f_i} D - C_0 = 0, \qquad i = 1, 2 \tag{39}$$

To simplify the function, firstly, we have

$$\frac{\mathrm{d}X_i}{\mathrm{d}f_i} = \frac{\partial X_i}{\partial f_i} + \frac{\partial X_i}{\partial p_i} \frac{\mathrm{d}p_i^*}{\mathrm{d}f_i} + \frac{\partial X_i}{\partial p_j} \frac{\mathrm{d}p_j^*}{\mathrm{d}f_i}, \qquad i = 1, 2, \ j = 1, 2 \tag{40}$$

Eq. (40) represents the direct effect on the market demand of a frequency change and also the indirect effects through the effect on their own and competitor's prices.

In order to get a simplified function, we derive Eq. (41) from Eq. (37) as the following.

$$X_i = -(p_i + \delta_i - C_i) \frac{\partial X_i}{\partial p_i} \tag{41}$$

Substituting Eq. (40) and Eq. (41) into Eq. (39), we could obtain

$$\begin{aligned} \frac{\partial \pi_i}{\partial f_i} &= \frac{\mathrm{d}p_i^*}{\mathrm{d}f_i} X_i D + (p_i^* + \delta_i - C_i) \frac{\mathrm{d}X_i}{\mathrm{d}f_i} D - C_0 \\ &= -(p_i + \delta_i - C_i) \frac{\partial X_i}{\partial p_i} \frac{\mathrm{d}p_i^*}{\mathrm{d}f_i} D + (p_i^* + \delta_i - C_i) [\frac{\partial X_i}{\partial f_i} + \frac{\partial X_i}{\partial p_i} \frac{\mathrm{d}p_i^*}{\mathrm{d}f_i} + \frac{\partial X_i}{\partial p_j} \frac{\mathrm{d}p_j^*}{\mathrm{d}f_i}] D - C_0 \\ &= (p_i^* + \delta_i - C_i)(\frac{\partial X_i}{\partial f_i} + \frac{\partial X_j}{\partial p_j} \frac{\mathrm{d}p_j^*}{\mathrm{d}f_i}) D - C_0 = 0, \qquad i = 1, 2, \ j = 1, 2 \end{aligned} \tag{42}$$

Therefore, the frequency solution in the first stage is the solution $[f_1^*, f_2^*]$ to Eq. (42), which is the frequency equilibrium.

From the above section, we have obtained the analytical expression of X_1, X_2, p_1^* and p_2^*, therefore, we can calculate the equilibrium prices, equilibrium profits and equilibrium social welfare, respectively, using the real data in the following section.

5. Empirical analysis

We look at CR Express from Chengdu and Chongqing as our case study because they both operate well, and the sum of their market share is almost 50% of the whole CR Express industrial market in 2018. Chengdu and Chongqing are very close to each other as well, both located in the midwestern region of China (as shown in Fig. 5), so that the two CR Express lines have an overlapping hinterland. Besides, most of their routes have the same or nearby destinations. Accordingly, most researchers and operators think that CR Express from Chengdu and Chongqing have a strong competition. For this reason, this is a good example to verify the model and conduct some managerial insights for the research questions in this paper.

In order to analyse more accurately, we use CR Express lines that origin from Chengdu and Chongqing respectively, and have the same destination Hamburg (Chongqing/Chengdu-Alashankou-Hamburg) as our case study. Parameters of these lines that we collected from public reports and our investigations are shown as Table 2, where unit inland transport fee is equal to USD 0.55/(FEU*km) according to container road transport rules (CNY 4.2/(FEU*km)) made by the Ministry of Transport of China and considering market fluctuation as well. Moreover, we consider the real distance between two neighbouring CR Express operators not normalized 1 mentioned in the above models. Therefore, we calculate hinterland connectivity costs based on real distance between Chengdu rail terminal and Chongqing rail terminal, which is 333 kilometers as shown in the map. Based on the whole rail transport distance, we estimate CR Express transport costs from Chengdu and Chongqing to be USD 6369 and USD 6562 per FEU according to pricing rules from the railway authority. There is no setup cost for CR Express transport, therefore, we only consider fixed organization cost per train as USD 100. With regard to local government subsidy, policy is diverse in different regions and at different times, therefore, we assume unit subsidy for Chengdu and Chongqing are USD 3000 and USD 3500 according to our interviews with eight managers from three CR Express operation firms, and six official staff from three local governments. Similarly, the total demand is hard to estimate, therefore, we assume the total demand level is equal to 400 FEU to conduct analysis, and then set different demand levels to see whether we could get the same pattern. Generally, the number of FEU every CR Express train is 41 while fully loaded.

Figure 5: Location of Chengdu and Chongqing in China.

Table 2: Parameters in empirical analysis.

Parameter	**Value**
Inland transport cost t_i (\$/FEU*km)	0.55
Subsidy given by Chengdu government θ_1 (\$/FEU)	3000
Subsidy given by Chongqing government θ_2 (\$/FEU)	3500
Variable operation cost of Chengdu C_1 (\$/FEU)	6369
Variable operation cost of Chongqing C_2 (\$/FEU)	6562
Fixed operation cost C_0 (\$/train)	100
Frequency of Chengdu f_1 (trains/week)	3
Frequency of Chongqing f_2 (trains/week)	5
Total demand D (FEU/week)	400
Port disutility parameter θ	10
Total FEU carried by per CR Express n (FEU/train)	41

5.1. Equilibrium price and profit in the basic model

Using parameters in Table 2, we explore the relationship between price and profits of CR Express operators first in the basic model, where only prices are decision variables.

From Fig. 6, the red and blue dotted lines are isoprofit curves of operator 1 and operator 2, respectively. In addition, the blue and cyan lines show the reaction functions of operator 1 and operator 2, respectively, i.e. the best response of each operator given the price decision of another. The red star point, therefore, is the Nash equilibrium in the basic model, where operators could obtain their respective maximum profits. We found the equilibrium prices for two operators are \$3489.7 and \$3383.7, respectively, and the equilibrium profits are $\$8.63 * 10^3$ and $\$98.46 * 10^3$.

Fig. 7 illustrates how operator 2's profit changes with own price while considering different competitor's price decisions. From this figure, we could conclude that profit of an operator will increase first and then decrease with his own price increasing. This is because operators will get more profits when they

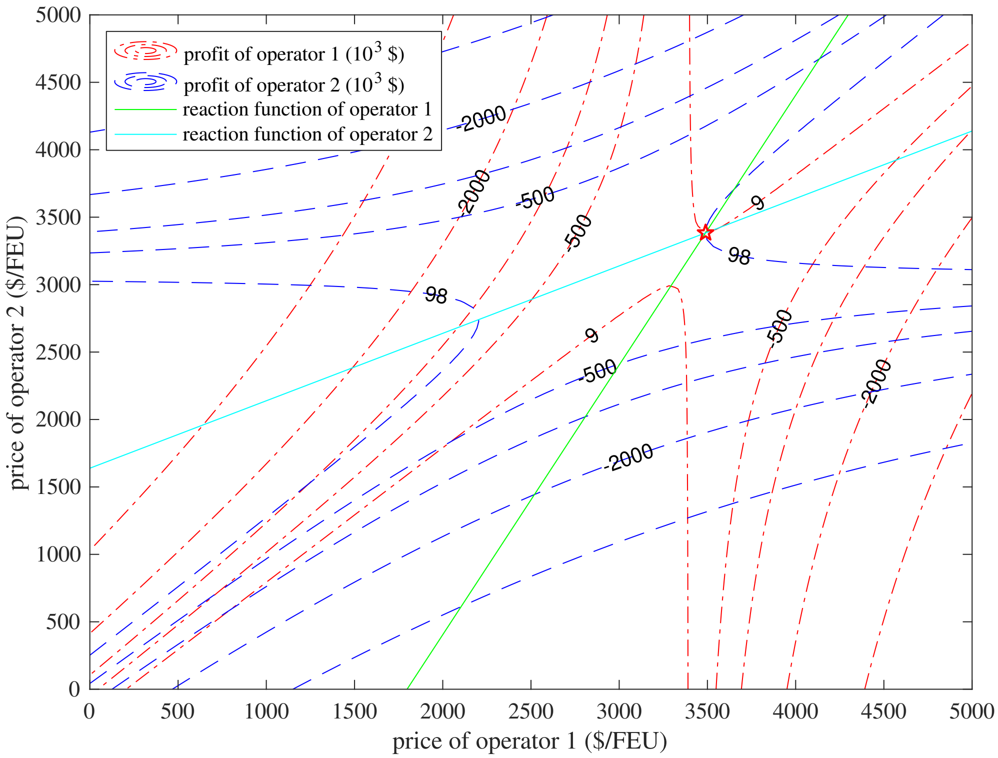

Figure 6: Isoprofit curves and reaction functions of the game.

charge customers more but only within a “reasonable” range. However, they will lose revenue because of the lower market share when the price is too high. At this time, the competitor will get more profits. Also, this reasonable range of price depends on competitor’s price. Another interesting finding is every line cross at one point where the unit price is equal to the difference between the unit government subsidy and the unit FEU operation cost, which is the breakeven price. (that is to say, $unit\ \ FEU\ \ price = unit\ \ FEU\ \ operation\ \ cost - unit\ \ FEU\ \ government\ \ subsidy$).

Besides, the relationship between profits of operators and the prices of their competitor varies. When the operators decide a lower price than the breakeven price, their profits will decrease with an increase in their competitor’s price. When they charge higher than the breakeven price to customers, their profits will increase with an increase in their competitor’s price. This is because the difference between two operators gets smaller with the competitor increase their price.

5.2. Influence of parameters on equilibrium profits

In Section 3.4, we analyse the influence of parameters on equilibrium price using numerical equation. In this section, we use empirical method to see the influence of parameters on equilibrium price and profit.

Impact of frequency. From Fig. 8, we see the equilibrium price will decrease with increasing frequency. This is because there is stronger competition when the frequency increasing as there is more supply for the whole market. In order to keep the market share and gain profits, operators will decrease their prices and pass some benefits to customers. Also, an operator will decrease their price to attract customers when competitor increase running frequency. But, we could see that frequency seems not the key factor that influences the price strategy. Operator’s profits increase first and decrease slightly with running CR Express more frequently, as shown in Fig. 9. The reason for this is that operators could gain more profits when supply in the whole market is insufficient, but they have to transfer some benefits to retain customers when the supply is excess.

Impact of government subsidy. It’s clear that government subsidy has a strong influence on the equilibrium price from Fig. 10. The price will decrease linearly with either his own or competitor’s subsidy increasing.

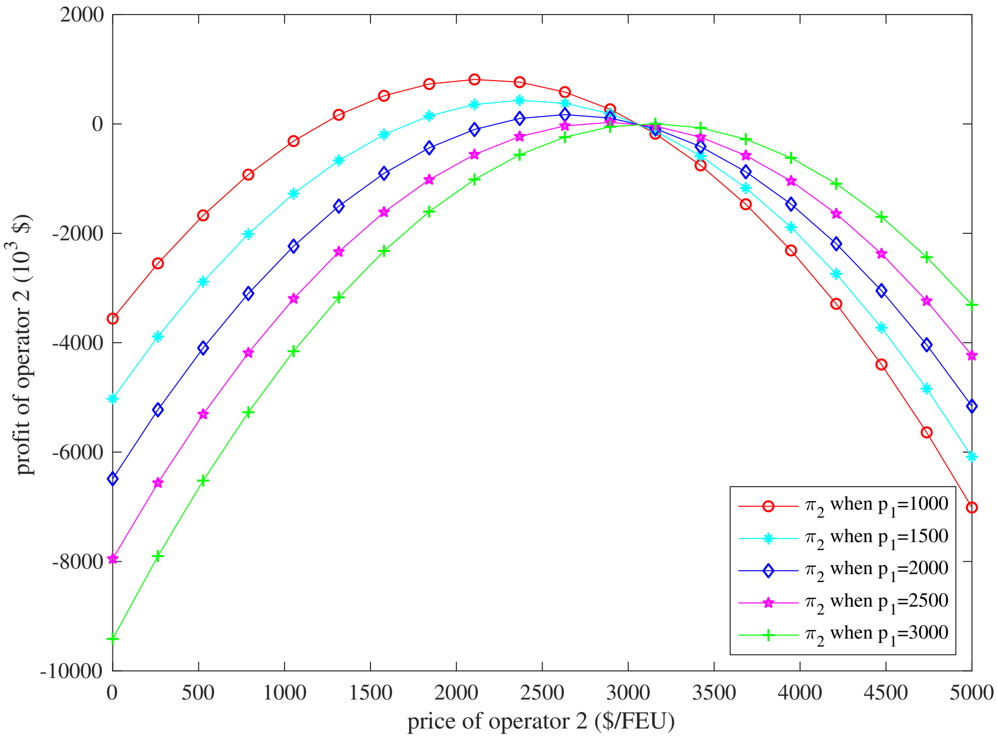

Figure 7: CR Express operators' profit distribution.

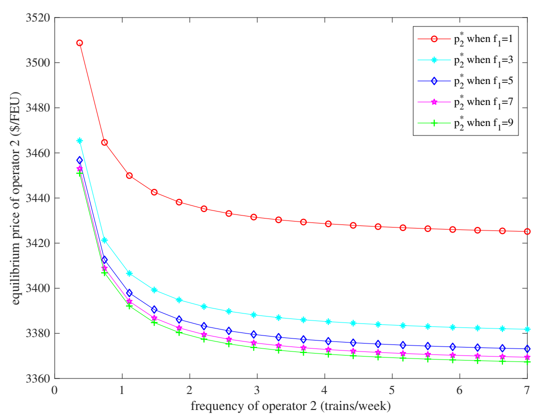

Figure 8: Influence of frequency on equilibrium prices.

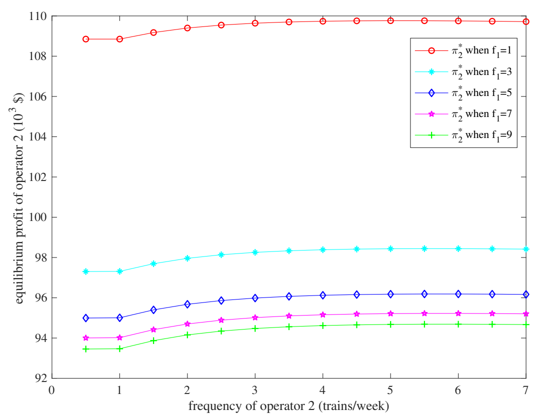

Figure 9: influence of frequency on equilibrium profits.

This is because, for operator himself, higher government subsidy could cover more cost so that operator could gain considerable profit as well when they charge customers lower prices. Operators also have to reduce prices to retain market share if the competitor gives a lower price because of high government subsidy. From this aspect, the competition between two CR Express operators is the competition between two local governments to some degree. Fig. 11 shows that the equilibrium profits decrease first and then increase with its own subsidy increasing. Profit will decrease first because of the lower price, but it will rebound while the price is lower than a point because of the high subsidy. The extreme point depends on the difference between subsidy and cost.

Impact of local road infrastructure investment. Local road infrastructure investment could largely decide the transport fee, so we use inland transport cost to represent the influence of local road infrastructure investment. From Fig. 12, we can conclude that local road infrastructure investment, that is also accessibility of CR Express, determines the equilibrium price. The better accessibility, the lower inland transport cost,

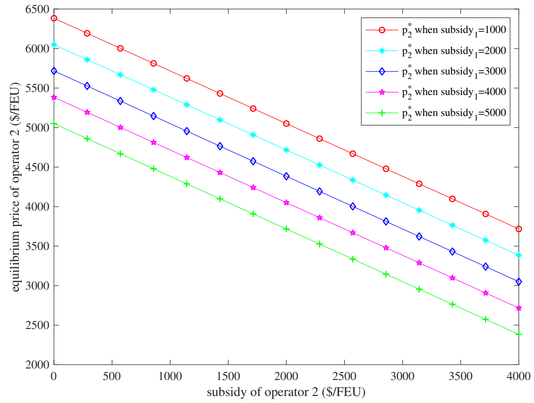

Figure 10: Influence of government subsidy on equilibrium prices.

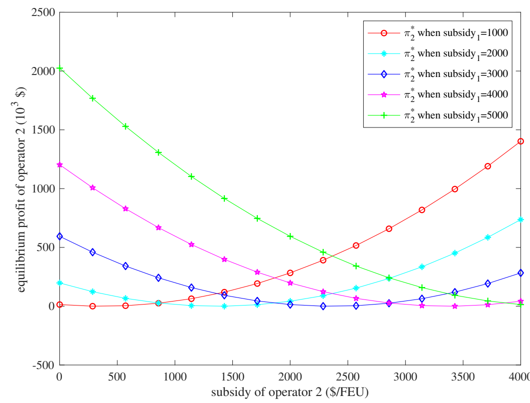

Figure 11: Influence of government subsidy on equilibrium profits.

and the lower price operators could charge. Improved accessibility means that the difference between two neighbouring CR Express becomes effectively smaller if it is easy to reach; therefore, operators tend to reduce prices to enhance competitiveness. However, the equilibrium profits of operators will decrease when inland transport cost increases, which is seen as Fig. 13.

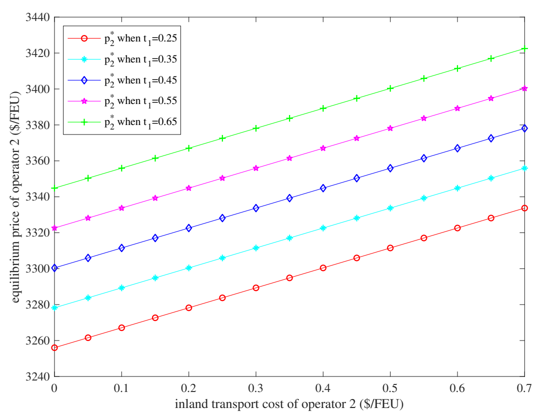

Figure 12: Influence of local road infrastructure investment on equilibrium prices.

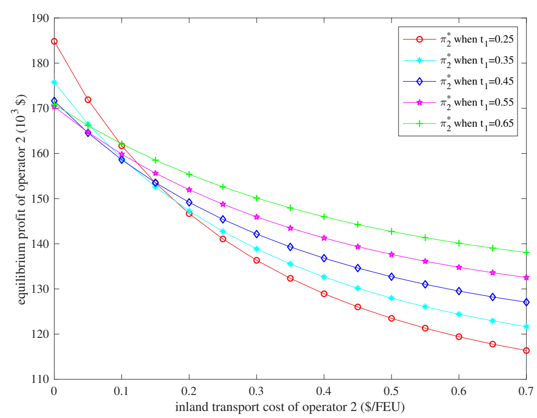

Figure 13: Influence of local road infrastructure investment on equilibrium profits.

5.3. Comparison between regulated market and partially regulated market

Considering the partially regulated market, i.e. when frequency is endogenous, using the parameters in Table 2 and function in Eq. (42), we solve the problem to find that the equilibrium frequency levels are $f_1 = 1.9$ and $f_2 = 7.8$, and the equilibrium prices are $p_1 = 3491.3$ and $p_2 = 3393.9$. Then, we calculate the equilibrium profits as $\pi_1 = 8.79 * 10^3$, $\pi_2 = 101.65 * 10^3$ and the social welfare as $SW = V - 124.8 * 10^4$. Contrasting with results in the basic model which is given frequencies $f_1 = 3$ and $f_2 = 5$, the equilibrium prices are $p_1 = 3489.7$, $p_2 = 3383.7$, the equilibrium profits are $p_1 = 8.63 * 10^3$, $p_2 = 98.46 * 10^3$, and the social welfare is $SW = V - 125.1 * 10^4$. It is obvious that not only both operators can make more profits but also social welfare increases.

In order to explore whether operators could make more benefits and social welfare is higher in different scenarios, we solve the equilibria for different demand levels, as shown in Table 3.

Through comparing results of regulated market and partially regulated market, we see operators could get more profits and social welfare becomes higher under different demand scenarios. Another finding is that operators will let their own frequency just meet demand if they could decide frequencies by themselves. Therefore, it seems beneficial for both government and operators that governments relax the given frequency

Table 3: Comparison between results of the basic model and the extended model

Regulated market	Demand	$p_1^*(\$)$	$p_2^*(\$)$	$\pi_1^*(10^3\$)$	$\pi_2^*(10^3\$)$	$SW(10^6\$)$
	400	3489.7	3383.7	8.63	98.46	V-1.251
$f_1 = 3,\ f_2 = 5$	328	3485.4	3378.6	6.54	78.89	V-1.028
	280	3482.5	3375.2	5.27	67.71	V-0.879
Partial regulated market						
$f_1 = 1.9,\ f_2 = 7.8$	400	3491.3	3393.9	8.79	101.65	V-1.248
$f_1 = 1.6,\ f_2 = 6.4$	328	3490.8	3393.0	7.16	83.16	V-1.024
$f_1 = 1.4,\ f_2 = 5.5$	280	3490.4	3392.1	6.07	70.84	V-0.871

constraint to make the market more flexible, which means allowing operators to make frequency decisions according to market demand.

6. Conclusion

CR Express has been a crucial component in the context of the "B&R" Initiative to increase connectivity and to develop more cooperation with involved Eurasian countries. CR Express has shown a dramatic development, however, different CR Express operators have strong competition in this initial stage because of the fierce hinterland competition and substitutability between neighbouring lines. In order to explore CR Express competition and their pricing strategy, this study developed a non-cooperative game model in a spatial setting with regard to a regulated market and also an extended model for partially regulated market. Our basic model accounts for strategic decisions about pricing for operators while considering given frequencies, local government subsidies, local road infrastructure investments, and operation costs. Then, we extend the model to explore strategic decisions about running frequency for operators if the government relax the regulated frequency constraint. Further, we investigate whether social welfare would be higher if the government let the market become a partially regulated market. We then verify our models and conclude some results using the real data of two CR Express lines from Chengdu and Chongqing.

With regard to pricing strategy, it's best for operators to be flexible in pricing based on their own and competitor's running frequencies, government subsidies, local road infrastructure investments, and operation costs. Government subsidy is the most important factor that influences operators' pricing strategy and profits. Operators would like to set a lower price and give some benefits to customers if government subsidies could cover much of their operation costs. Frequency and local road infrastructure investment both have an effect on pricing decisions.

It will have benefits for social welfare and operators if the government give operators freedom to decide their own frequency. Also we found that the best frequency decision for operators is to just meet the market demand based on different scenarios.

Acknowledgements

This paper is supported by the Fundamental Research Funds for the Central Universities (2018YJS050).

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Silk Road
Maritime Silk Road
Moscow
Rotterdam
Duisburg
Venice
Istanbul
Athens
Tehran
Samarkand
Dushanbe
Bishkek
Almaty
Huoerguosi
Urumqi
Lanzhou
Xi'an
Beijing
Fuzhou
Quanzhou
Guangzhou
Zhanjiang
Beihai
Haikou
Hanoi
Kolkata
Colombo
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Portugal
Italy
Greece
Turkey
Iraq
Iran
Afghanistan
Pakistan
Saudi Arabia
Yemen
Oman
Algeria
Libya
Egypt
Sudan
Chad
Mali
Niger
Nigeria
Mauritania
South Sudan
Ethiopia
Somalia
Kenya
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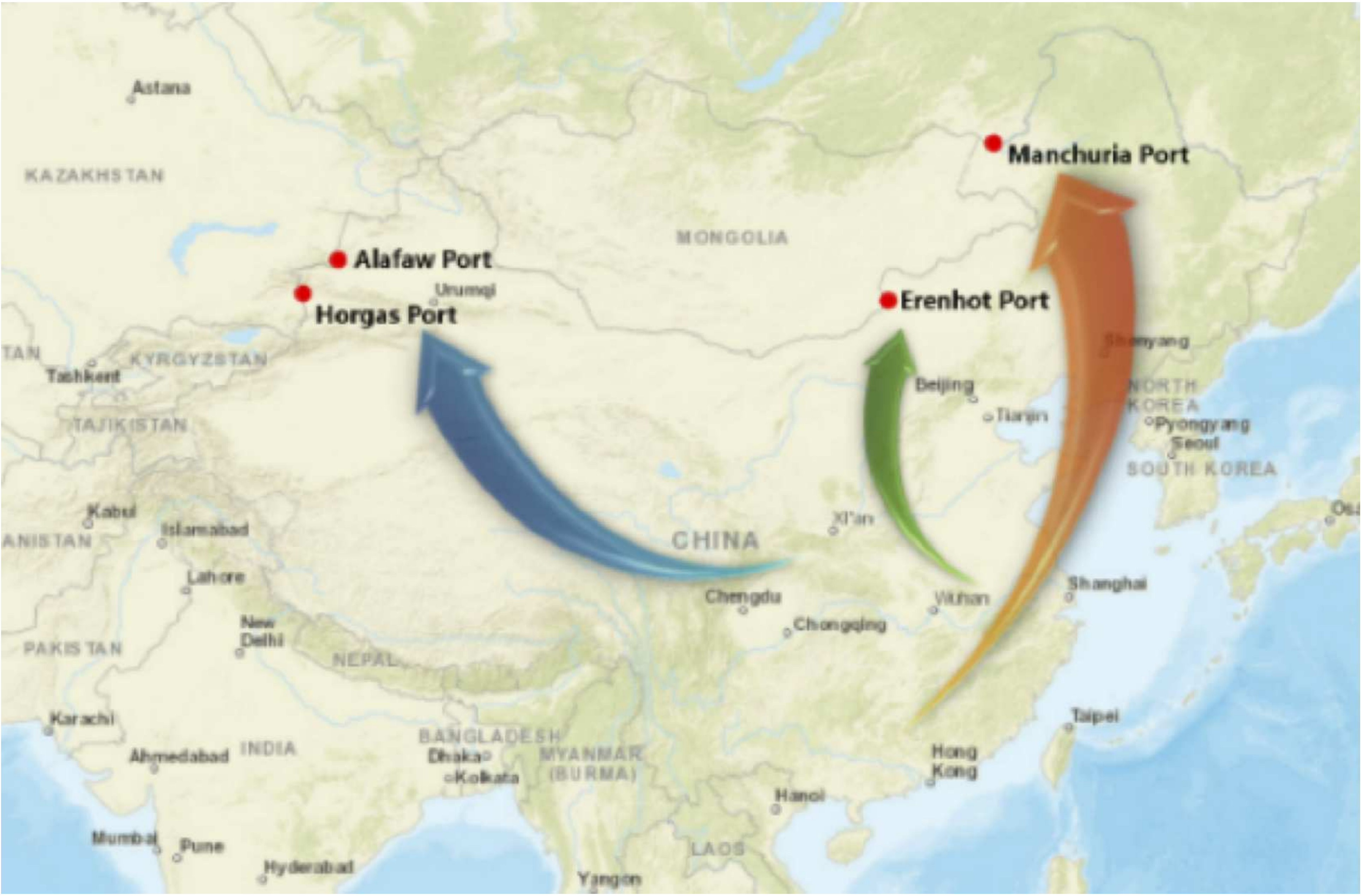
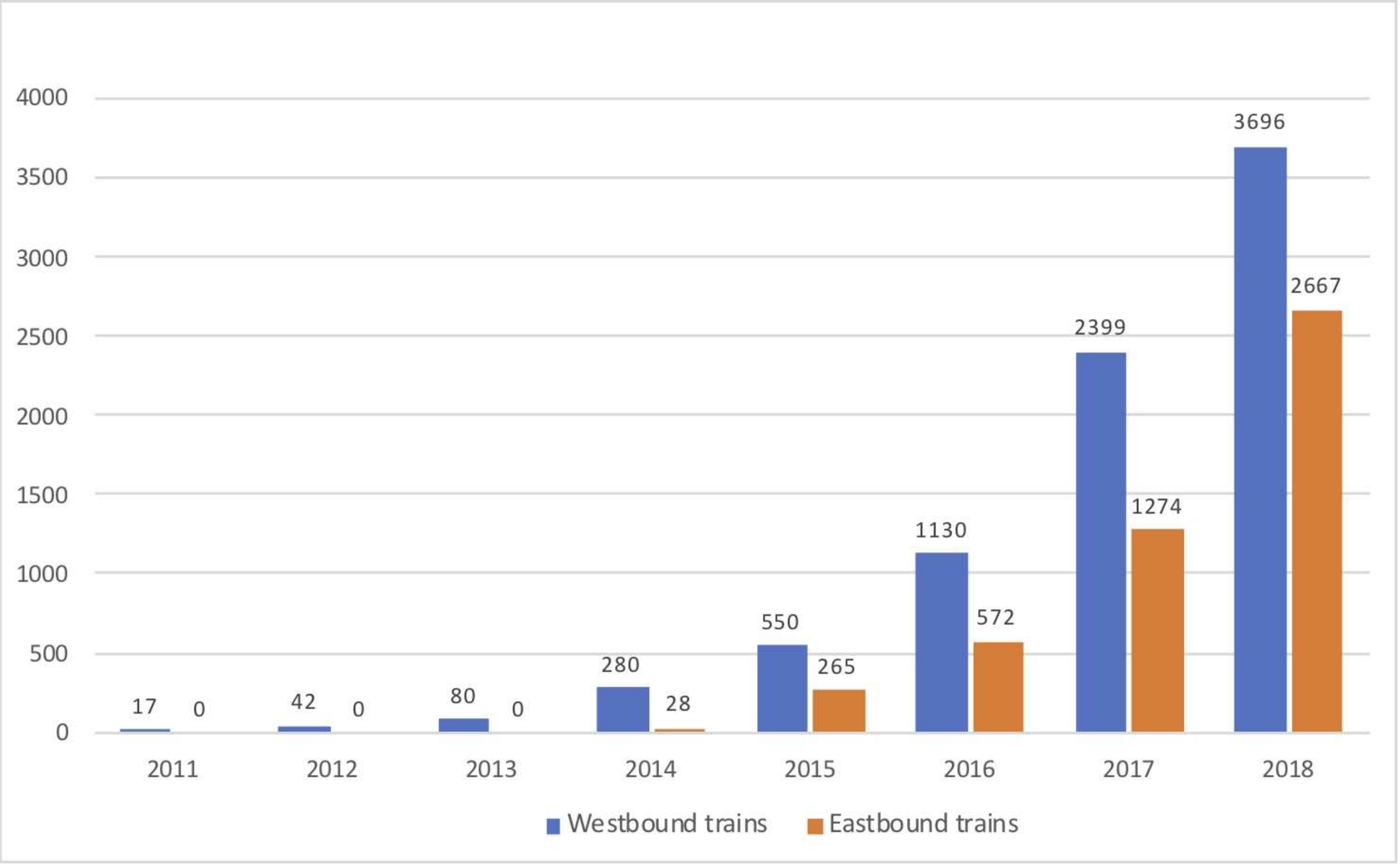
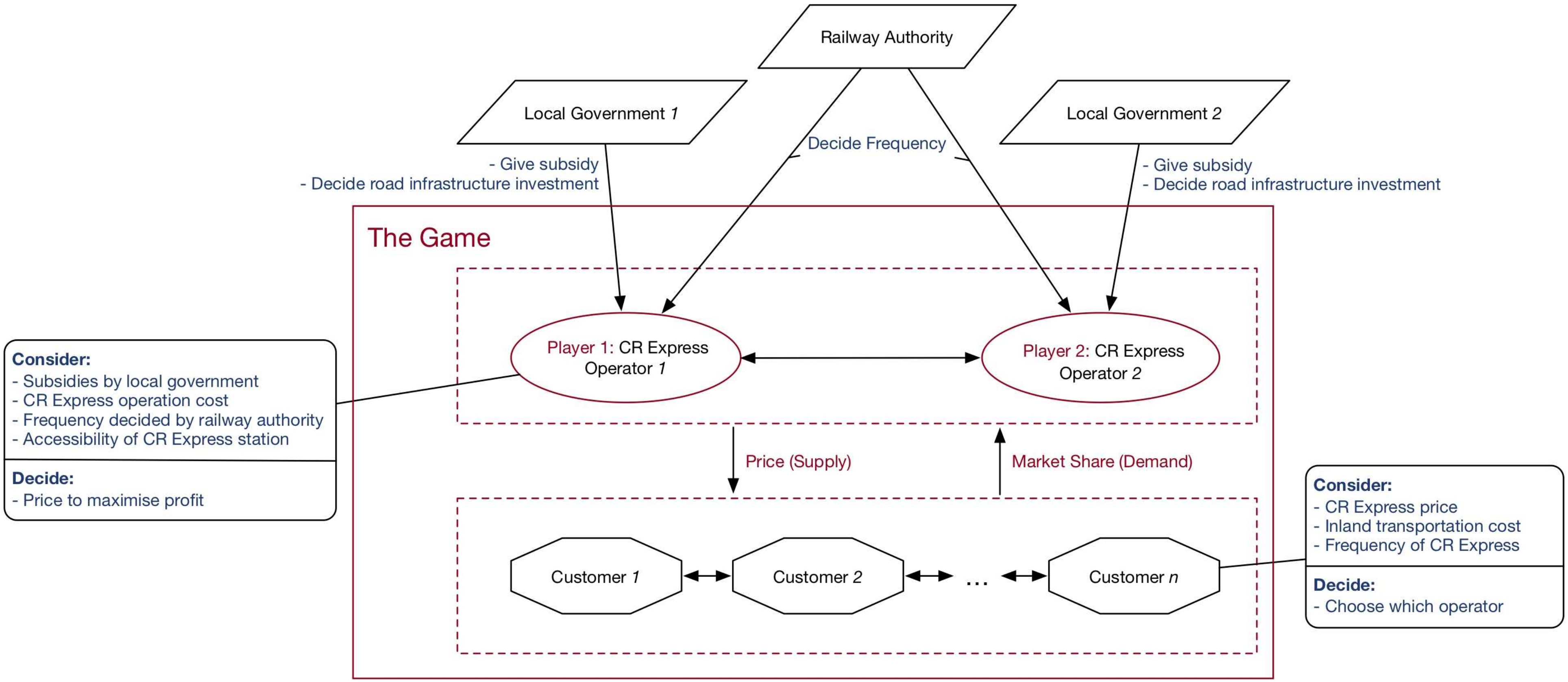
Australia
Papua New Guinea


Manchuria Port
Alafaw Port
Horgas Port
Erenhot Port
Urumqi
KAZAKHSTAN
MONGOLIA
CHINA
KYRGYZSTAN
TAJIKISTAN
PAKISTAN
INDIA
NEPAL
BANGLADESH
MYANMAR (BURMA)
LAOS
NORTH KOREA
SOUTH KOREA
Astana
Tashkent
Kabul
Islamabad
Lahore
New Delhi
Karachi
Ahmedabad
Mumbai
Pune
Hyderabad
Dhaka
Kolkata
Yangon
Hanoi
Hong Kong
Taipei
Shanghai
Wuhan
Chongqing
Chengdu
Xi'an
Beijing
Tianjin
Pyongyang
Seoul

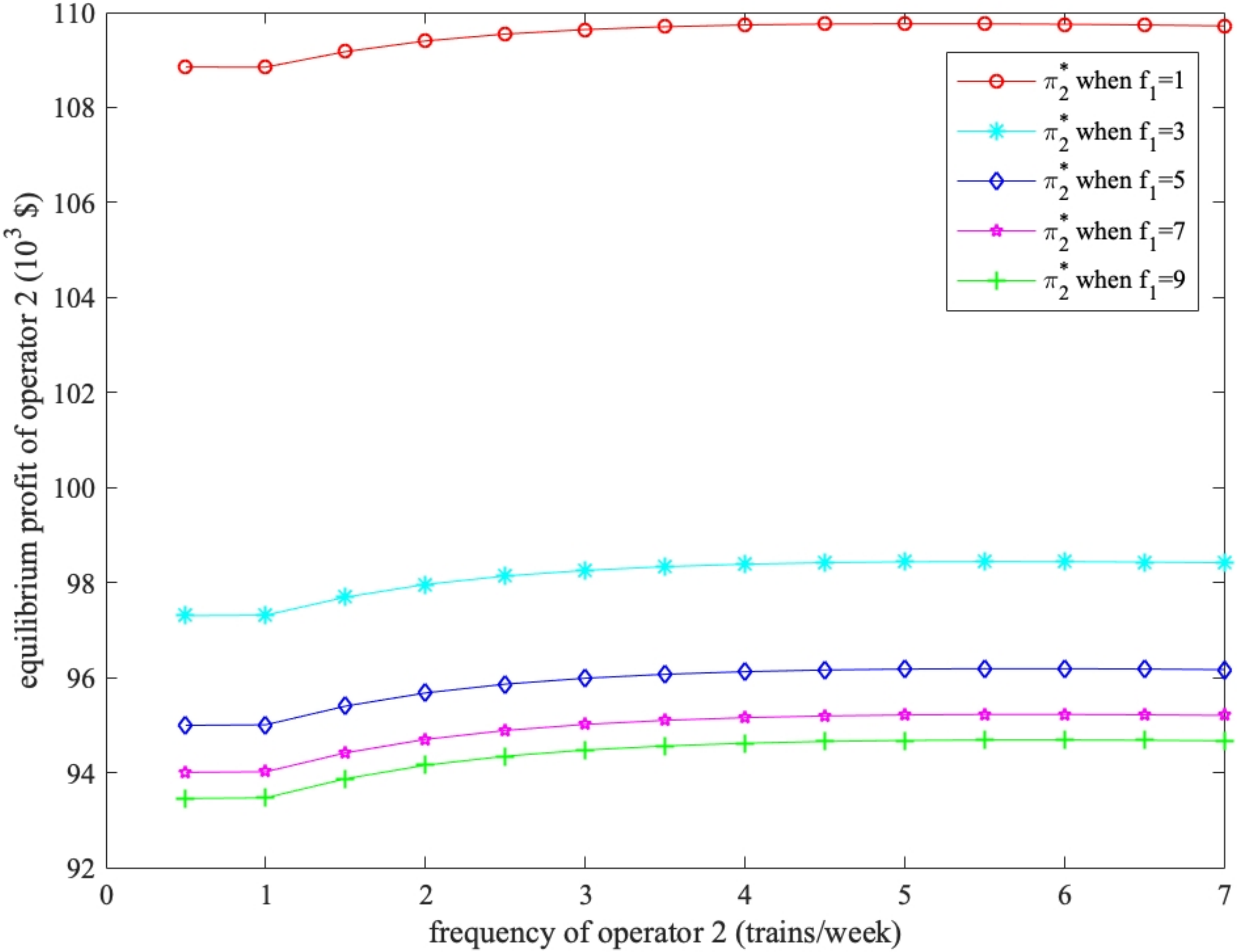


4000
3500
3000
2500
2000
1500
1000
500
0
17
0
42
0
80
0
280
28
550
265
1130
572
2399
1274
3696
2667
2011
2012
2013
2014
2015
2016
2017
2018
Westbound trains
Eastbound trains

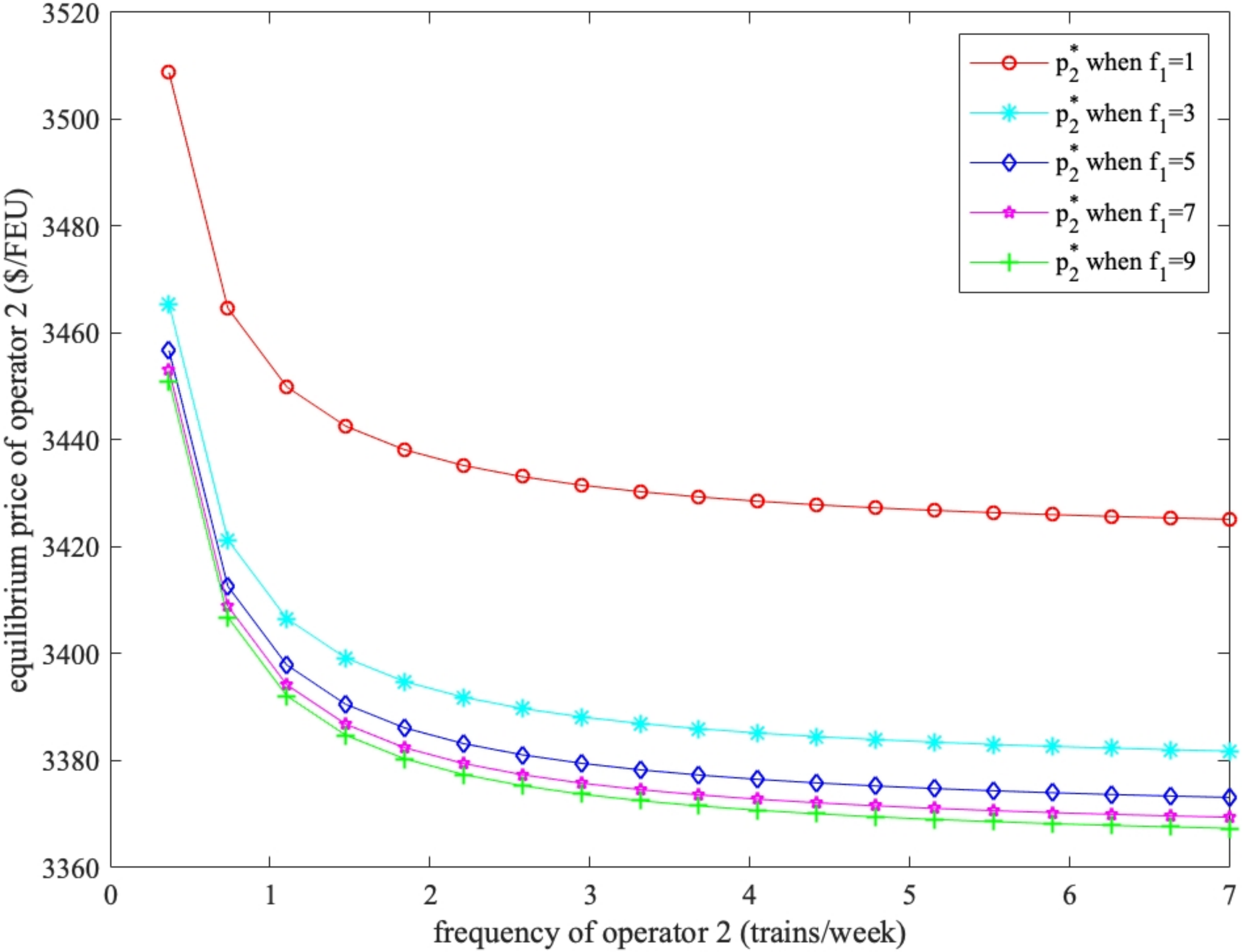

Railway Authority
Local Government 1
Local Government 2
Decide Frequency
- Give subsidy
- Decide road infrastructure investment
- Give subsidy
- Decide road infrastructure investment
The Game
Player 1: CR Express Operator 1
Player 2: CR Express Operator 2
Consider:
- Subsidies by local government
- CR Express operation cost
- Frequency decided by railway authority
- Accessibility of CR Express station
Decide:
- Price to maximise profit
Price (Supply)
Market Share (Demand)
Customer 1
Customer 2
...
Customer n
Consider:
- CR Express price
- Inland transportation cost
- Frequency of CR Express
Decide:
- Choose which operator

1

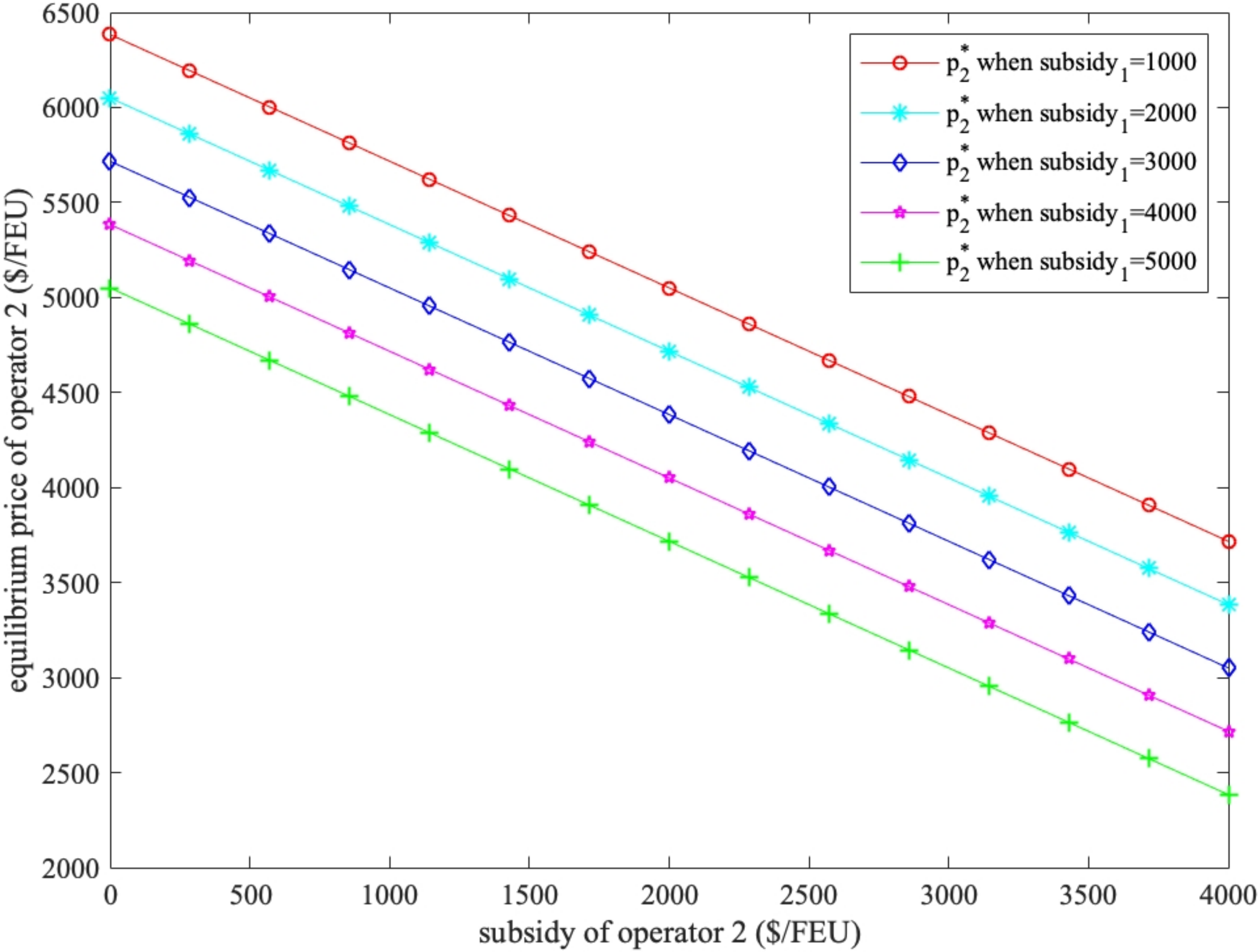

RUSSIA
Astana
Pavlodar
Semipalatinsk
Qaraghandy
KAZAKHSTAN
Balqash
L. Balqash
Bishkek
Alma Ata
KYRGYZSTAN
TAJIKISTAN
PAKISTAN
Islamabad
Rawalpindi
Srinagar
Gujranwala
Lahore
Faisalabad
Multan
Bahawalpur
Irkutsk
L. Baykal
Ulan Ude
Chita
Komsomolsk
Khabarovsk
Ulaangom
Hovd
Altay
Bayanhongor
Ulaanbaatar
Choybalsan
MONGOLIA
Dalandzadagad
Hailar
Qiqihar
Harbin
Jixi
Changchun
Jilin
Vladivostok
Liaoyuan
Fuxin
Fushun
Benxi
Jinzhou
Yingkou
Feng Cheng
Dandong
NORTH KOREA
Pyongyang
Karamay
Yining
Shihezi
Urumqi
Hami
Korla
Kashi
Qiemo
Hotan
Yumen
CHINA
Golmud
Xining
Lanzhou
Yinchuan
Baotou
Hohhot
Datong
Zhangjiakou
Beijing
Tianjin
Tangshan
Dalian
Taiyuan
Shijiazhuang
Handan
Jinan
Taian
Qingdao
Seoul
Incheon
SOUTH KOREA
Taejeon
Taegu
Pusan
Yellow Sea
Sea of Japan (East Sea)
Niigata
JAPAN
Tokyo
Nagoya
Kyoto
Osaka
Hiroshima
Sakai-minato
Kita-kyushu
Fukuoka
Shikoku
Kyushu
Honshu
Luoyang
Zaozhuang
Kaifeng
Xian
Xuzhou
Huaibei
Shiquan
Huainan
Nanjing
Hefei
Wuhu
Wuxi
Shanghai
Huzhou
Jiaxing
Hangzhou
Ningbo
Mianyang
Chengdu
Chongqing
Zigong
Wuhan
Huangshi
Yueyang
Nanchang
Jingdezhen
Shang Rao
Changsha
Pingxiang
Wenzhou
Fuzhou
Taipei
Taiwan
Xiamen
Shantou
Kaohsiung
Guangzhou
Hong Kong
Shaoguan
Nanning
Zhanjiang
Guiyang
Kunming
Dukou
Lhasa
East China Sea
Ryukyu Islands
Pacific Ocean
NEPAL
Kathmandu
BHUTAN
Thimphu
New Delhi
Bikaner
Jaipur
Agra
Lucknow
Kanpur
Allahabad
Varanasi
Patna
INDIA
Dhaka
BANGLADESH
Khulna
Chittagong
Imphal
Dhanbad
Jamshedpur
(Calcutta) Kolkata
Bhopal
Jabalpur
Ahmadabad
Indore
Vadodara
Jamnagar
Rajkot
Surat
Nagpur
Ulhasnagar
Mumbai (Bombay)
Pune
Sholapur
Hyderabad
Vishakhapatnam
Belgaum
Panaji
Bay of Bengal
Sittwe
Monywa
Mandalay
MYANMAR
Rangoon
VIETNAM
Hanoi
Hai Phong
Gulf of Tonkin
LAOS
Chiang Mai
Vientiane
Nong Khai
THAILAND
Khon Kaen
Vinh
Da Nang
South China Sea
Laoag
PHILIPPINES
Baguio
Luzon



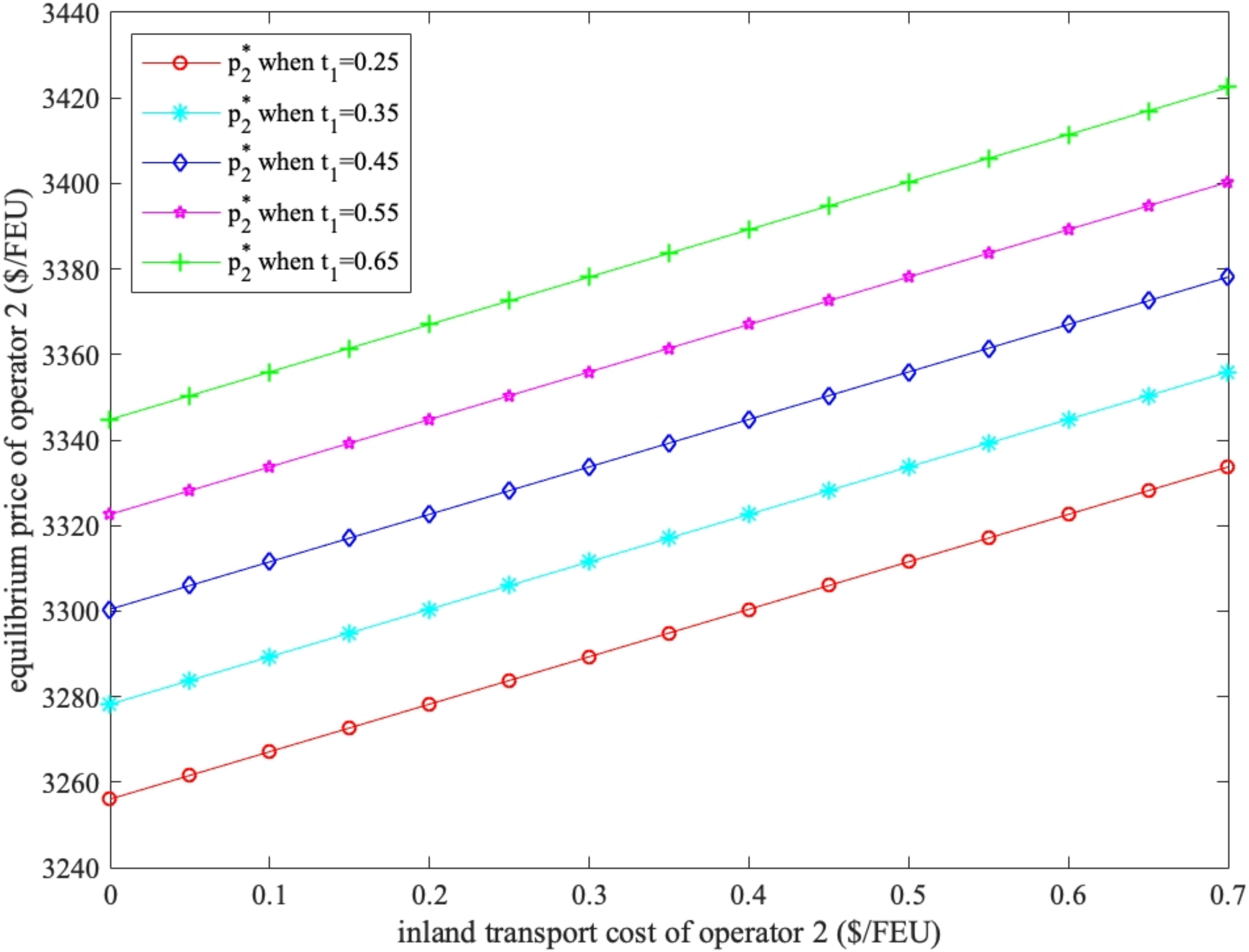
110
108
106
104
102
100
98
96
94
92
0
1
2
3
4
5
6
7
equilibrium profit of operator 2 (10^3 \$)
frequency of operator 2 (trains/week)
π_2^* when f_1=1
π_2^* when f_1=3
π_2^* when f_1=5
π_2^* when f_1=7
π_2^* when f_1=9



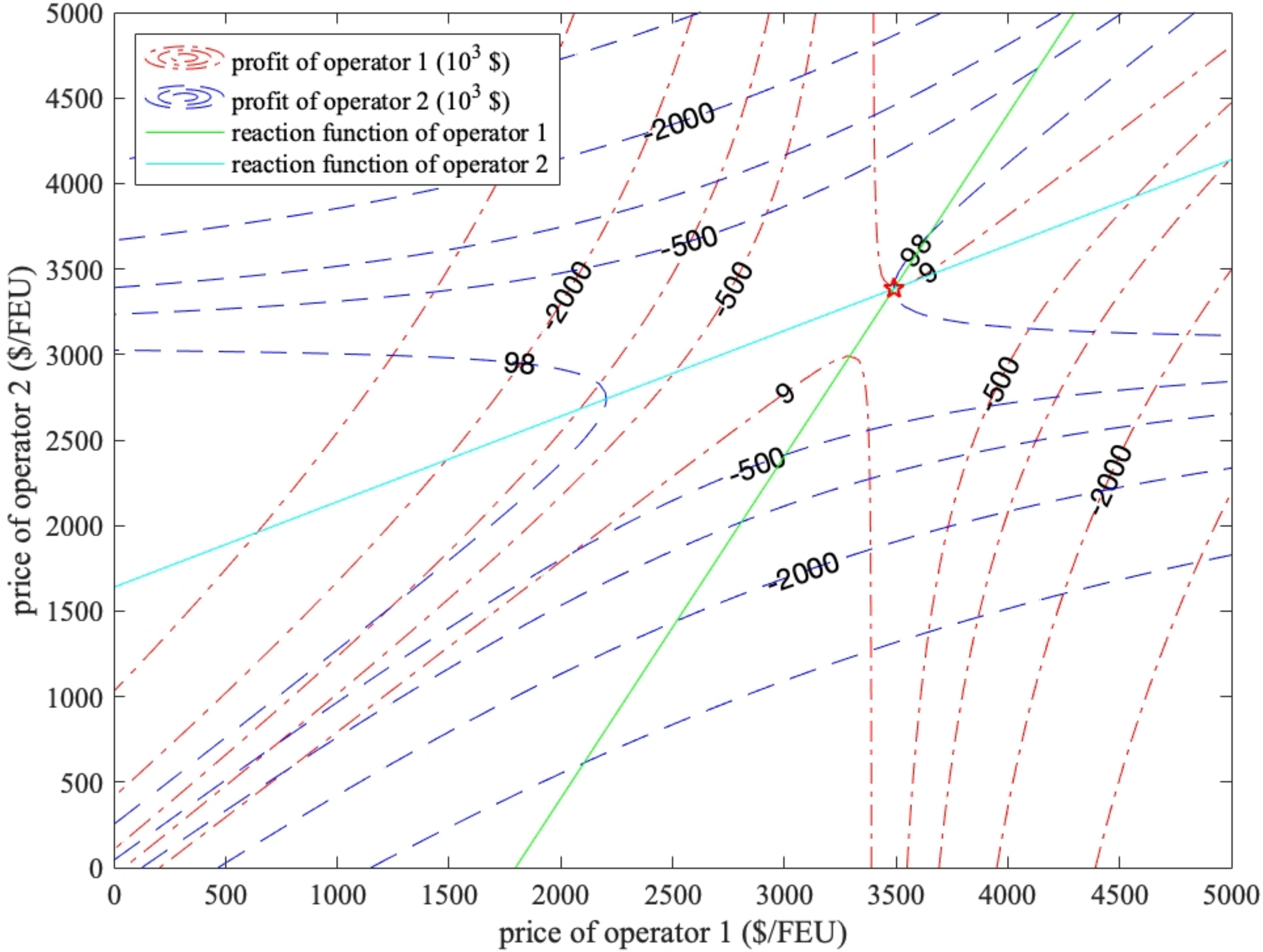
3520
3500
3480
3460
3440
3420
3400
3380
3360
0
1
2
3
4
5
6
7
equilibrium price of operator 2 ($/FEU)
frequency of operator 2 (trains/week)
p_2^* when f_1=1
p_2^* when f_1=3
p_2^* when f_1=5
p_2^* when f_1=7
p_2^* when f_1=9



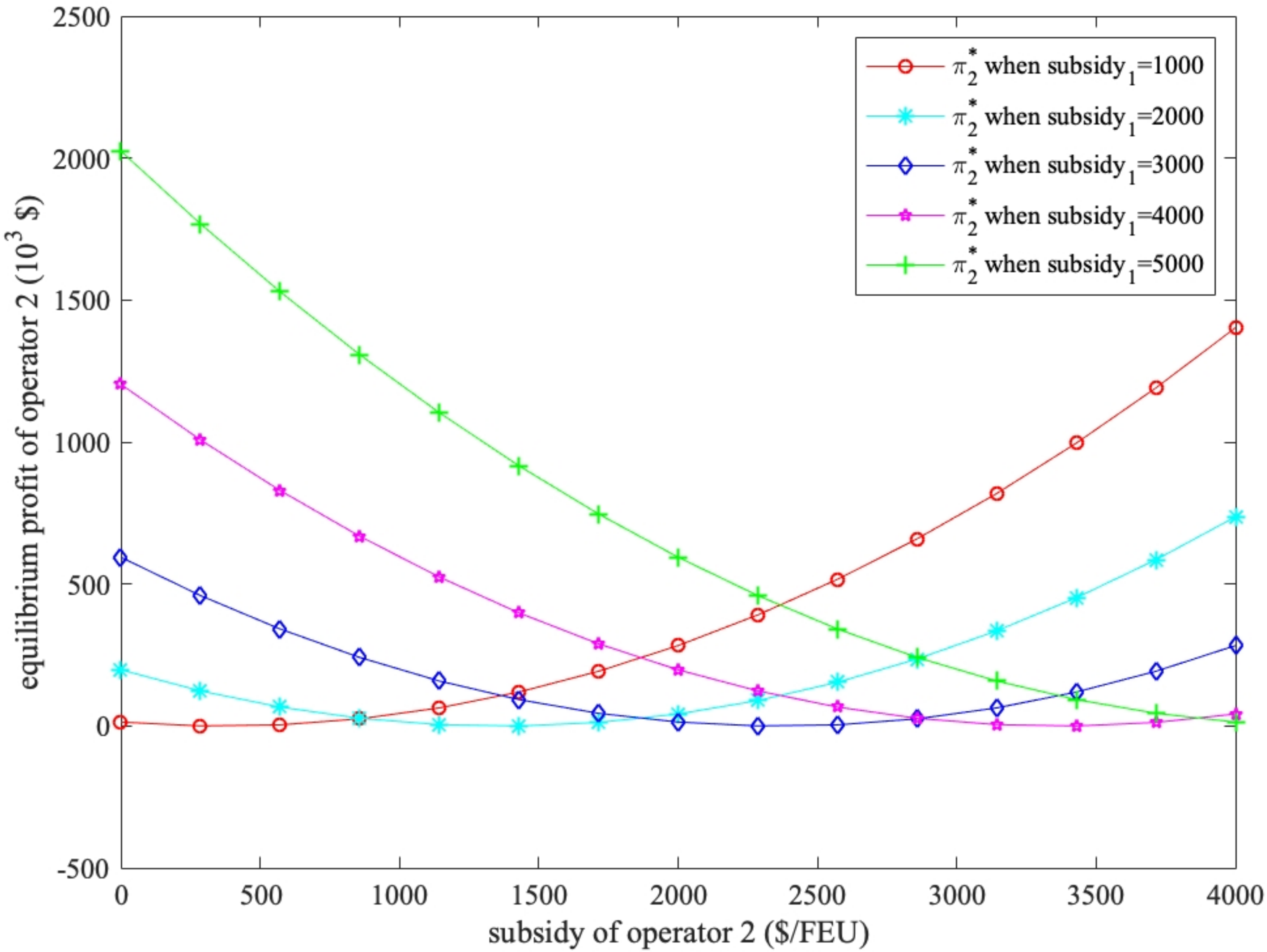
equilibrium price of operator 2 ($/FEU)
subsidy of operator 2 ($/FEU)
p_2^* when subsidy$_1$=1000
p_2^* when subsidy$_1$=2000
p_2^* when subsidy$_1$=3000
p_2^* when subsidy$_1$=4000
p_2^* when subsidy$_1$=5000
6500
6000
5500
5000
4500
4000
3500
3000
2500
2000
0
500
1000
1500
2000
2500
3000
3500
4000



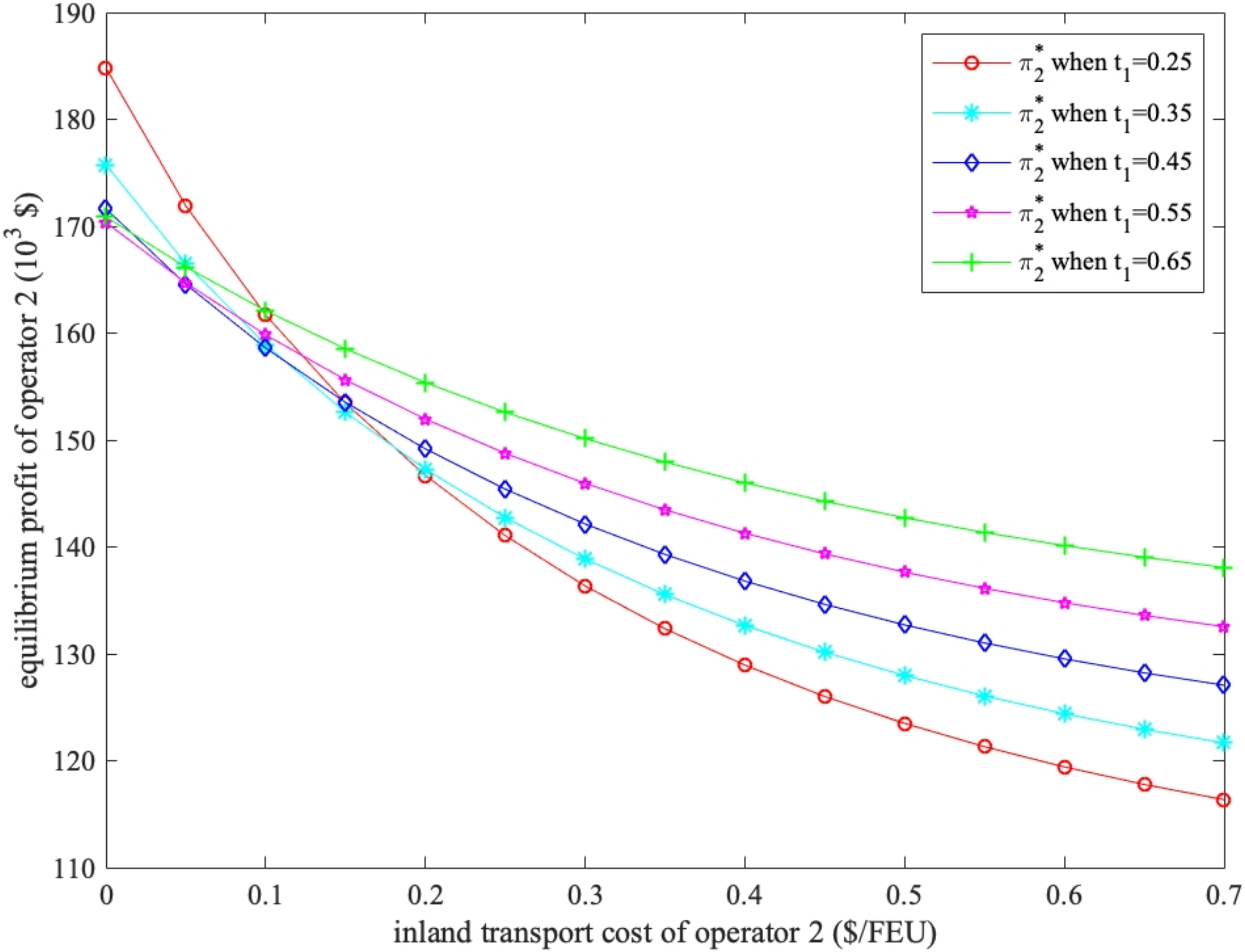
3440
3420
3400
3380
3360
3340
3320
3300
3280
3260
3240
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
equilibrium price of operator 2 ($/FEU)
inland transport cost of operator 2 ($/FEU)
p_2^* when t_1=0.25
p_2^* when t_1=0.35
p_2^* when t_1=0.45
p_2^* when t_1=0.55
p_2^* when t_1=0.65



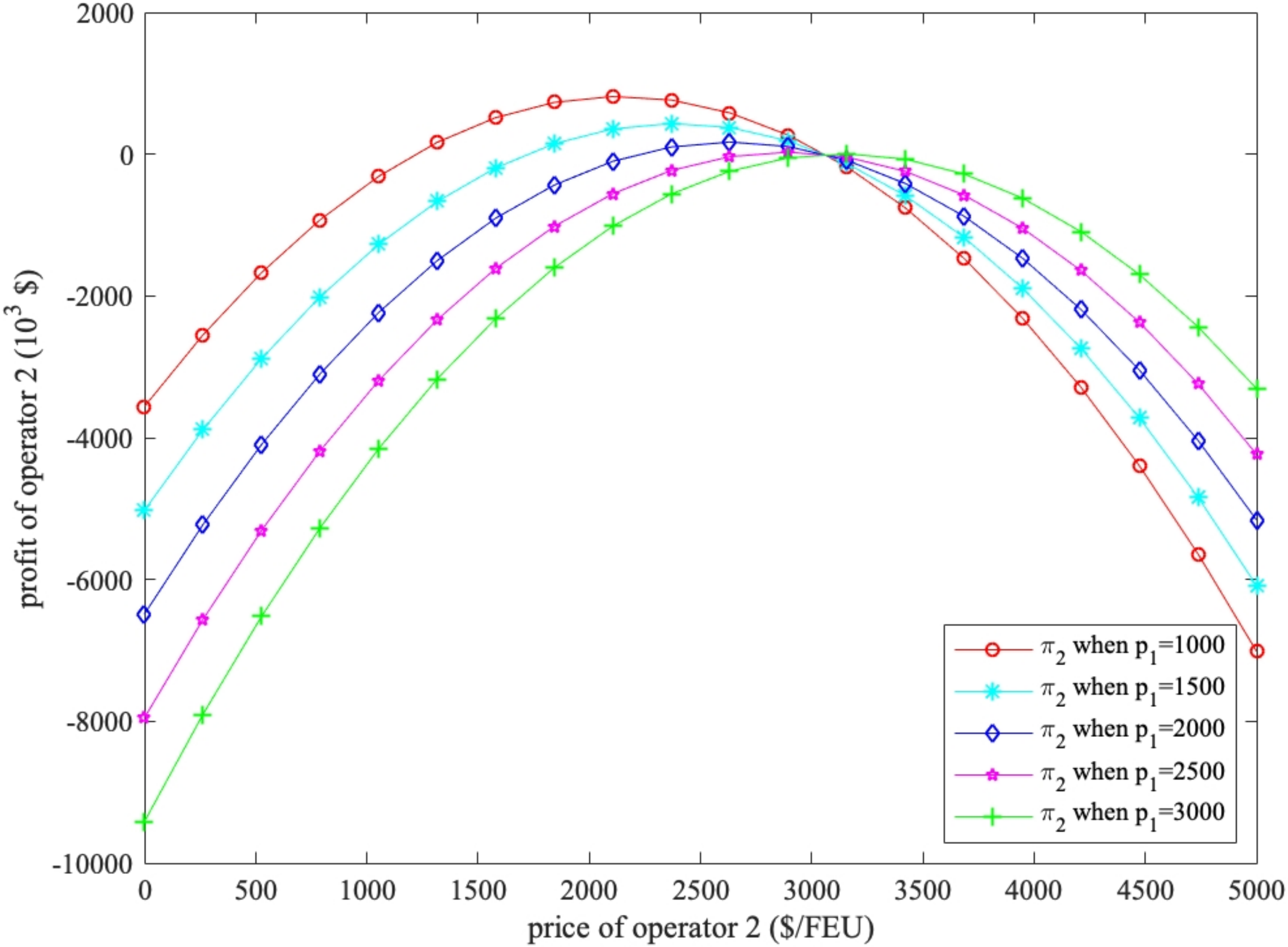
profit of operator 1 (10^3 $)
profit of operator 2 (10^3 $)
reaction function of operator 1
reaction function of operator 2
-2000
-500
98
9
price of operator 1 ($/FEU)
price of operator 2 ($/FEU)
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000



π_2^* when subsidy$_1$=1000
π_2^* when subsidy$_1$=2000
π_2^* when subsidy$_1$=3000
π_2^* when subsidy$_1$=4000
π_2^* when subsidy$_1$=5000
equilibrium profit of operator 2 (10^3 \$)
subsidy of operator 2 (\$/FEU)
2500
2000
1500
1000
500
0
-500
0
500
1000
1500
2000
2500
3000
3500
4000



equilibrium profit of operator 2 (10^3 $)
inland transport cost of operator 2 ($/FEU)
π_2^* when t_1=0.25
π_2^* when t_1=0.35
π_2^* when t_1=0.45
π_2^* when t_1=0.55
π_2^* when t_1=0.65
190
180
170
160
150
140
130
120
110
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7


2000
0
-2000
-4000
-6000
-8000
-10000
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
profit of operator 2 (10^3 $)
price of operator 2 ($/FEU)
π_2 when p_1=1000
π_2 when p_1=1500
π_2 when p_1=2000
π_2 when p_1=2500
π_2 when p_1=3000

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