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China Railway Express Subsidy Model Based on Game Theory under “the Belt and Road” Initiative

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Received: 25 December 2019; Accepted: 6 March 2020; Published: 8 March 2020



Abstract: China Railway Express (CR Express) is an emerging freight transport mode between China and Europe, which provides a new option in addition to air transport and ocean shipping. At the initial stage of development, due to the higher freight costs compared to ocean shipping, the government subsidy provided for the China Railway Express operator plays an important role in the process of market cultivation. The original intention of the government subsidy was to promote the rapid and sustainable development of China Railway Express and the further subsidy scheme should encourage China Railway Express operators to act towards the expected goal of the local government. This research is devoted to modeling and solving the problem of optimal subsidy amount in the operation of China Railway Express. Firstly, a subsidy model is established with the consideration of different objectives of local government and China Railway Express operator, which are affected by the operational effort level of the China Railway Express operator, actual freight rate and the highest freight rate that the shipper is willing to pay. Then, the validity of the proposed model is analyzed in the case study of the China Railway Express line (Wuhan–Hamburg). The effects of different subsidy amounts on the social benefits of local government and profits of the China Railway Express operator are analyzed and the sensitivity analysis is carried on the operational effort level of China Railway Express operator and the highest freight rate that shipper is willing to pay. The analysis results show that the optimal subsidy amount is between 2000 and 2500 USD per Forty-Foot Equivalent Unit (FEU). Finally, suggestions are proposed according to the analysis results. These findings can provide useful references for promoting the sustainable development of China Railway Express.

Keywords: the belt and road initiative; China Railway Express; government subsidy; Wuhan Asia–Europe Logistics

1. Introduction

China Railway Express (CR Express) refers to international joint railway freight transport services based on fixed train numbers and lines, schedules and whole-course operation hours between China and Europe and others on the Silk Road Economic Belt and the 21st-Century Maritime Silk Road (hereinafter referred to as the Belt and Road Initiative (BRI)) countries. The development of CR Express has promoted intercommunication and interconnection with European countries, and has become the third logistic mode between China and Europe in addition to maritime and air transport services. By the end of 2018, 59 Chinese cities had operated CR Express lines to 49 cities in 15 European countries. Since the first China–Europe rail cargo transportation service opened from Chongqing, China to Duisburg, Germany in 2011, the total number of trains in operation has exceeded 11,000, making CR Express an important carrier for promoting the implementation of the BRI and deepening China's economic and trade cooperation with European countries. In 2018, there were 6363 CR Express trains and the number increased by 72% compared with 2017, as shown in Figure 1.

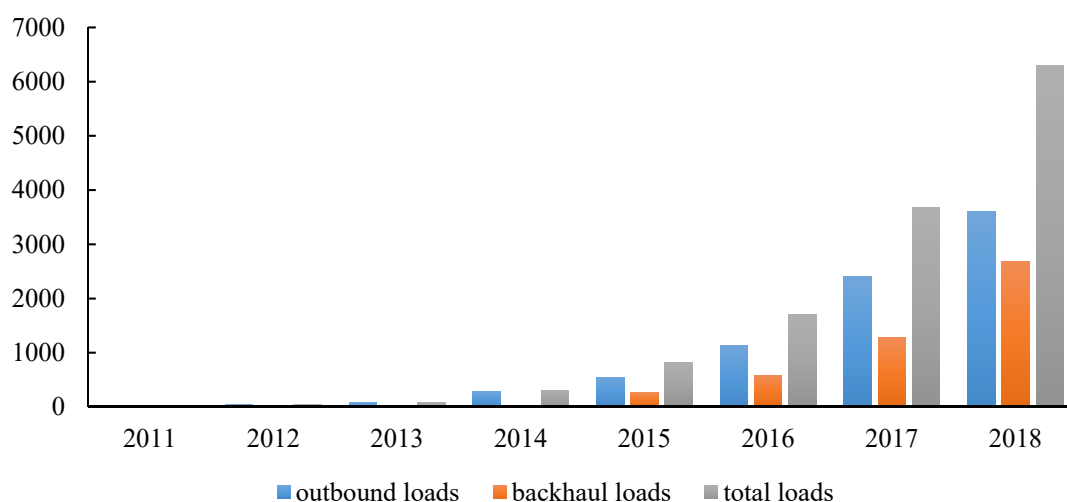


Figure 1. The number of loads of CR Express.

The operation of CR Express opens a new era for rail freight, which provides an alternative means of freight between China and Europe. The average transport time from Chinese seaport cities to European coastal cities by ocean shipping is 35–42 days, while that of CR Express is only 11–15 days. However, the transportation cost of CR Express is much higher than that of ocean shipping, which implies that CR Express has a challenge in competing with ocean shipping [1]. In order to support and guide the development of CR Express at the early stages, most local governments provide subsidy to CR Express operators. For instance, the government of Zhengzhou subsidizes the operation of CR Express (Zhengzhou–Europe) to cover the freight cost gap between the CR Express and ocean shipping [1]. The subsidy information of some CR Express routes [1,2] is shown in Table 1.

Table 1. Subsidy of China railway (CR) Express routes.

Routes	Distance (km)	Freight Rate (USD/FEU)	Subsidy (USD/FEU)	Proportion
Chongqing–Duisburg (Germany)	11,179	10,200	6400	62.7%
Zhengzhou–Hamburg (Germany)	10,214	9500	7400	77.9%
Wuhan–Pardubice (Czech)	10,100	11,000	5600	50.9%
Chengdu–Lodz (Poland)	9826	10,600	7000	66.0%

At the early stage of development, the subsidy does exert positive effects. The subsidy is significant for CR Express operators to cover operating loss and maintain normalized operation. It is obvious that CR Express operators are heavily subsidized. From Table 1, it can be seen that CR Express operators of Chongqing, Zhengzhou, Wuhan and Chengdu all get huge subsidies from local governments, with an average of 6000 USD per Forty-foot Equivalent Unit (FEU). The total number of CR Express trains is 6363 in 2018, which is approximately equal to 226,0883FEU (usually, each train carries about 41 FEU containers). According to the data in Table 1, the total amount of government subsidy is an enormous number. The original intention of the government subsidy was to promote the rapid and sustainable development of CR Express instead of just covering operating loss. However, due to the higher freight costs compared to ocean shipping, CR Express could not keep the operation economically viable without subsidies [1]. Therefore, the further development of CR Express should be oriented to reducing transportation costs, instead of relying on subsidies from local government to compete with ocean shipping in terms of freight rate. The further subsidy scheme should encourage CR Express operators

to act towards the expected goals of local government, and it is necessary to research a subsidy scheme of more incentive effects.

In the operation process of CR Express, there are several entities, including CR Express operators, China State Railway Group Co., Ltd (CHINA RAILWAY), foreign railway transportation enterprises and other logistics enterprises. CR Express operators are the integrated transport operators for the whole transport process [1]. CHINA RAILWAY and foreign railway transportation enterprises are the actual carriers of the domestic part and foreign part of railway transportation, respectively. The main problems in the operation of CR Express include high transportation cost [1], low market competitiveness [3] and lack of goods (especially backhaul goods) [4]. Some CR Express trains carry goods from China to European countries, but return to China empty or with little cargo on board [5].

There are some ways to reduce operating costs and increase operational efficiencies: (1) Implementing combined transportation in countries with wide-gauge tracks like Russia and Kazakhstan. According to the definition given by the China Railway Express Transport Coordination Committee, combined transportation refers to combining three outbound CR Express trains with the same destination into two trains at railway port stations to better utilize the transportation capacity in countries with wide-gauge tracks. (2) Optimizing transportation organization, such as setting up a collection and distribution hubs according to the freight volume of different cities [4]. (3) Promoting service quality, such as improving the convenience and reliability of freight service. (4) Maximizing utilization of transportation capacity, such as maintaining a steady source of outbound goods and developing European market to attract more backhaul goods. Among the above measures, combined transportation is a cooperation project between CHINA RAILWAY and foreign railway transportation enterprises, and optimizing transportation organization is the task of local railway bureaus along the CR Express routes. These two measures could not be realized by the local CR Express operator. Therefore, the options for the CR Express operator mainly include promoting service quality and maximizing utilization of transportation capacity, the goal of which is to attract more outbound and backhaul goods.

In the subsidy problem of CR Express, the main stakeholders are CR Express operators, shippers and local governments. Stakeholder theory holds the view that the organization involves many stakeholders, and each stakeholder has their own interest claims. It is necessary to balance the interests of all stakeholders. As an enterprise, CR Express operator will choose the appropriate operation mode and operational effort level to maximize profits. The operational effort level [6] refers to the efforts that the CR Express operator exerts in the operation of CR Express, like promoting service quality and maximizing the utilization of transportation's capacity to attract more outbound and backhaul goods. The CR Express operator is required to provide the corresponding price and service quality to stimulate shippers' transportation demand. In order to seize the development opportunities of "the Belt and Road" Initiative, local governments encourage CR Express operators to operate CR Express lines by providing a subsidy. The goal of local governments is to maximize social benefits. If the subsidy scheme fails to balance the interests of all stakeholders, it will seriously affect operational efficiency. Therefore, a proper subsidy scheme is required to arouse the enthusiasm of all stakeholders and balance the interests of all stakeholders.

The rest of the paper is organized as follows. The relevant literature on the CR Express subsidy is reviewed in Section 2. An incentive subsidy model based on game theory is proposed in Section 3. Section 4 demonstrates the validity of the proposed model through case study. Section 5 discusses the model limitations and model extensions. Finally, conclusions are presented in Section 6.

2. Literature Review

In recent years, the Belt and Road Initiative and CR Express has become an important topic in academic circles. Many scholars have conducted relevant researches on international transportation and logistics under the background of the Belt and Road Initiative. For instance, Lee et al. [7] analyzed the expected impacts of the BRI on trade and implications on structural changes in transportation

systems, port networks, and international logistics. Seo et al. [8] adopted a multimodal model to explore the various alternative routes for laptop exports from Chongqing, China to Rotterdam, the Netherlands. Their findings can be utilized to make a balance between transit time and transport cost for the effective multimodal transport of laptops from Chongqing to Rotterdam. Sheu et al. [9] proposed a spatial–temporal logistics interaction model integrated with a Markov chain to forecast time-varying logistic distribution flows under the background of BRI. Vinokurov et al. [10], based on the analysis of trade flows, railway tariffs, existing restrictions and individual routes' potential efficiency, assessed the prospects of seven actual and potential trans-Eurasian overland transport corridors and identified the most promising transport corridors. Chhetri et al. [11] analyzed the key challenges of the BRI: underdeveloped infrastructure in Asia, road congestion, dilapidated infrastructure, incessant supply chain disruptions, and capacity constraint, which impose significant economic costs. Yii et al. [12] pointed out that the crucial challenge encountered in the Belt and Road Initiative was the different track gauge standards in different countries. In the study, they examined the impact of the Belt and Road Initiative and its importance to economic growth by further investigating determinants such as transportation infrastructure and trade. Fardella et al. [13] concentrated on the impact of the Belt and Road Initiative on Europe as well as the impact of new railways and port infrastructures on bilateral trade between China and Europe. The research showed that the development of new railway connections would benefit most of the Northern and Central European countries.

In the research on CR Express, scholars focused on the problems of CR Express and put forward optimization measures. Jiang et al. [14] summarized the development achievement of CR Express and analyzed the existing problems, such as the lack of backhaul cargo, uncertain transportation time. Wang et al. [15] pointed out that CR Express could achieve profit only if selective goods (high-value and low-weight goods) were shipped to appropriate locations (the hinterland of the Eurasian Continent). Zhao et al. [16] evaluated 27 Chinese cities using complex network theory which were selected as pre-candidate consolidation centers based on government policy and CR Express operation experience, and then used the TOPSIS model to identify 10 cities as the optimal consolidation centers. Lei [17] carried out a solution to the optimization model of CR Express multimodal transport under the requirements of shipper and analyzed the results from the following aspects: transportation cost, transport time limit, time window and cost window, preferential subsidy, and proposal for formulating the plan. Liu [18] investigated the CR Express operator selection problem and used the Lingo model to calculate the lowest transportation cost between China and Europe. Wu et al. [19] proposed a network planning location model for CR Express as well as an algorithm based on a genetic algorithm approach to minimize total operation cost. The results indicated that Zhengzhou and Chengdu were selected as consolidation centers. Abdirassilov et al. [20] showed the use of artificial neural networks for predicting container train flows between China and Europe, and concluded that priority should be given to solution to problems such as reduction in cargo delivery time, development of transport infrastructure and prediction of future cargo flows. Zhou et al. [21] proposed a time–distance cost function to compare China Railway Express with traditional transportation modes. The study found that different types of cargoes exhibited distinct sensitivity to time. Li et al. [5] focused on nine railway lines connecting Europe and China, which started operations between 2011 and 2015, and concluded that the intercontinental railways had a positive effect on China's exports to its trading partners in Central Asia and Europe. Bucsky [22] examined a variety of data sources to identify the structure and evolution of cargo volumes along the Eurasian Land Bridge according to the development of new railway freight services between Chinese cities and Europe.

Compared with other aspects of CR Express research, the research on the subsidy of CR Express is relatively scarce. Jiang et al. [1] explored the current and the prospective hinterland patterns of CR Express according to the binary logit model. The results showed that government subsidy for CR Express operators contributed to decreasing 60% of CR Express freight cost. Li et al. [3] studied the competitiveness of the CR Express and pointed out that CR Express relied on a great deal of subsidies from local government and the market share of CR Express would be affected with a reduction

in subsidies, which would have a negative impact on the sustainable development of CR Express. Wang et al. [4] analyzed the current situation that most CR Express routes would find it difficult to remain operational without subsidy from the local government and proposed a “hub-and-spoke” organizational model of CR Express to generate scale economies and reduce costs. Du et al. [6] obtained the optimal subsidy amount for the government by analyzing the relationship between local government and local relevant enterprises. Du [23] investigated the game mechanism of CR Express from a game components and relationships perspective, formulated incomplete information dynamics game theory models with the goal of maximizing social benefits and discussed the optimal subsidy scheme. Ye [24] analyzed the train frequency and proposed a mathematical model to minimize the local government’s subsidy and maximize the total profit of freight forwarder. The research found that reducing transportation cost and increasing train frequency could contribute to the reduction in government subsidy. Kundu et al. [25] proposed a competition model based on game theory to analyze the effect of the government subsidy on shippers’ mode switching (from maritime to rail) behavior.

Other research related to this study focused on railway subsidy, freight transport subsidy and public transport subsidy. Harrod [26] discussed the problem of pricing train paths and government subsidy in the North American railway network. It was concluded that the auction pricing would lead to loss of revenue, which was not conducive to a reduction in government subsidy. Xu et al. [27] assessed the influence of different railway fares and subsidy policies on urban form, residents’ utility level and social benefits. The numerical calculation showed that a low subsidy policy based on distance should be the first choice, because it could improve residents’ social benefits and utility level. Tsamboulas [28] analyzed how to use government subsidies to improve the financial situation of railway investment under the circumstance of negative financial evaluation. Yang et al. [29] focused on the subsidy provided for rail containers by local government and proposed an optimal subsidy scheme by developing a bi-level programming model. Santos et al. [30] discussed the influence of freight transportation policies aiming at promoting railway intermodal transport in European countries. The results showed that subsidy had an important impact on the freight volume, which could increase the competitiveness of intermodal transport. Cowie [31] assessed the changes in subsidy and the operational efficiency of British train-operating companies since the passenger rail privatization. In the field of public transport subsidy, scholars concentrated on the optimal subsidy scheme and the effects of subsidy on alleviating urban road congestion. Schmitz et al. [32] studied the compensation for farmers in western Canada after the grain transport subsidy was removed. Kulshreshtha et al. [33] proposed two quantitative models to estimate the effects of the transport subsidy for various grains in Canada. The analysis suggested that the loss of subsidy would result in a reduced level of farm income unless the subsidy was provided in other forms. Borjesson et al. [34] compared the optimal public transport subsidy schemes in different Swedish cities, which were derived by assuming optimal bus frequency, pricing and bus stop spacing. Nilsson et al. [35] compared two approaches for promoting the development of public transport: targeted subsidy and competitive tendering. It was concluded that targeted subsidy and competitive tendering would realize the same maximization of social welfare under full information, while a targeted subsidy would be a better choice under asymmetric information. Sun et al. [36] analyzed the effects of an external subsidy on the public transport systems. The numerical evaluations showed that a combination of subsidy schemes and regulation yields the highest social welfare. Wang et al. [37] proposed a subsidy optimization model with the aim of maximizing the efficiency of the subsidy. The decision variables of the model included passenger demand, train operating headway and fares. Yuan et al. [38] established a dynamic price and subsidy adjustment model to balance the satisfaction of involved stakeholders. Hu et al. [39] adopted the multi-objective programming method to solve the pricing and subsidy problems of the urban transit PPP projects with the objective of maximizing social welfare, maximizing the private sector’s profit and maximizing the consumer surplus, respectively.

At the early stage of development, local governments play an important role in dealing with the problem of high operating costs resulting from the immature development of the CR Express. In the

government's incentive policy, subsidy is regarded as an effective way to promote the sustainable development of CR Express. Under the premise of rational decision-making, local governments, shippers and CR Express operators are independent decision-makers that optimally choose an operational strategy to maximize their own interests. Game theory is a theory studying decision-making and the decision-making equilibrium between two or more decision-makers, which is widely used in the field of subsidy problems between government and enterprise, such as the construction of microgrids [40,41] and the development of supply chains [42,43]. From a game-theoretical perspective, the subsidy problem of CR Express can be viewed as a non-cooperative game, where there are three players—the local government, CR Express operators, and shippers—who have different goals and interact with each other. Therefore, this paper uses game theory to build a subsidy model.

In game-theoretical terms, the equilibrium subsidy amount refers to the revenue-maximizing and incentive-compatible subsidy amount in this game, with which no player has any incentive to unilaterally deviate from his current strategy [44]. However, an equilibrium subsidy amount may not be socially optimal. The sum of producer surplus and consumer surplus is called social benefit. In game theory, a non-cooperative game usually results in a loss of social benefits because players with self-interests or even conflicting interests will try to achieve their own selfish goals, which is detrimental to social benefits. Theoretically, the subsidy scheme could be socially optimal by maximizing the sum of producer surplus and consumer surplus.

At present, the domestic and international research on CR Express has mostly focused on the relevant suggestions based on the analysis of the development status and existing problems. Some research using mathematical models has been conducted. However, there is relatively little research on the subsidy of CR Express. Some scholars have pointed out the problems of current subsidy policy, but it is not clear what the proper subsidy scheme is. Therefore, the main purpose of this paper is to propose an incentive subsidy scheme based on game theory. By taking the interests of stakeholders into consideration, we construct a game subsidy model of CR Express and show through case study that it can play a role in reducing the subsidy and promoting the sustainable development of CR Express.

3. Subsidy Model based on Game Theory

3.1. Problem Description

In the subsidy problem of CR Express, the stakeholders involved include CR Express operators, shippers and local governments, which have their own interest demands. The behaviors of each participant interact with each other, instead of being completely isolated. The goal of each participant is to achieve their own maximum utility, which is related to the subsidy. Game theory is useful in analyzing the behaviors of participants with different goals.

The CR Express operator is the local operator of CR Express lines in different cities, which collects goods shipped to Europe from shippers. Hence, the CR Express operator is the platform company connecting the freight demand of shippers and transport capacity of CHINA RAILWAY. As the operator of CR Express lines, the CR Express operator could make a choice between improving operational performance to attract more goods and maintaining operation relying on subsidies. Consequently, the strategy of CR Express operator in the game includes improving operational performance or not.

Local government is the provider of subsidy and the decision-maker of subsidy scheme. Some local governments provide excessive subsidy for CR Express operator to seize a competitive advantage in the fierce market competition, while others not. The strategy of local government in the game includes providing the rationally designed subsidy scheme or excessive subsidy.

Shippers select CR Express to transport goods in the Sino–EU trade, which generates freight demands. Besides freight rate, shippers will consider the quality of freight service such as safety, punctuality, convenience degree when selecting CR Express operator. Therefore, shippers will choose operators with a lower freight rate and better service quality.

Aiming to promote the sustainable development of CR Express, this paper will conduct a two-stage game to build a subsidy model, which incorporates profit-oriented CR Express operators, the social-benefits-maximizing local government and utility-maximizing shippers. The proposed two-stage game runs as follows: in the first stage, the local government chooses a subsidy scheme to maximize social benefits. Given the subsidy scheme, CR Express operators choose an appropriate operational effort level and freight rate to achieve the goal of maximizing profit at the second stage, which substantially affects shippers' choices between CR Express and other transportation modes.

3.2. Model Assumption

In order to facilitate the research, we adopt the following reasonable assumptions.

(1) The CR Express operator can choose the effort level of operating CR Express routes. The freight volume can be divided into basic freight volume and variable freight volume, affected by operational effort level and freight rate

$$F = F_0 + F_1 + F_2 \quad (1)$$

In Equation (1), F represents total freight volume; F_0 , F_1 , F_2 represent the basic freight volume, variable freight volume affected by operational effort level, and variable freight volume affected by freight rate, respectively. The operational effort level [6], which is noted as parameter a , refers to the efforts that CR Express operator exerts in the operation of CR Express, such as promoting service quality and maximizing utilization of transportation capacity to attract more outbound and backhaul goods. The operational effort level belongs to an interval $[0, 1]$, with a maximum value of 1 and a minimum value of 0, which could be applied for judging whether CR Express operators are hard-working. Consequently, the selection of CR Express operator in the game is quantified as a value in the range of 0 and 1. Because shippers will choose operators with lower freight rate and better service quality, the variable freight volume affected by operational effort level is positively correlated with the operational effort level. However, the variable freight volume cannot increase unrestrictedly with the improvement in operational effort level, and the growth rate will gradually slow down, which means that the positive value of the first derivative and negative value of the second derivative of $a(F'_1(a) > 0, F''_1(a) < 0)$. It is assumed that when the operational effort level is at the lowest value, namely $a = 0$, the corresponding variable freight volume is equal to 0.

According to the references [23], the variable freight volume affected by operational effort level can be expressed as follows

$$F_1 = f_1 \cdot (-a^2 + 2a) \quad (2)$$

The variable freight volume affected by freight rate is negatively correlated with the freight rate. According to the actual situation, the shippers are sensitive to the freight rate. The freight demand elasticity of price is relatively large, which means that the increase in freight rate will result in a rapid decrease in freight volume. Therefore, the variable freight volume affected by freight rate can be expressed as follows:

$$F_2 = -f_2 \cdot (v - v_0)^2 \quad (3)$$

The freight volume of the CR Express operator is obtained as Equation (4):

$$F = F_0 + f_1 \cdot (-a^2 + 2a) - f_2 \cdot (v - v_0)^2 \quad (4)$$

In Equation (4), f_1 , f_2 represent freight volume coefficient affected by operational effort level, freight rate, respectively, and v, v_0 represent actual freight rate and benchmark freight rate, respectively.

(2) The output value of the CR Express operator is the positive effects of CR Express operators' improving operational performance in social benefits. From the angle of the regional level, CR Express will help promote regional economic development. From the angle of the national level, CR Express will help to further open the region to the outside world, promote economic and trade exchanges with European countries, and strengthen international cooperation. For the CR Express operator, we

assume a linear relationship between the output value and operational effort level. The output value is positively related to the operational effort level. The relationship between operational effort level and output value can be expressed as follows:

$$M(a) = na + \tau \quad (5)$$

n represents correlation coefficient between output value and operational effort level ($n > 0$), and $\tau \sim N(0, \sigma^2)$, which represents the influence of uncertain variables on output value.

(3) The operating cost of the CR Express operator is related to operational effort level. In general, the operating cost is mainly composed of two parts, namely fixed cost and variable cost. The fixed cost remains unchanged at the same level of operational effort and decreases with the improvement in operational efficiency. The variable cost increases as the operational effort level increases. CR Express operators will experience a disutility $\frac{1}{2}ba^2$ when exerting effort level a . It is assumed that the relationship between operating cost and operational effort level is as follows

$$C(a) = C_0 + \frac{1}{2}ba^2 \quad (6)$$

C_0 represents fixed cost, and b represents cost coefficient, $b > 0$.

(4) The government subsidizes CR Express operator according to its output value. The subsidy amount is determined by output value and subsidy coefficient. Subsidy amount can be calculated as follows

$$S(a) = kM(a) \quad (7)$$

S represents total subsidy amount, k represents subsidy coefficient, and M represents output value of CR Express.

3.3. Model Construction

(1) Government benefit function

The objective of government is to maximize social benefits. According to the economic theory [45–47], social benefits are comprised of producer surplus and consumer surplus. In order to maximize social benefits, the government provides a subsidy to the CR Express operator and supervises it. The government benefit function is as follows

$$B = P_S + C_S \quad (8)$$

B represents social benefits, P_S represents producer surplus, and C_S represents consumer surplus.

The CR Express operator is the producer of services, so the producer surplus refers to its operating profit, which is expressed as

$$P_S = Fv + S - C \quad (9)$$

F represents freight volume, and v represents freight rate actually paid by the shipper.

The shipper is the consumer of cargo transportation service, so the consumer surplus refers to the difference between the highest freight rate that the shipper is willing to pay and the actual freight rate paid, which is expressed as

$$C_S = F(v_{max} - v) \quad (10)$$

v_{max} represents the highest freight rate that the shipper is willing to pay.

Thus, the government benefit function is as follow

$$B = Fv + S - C + F(v_{max} - v) = Fv_{max} + S - C \quad (11)$$

(2) Operating profit of CR Express operator

The operating income of the CR Express operator mainly comes from the freight rate paid by the shipper and the subsidies provided by the government. The expenditure is mainly the operating cost. The profit function can be expressed as Equation (9).

The government needs to choose the appropriate subsidy amount to achieve its goals, which is affected by the constraints of the CR Express operator. An opportunity benefit exists. The CR Express operator will accept the government's commission only when the profit of operating CR Express routes is not less than the opportunity benefit. Therefore, the constraints can be expressed as

$$Fv + S - C \geq P_O \quad (12)$$

P_O represents opportunity benefit.

(3) Operational effort level of CR Express operator

The CR Express operator possesses comprehensive and accurate operation-related information, and will choose operational effort level, which will maximize profit:

$$\max P = \max(Fv + S - C) \quad (13)$$

Thus, CR Express subsidy model is as follows

$$\max B = \max \left[Fv_{max} + k(na + \tau) - \left(C_0 + \frac{1}{2}ba^2 \right) \right] \quad (14)$$

$$s.t. Fv + k(na + \tau) - \left(C_0 + \frac{1}{2}ba^2 \right) \geq P_O \quad (15)$$

$$\max P = \max \left[Fv + k(na + \tau) - \left(C_0 + \frac{1}{2}ba^2 \right) \right] \quad (16)$$

3.4. Model Solution

Substitute Equation (4) into Equation (16), derive the first-order derivative of Equation (16) and set it equal to 0 (in order to facilitate calculation, the influence of uncertain variables on output value of CR Express operator is not considered in the following calculation).

$$\frac{dP}{da} = kn - ab + (2 - 2a)f_1v = 0 \quad (17)$$

$a^* = \frac{kn + 2f_1v}{2f_1v + b}$, that is, the operational effort level that CR Express operator will choose to maximize profits. Substitute a^* into Equations (14) and (15), derive the first-order derivative of k , and set it equal to 0.

$$\frac{dB}{dk} = \left[\frac{2n}{2f_1v + b} - \frac{2n(kn + 2f_1v)}{(2f_1 + b)^2} \right] f_1v_{max} + \frac{2n^2k + 2f_1vn}{2f_1v + b} - \frac{bn(kn + 2f_1v)}{(2f_1v + b)^2} = 0 \quad (18)$$

$$k^* = \frac{2bf_1v_{max} + 4f_1^2v^2}{2f_1v_{max}n - 4nf_1v - bn} \quad (19)$$

k^* is the optimal subsidy coefficient. With the government's goal of maximizing social benefits, the optimal subsidy coefficient is related to the cost coefficient of the CR Express operator, operational effort level-freight volume coefficient, operational effort level-output value coefficient, the highest freight rate that the shipper is willing to pay, and the actual freight rate.

According to the solution results, the subsidy amount, operating profit of CR Express operator and social benefits can be calculated as follows

$$S = k^*na = \frac{(2bf_1v_{max} + 4f_1^2v^2)na}{2f_1v_{max}n - 4nf_1v - bn} = \frac{(2bf_1v_{max} + 4f_1^2v^2)a}{2f_1v_{max} - 4f_1v - b} \quad (20)$$

$$P = Fv + S - C = F_0v + (2a - a^2)f_1v - f_2(v - v_0)^2v + \frac{(2bf_1v_{max} + 4f_1^2v^2)a}{2f_1v_{max} - 4f_1v - b} - C_0 - \frac{1}{2}ba^2 \quad (21)$$

$$B = Fv_{max} + S - C = F_0v_{max} + (2a - a^2)f_1v_{max} - f_2(v - v_0)^2v_{max} + \frac{(2bf_1v_{max} + 4f_1^2v^2)a}{2f_1v_{max} - 4f_1v - b} - C_0 - \frac{1}{2}ba^2 \quad (22)$$

The analysis of the results is as follows:

(1) Take the derivative with respect to v_{max}

$$\frac{dS^*}{dv_{max}} = -\frac{(8abvf_1^2 + 2af_1b^2 + 8av^2f_1^3)}{(2f_1v_{max} - 4f_1v - b)^2} < 0 \quad (23)$$

It can be seen that the subsidy amount is negatively correlated with the highest freight rate that the shipper is willing to pay, which means that the higher freight rate that the shipper is willing to pay, the lower the subsidy amount will be. Therefore, CR Express operator should attract more shippers of high-value-added goods (electronic products like mobile phones and laptops) which could afford higher transport fees and take full advantage of the characteristics of “faster than ocean shipping and cheaper than air transportation”.

(2) Take the derivative with respect to v

$$\frac{dS^*}{dv} = \frac{(16avf_1^3 + 8abf_1^2)(v_{max} - v)}{(2f_1v_{max} - 4f_1v - b)^2} \quad (24)$$

It can be seen that the value of the above derivative depends on the quantity of v and v_{max} . The shippers in the freight market can be divided into two groups: shippers of higher willingness to pay and shippers of lower willingness to pay. The shippers of higher willingness to pay are usually more sensitive to transportation time and less sensitive to freight rate. For them, $v_{max} > v$, which means the positive value of above derivative. Therefore, the subsidy amount is positively correlated with the actual freight rate, which means that the subsidy amount will decrease with the decrease in actual freight rate for shippers of higher willingness to pay.

4. Case Study

This paper selects the CR Express (Wuhan–Alataw Pass–Hamburg) for case study. The routes operated by Wuhan Asia–Europe Logistics include CR Express (Wuhan–Alataw Pass–Hamburg), CR Express (Wuhan–Erenhot–Duisburg), CR Express (Wuhan–Manzhouli–Moscow), etc. CR Express (Wuhan–Europe) operated 423 trains in 2018, and the main categories of goods include electronic products, mechanical products, passenger cars, optical cables and daily necessities [48]. The main competitors of Wuhan–Europe Express include ocean transportation and air transportation. Collected from the references [1], the relevant information of the three modes of transportation is shown in Table 2.

Table 2. Comparison of Wuhan–Hamburg’s main modes of transportation.

Transportation Mode	Transport Fee	Transportation Time
CR Express	11,000 USD/FEU	12–14 days
Ocean Transportation	1800 USD/FEU	30 days
Air Transportation	46,000 USD/20 tons	4 days

We collected the data of container number transported by CR Express (Wuhan–Alataw Pass–Hamburg) in the last 4 years from Wuhan Asia–Europe Logistics (www.wae-logistics.com) and operating cost from references [1,3], as shown in Table 3.

Table 3. Operating data of CR Express (Wuhan–Hamburg).

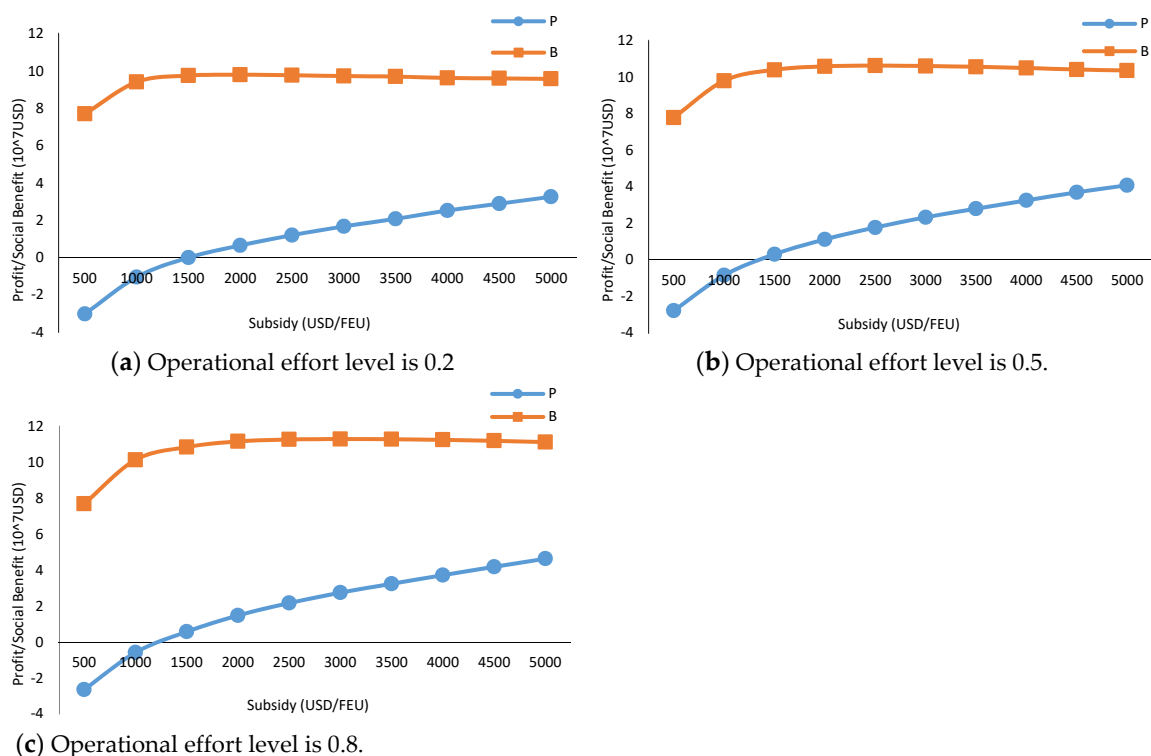
Year	Total Loads	Total Container (FEU)	Operating Cost (USD/FEU)
2016	122	5002	12,000
2017	161	6601	11,050
2018	173	7093	11,050
2019	167	6847	11,000

To determine the value of parameters, we assume that the operational effort level (parameter a) increased slowly from 0.4 to 0.55 with the development of CR Express in the last four years. According to the operating data and model in Section 3, the value ranges of parameters are shown in Table 4.

Table 4. Value ranges of parameters.

Parameter	Meaning	Value Range	Units
F_0	Basic freight volume	[5000,7000]	FEU
f_1	Effort level-freight volume coefficient	[90,120]	FEU
f_2	Freight rate-freight volume coefficient	[105,107]	FEU ³ /(10 ³ USD) ²
b	Cost coefficient	[16,22]	—
C_0	Fixed cost	[6.5*10 ⁴ ,7.8*10 ⁴]	10 ³ USD

To analyze the profits of CR Express operators and social benefits under different operational effort level, the specific value of parameters is selected. For example, under the high operational effort level, the value of the fixed cost is set to 6.5*10⁴ according to the assumption in Section 3. The results are shown in Figure 2.

**Figure 2.** Operating profit and social benefit under different operational effort level.

It can be seen from Figure 2 that both the profit of the CR Express operator and social benefit increase with the subsidy amount increase in the interval [500,2500]. While the subsidy amount continues to increase, the profit of the CR Express operator will keep growing while the social benefits remain nearly constant or decline slightly. Additionally, when the subsidy amount is low (500 or 1000 USD/FEU), the operator will be in a deficit state (a negative value of profit) and the social benefit is less than the maximum value, which reveals the necessity of reasonable subsidy. Consequently, from the angle of maximizing profits of CR Express operator and social benefits, the optimal subsidy amount is between 2000 to 2500 USD/FEU. Compared with the current subsidy standard of up to 6000–7000 USD/FEU, it is verified that the proposed model can control the total amount of government subsidy within a reasonable range.

Furthermore, the profit and social benefit present the same change trend at different operational effort levels. With the improvement of operational effort level, the same subsidy amount will yield more profit for the CR Express operator and more social benefit and the breakeven points (where the profit is 0) will move in the direction of a lower subsidy amount, which means that the demand for subsidy will be weakened. It is possible that, with the improvement of operational effort level, the CR Express operator could better guarantee the punctuality and reliability of the freight transportation to meet the demand of shippers. In summary, the subsidy provided by the local government is conducive to improving the operational effort level of CR Express operator, thereby promoting service quality, satisfying the demand of shippers and attracting more cargoes.

In order to analyze the relationship between the influencing factors and the profits of the CR Express operator and the social benefits of local government, in the following we conduct a sensitivity analysis of some parameters, including the operational effort level of the CR Express operator, the actual freight rate and the highest freight rate that the shipper is willing to pay.

(1) The operational effort level of CR Express operator

The other parameters are fixed, and the actual freight rate varies in the interval [5,15], with a step length of 1. For different combinations of actual freight rate and operational effort level, the results can be used to analyze the impact of the change in the operational effort level on the profits of the CR Express operator and social benefits, as shown in Figure 3.

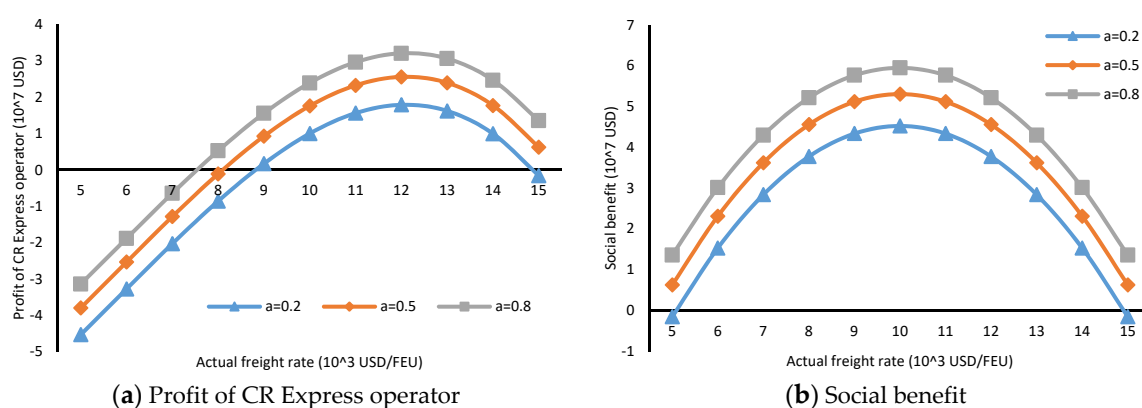


Figure 3. The impact of operational effort level on operating profit and social benefit.

It can be seen from Figure 3 that the change rule of the CR Express operator's profit with the increase in actual freight rate is similar at different operational effort level. The profit of CR Express operator increases with an increase in the actual freight rate when the actual freight rate takes values between 5 and 12, and decreases with an increasing value of the actual freight rate between 12 and 15, which indicates that the profit reaches its peak value when the actual freight rate is 12 thousand USD/FEU. The change in social benefit displays a similar phenomenon, with the maximum value when the actual freight rate is 10 thousand USD/FEU.

Additionally, when the operational effort level increases from 0.2 to 0.8, both the maximum values of profit and social benefit at the same actual freight rate increase and the breakeven points move in the direction of a lower freight rate. It shows that the improvement in operational effort level is useful to realize more profits and social benefits at the same freight rate.

Due to the differences in transport characteristics, there are huge gaps in freight rate between CR Express and ocean shipping. From the angle of maximizing the profits of CR Express operator and the social benefits, the optimal freight rate is between 10 to 12 thousand USD/FEU. The freight rate lower than 7 thousand USD/FEU will result in a deficit for the CR Express operator, regardless of the operational effort level. Therefore, it is unrealistic for the CR Express operator to reduce the freight rate blindly and compete with ocean shipping only in terms of freight rate. For the sustainable development of CR Express, the operator should improve operational efficiency and provide differentiated freight services of better quality.

(2) The highest freight rate that the shipper is willing to pay

The other parameters are fixed, and the actual freight rate varies in the interval [5,15], with a step length of 1. For different combinations of actual freight rate and operational effort level, the results can be used to analyze the impact of the change of the highest freight rate that the shipper is willing to pay on the social benefit, as shown in Figure 4.

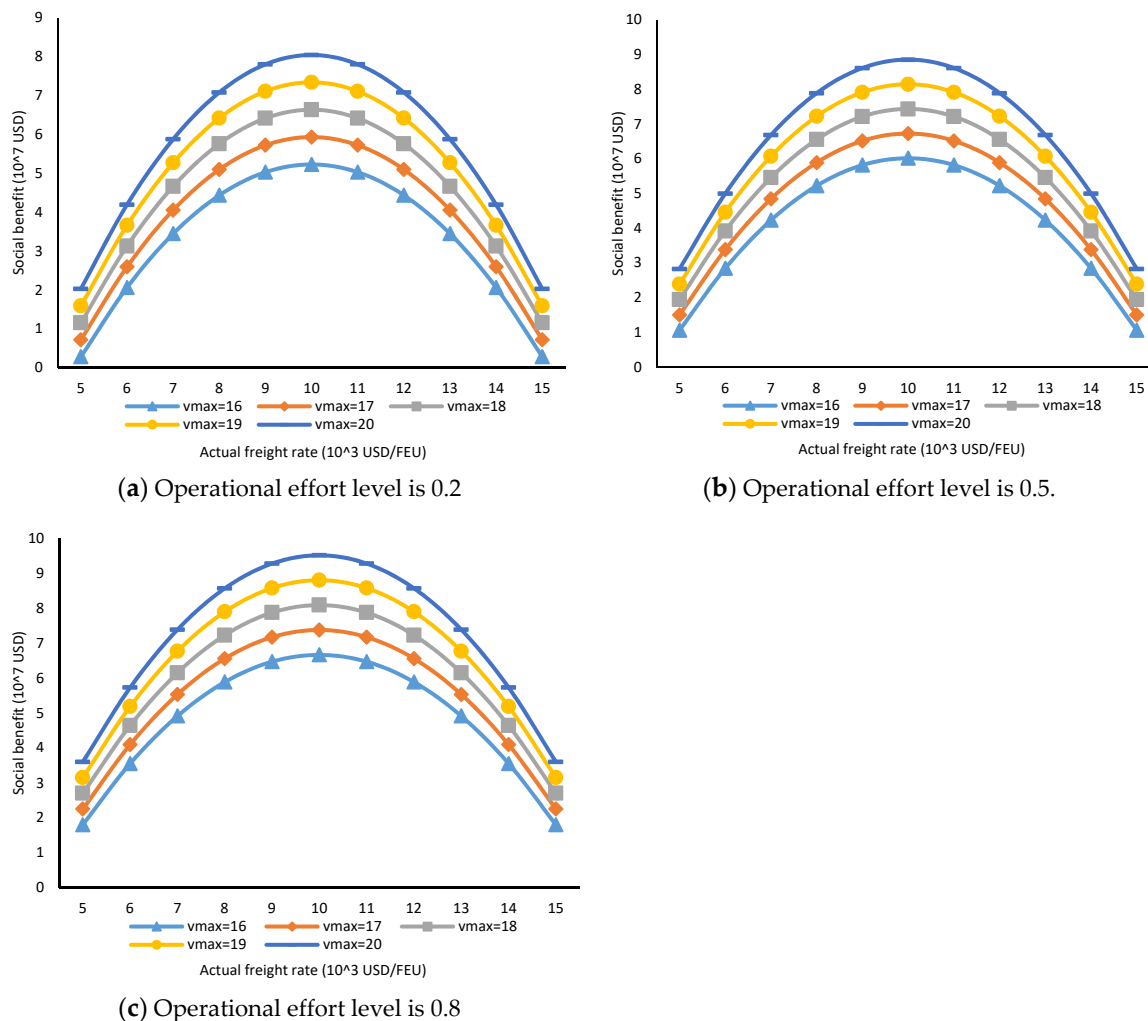


Figure 4. The impact of highest freight rate that shipper is willing to pay on social benefit.

It can be seen from Figure 4 that the change rule of social benefits with the increase in actual freight rate is similar at different operational effort levels. The social benefit increases with an increase

in the actual freight rate when the actual freight rate takes values between 5 and 10, and decreases with an increasing value of the actual freight rate between 10 and 15, which indicates that the social benefit reaches its peak value when the actual freight rate is 10 thousand USD/FEU.

Furthermore, at the same operational effort level and actual freight rate, the increase of the highest freight rate that the shipper is willing to pay could yield more social benefit. It is obvious that shippers of high value-added goods (typically, IT products) have higher willingness to pay, which are more likely to select CR Express than shippers of low value-added goods. Therefore, CR Express is more suitable for high value-added goods.

5. Discussions on Model Limitations and Model Extensions

There are some limitations to the present study. First of all, from the data acquisition perspective, CR Express is a newly emerging mode of freight transport which has only operated for a few years. Therefore, there are some restrictions in the availability of relevant data. Secondly, there are some strong assumptions made in this paper. For instance, the operating cost is divided into fixed cost and variable cost for reasons of simplicity. Further research is still needed to relax these assumptions once more operating data become available. Thirdly, the influence factors of freight volume considered include freight rate and operational effort level, which are analyzed from a microcosmic angle. Therefore, future studies should consider more influence factors such as economic development and the Sino–EU trade volume from a macroscopic perspective. Moreover, local governments will know more hidden information (e.g., operating cost and operating revenue) with the implementation of a subsidy scheme, and we will research an incentive subsidy scheme based on more transparent information between local government and the CR Express operator in the further study.

6. Conclusions

In order to motivate CR Express operators to exert their roles in reducing the subsidy to ensure sustainable development, this paper designs an incentive subsidy scheme. By taking the CR Express subsidy amount as the research object and the operational effort level of CR Express operator as the decision variable, this paper builds a subsidy model based on different objectives of local government and CR Express operator. The impact of different subsidy amount on the profits of CR Express operator and social benefits is analyzed, and the CR Express (Wuhan–Hamburg) route is selected to verify the validity of the model.

The main conclusions are as follows: (1) A subsidy model is designed for CR Express and the influencing factors of profits of the CR Express operator and social benefits include a subsidy provided by the local government, operational effort level, actual freight rate and the highest freight rate that the shipper is willing to pay. The profits of the CR Express operator will keep growing with the increase in subsidy amount, while social benefits will no longer increase after reaching the peak value. (2) The analysis results of CR Express (Wuhan–Hamburg) show that, from the angle of maximizing social benefits and the profits of the CR Express operator, the optimal subsidy amount is between 2000 and 2500 USD/FEU. Compared with the current subsidy scheme, the subsidy scheme proposed in this paper is more rational. (3) Different from ocean shipping, CR Express is more suitable for high-value-added goods. The development of CR Express in the future should focus on attracting more high-value-added goods and providing differentiated freight services to enhance market competitiveness.

This paper can provide reference for promoting sustainable development of CR Express.

Author Contributions: Conceptualization, F.F.; Formal analysis, T.Z., C.L. and L.F.; Funding acquisition, F.F.; Methodology, F.F. and T.Z.; Writing—original draft, T.Z.; Writing—review and editing, F.F., T.Z., C.L. and L.F. All authors have read and agreed to the published version of the manuscript.

Funding: This research was supported by National Social Science Foundation of China, 18BJY169.

Conflicts of Interest: The authors declare no conflict of interest. And the funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

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