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Railway Pricing Problem: The Effects of Monetary Decision-Making on a Duopolistic Freight Transportation Market

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A B S T R A C T

Rail system is considered as the most efficient mode of freight transportation. While it may be expected that demand of rail mode would be higher than other means of transportation, sometimes it has been observed that road transportation is much more applicable. Therefore, economic aspects of transportation market such as process and access charges are prominent. It must be considered that rail transportation has its own drawbacks. Low flexibility and fixed origins and destinations, as well as the relatively high rate of access charges are regarded as the most problematic limitations of rail systems. In current study, an evaluation is carried out using game theoretic approaches in order to determine demands of two competing systems including rail and road. Moreover, Stackelberg approach is utilized in order to calculate optimal access charge of rail infrastructure which maximizes profit of government. The results and findings of current study may contribute policy makers for decision-making in a competitive freight transportation market.

1. Introduction

With the rapid economic growth of societies in recent years, freight transportation has become a substantial and critical concern all over the world. Governments and institutional authorities besides freight forwarders and carriers, tend to maximize their own shares and benefits from freight transportation market and concurrently satisfy the customer requirements. In such conditions, the sustainability plays a key role in determination of freight transportation modes. Adaption of appropriate policies in infrastructure development and pricing strategies can lead to the profitability of the entire system. Economic, environmental, and social facets of sustainability need to be appraised for a straightforward decision making toward sustainable freight transportation. Therefore, there always exists a competition between different modes in competitive transport market.

Rail system is considered as the green mode of freight transportation which affords sustainability, compared to road transportation, which is considered less sustainable. However, rail transportation has its own constraints. Low flexibility and fixed origins and destinations, as well as the relatively high rate of access charges are regarded as the most problematic limitations of rail systems [1-3]. Therefore, solving a problem which maximizes the profit of both rail and road systems seems to be mandatory. Game theoretic approaches can contribute to the development of transportation models by concurrent profit maximization of both systems.

Figure 1 is an illustration of road and rail transportation networks of Iran. Moreover, this figure represents that besides accessibility to rail transportation system, road is the main mode of freight transportation in many cities of Iran.

It demonstrates that the accessibility to the railway infrastructure does not guarantee the

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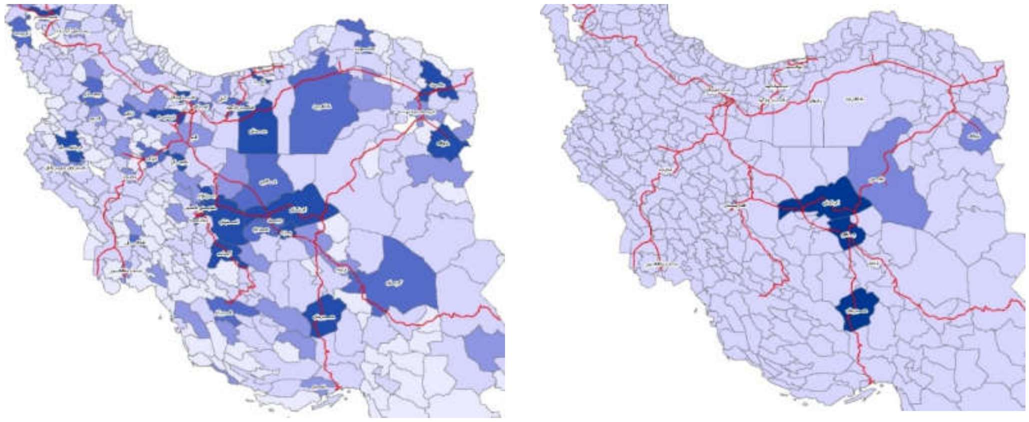

Road transportation network | Rail transportation network

Figure 1. Iran transportation network

utilization of the rail system for freight transportation. Therefore, the other policy-making strategies must be considered to make the railway system appealing for the freight shippers and customers. It can be concluded that the impacts of other transportation factors such as road and rail final transportation prices, as well as rail access charge are prominent.

Many studies have assessed mode choice of freight transportation from various points of view [4-8]. In a study performed by Arencibia, Feo-Valero [4], a contribution is devoted to the freight transport demand analysis by application of discrete choice models. This study tries to divert traffic from road to alternative modes, such as rail or maritime for the carriage between Spain and the European Union. In a study performed by Wang, Yang [5], a fuzzy bi-objective optimization model is formulated for the network design problem considering economic aspects, in order to determine the most efficient modes of freight transportation under uncertain information. In a research performed by Feng, Liu [6], rail transportation pricing policy in addition with environmental considerations have been evaluated. Guo, Peeta [7] assessed cooperation between rail and road transportation systems in order to develop loading and unloading facilities and infrastructure planning. In a research proposed by Bask and Rajahonka [8] the main focus is on the role of environmental sustainability and intermodal transport in transport mode decisions.

Determination of access charges in railway system is another emerging concept which has been evaluated in some previous studies [9-11]. While all these studies have considered transportation prices and marginal costs, there exists a gap in identification of optimal access charge that maximizes the government profit. Moreover, proposing a model that elucidates optimal transportation prices of competing systems with simultaneous maximization of their profits is crucial. Therefore, the present study develops a game-theoretic approach for modeling the competition between road and rail systems in a duopolistic freight transportation market, with consideration of external costs imposed by these systems.

The rest of the paper is structured as follows: Section 2 introduces a description of the problem. Section 3 is contributed to the problem modeling. In Section 4, the equilibrium solutions are presented. In Section 5, a numerical example is introduced; and the paper is concluded in the final section.

The main nomenclature of the current study is illustrated in Table 1.

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Table 1. Nomenclature

θ_u	Fuel consumption rate of a truck for carrying one unit of demand within one unit of distance
θ_a	Fuel consumption rate of a train for carrying one unit of demand within one unit of distance
α	The market baseline for demand of road system
β_p	Elasticity of demand with respect to transportation price
γ_p	Cross-elasticity of demand with respect to transportation price
D_R	Distance between origin and destination for road system
D_L	Distance between origin and destination for rail system
f	Base price of one unit of fuel
$\bar{c}_R$	Summation of costs excluding the fuel cost, imposed on road system for carrying one unit of demand from origin to destination
$\bar{c}_L$	Summation of costs excluding the fuel cost, imposed on rail system for carrying one unit of demand from origin to destination
c_R	Total cost, imposed on road system for carrying one unit of demand from origin to destination
c_L	Total cost, imposed on rail system for carrying one unit of demand from origin to destination
p_R	Transportation price for carrying one unit of demand from origin to destination for road system
p_L	Transportation price for carrying one unit of demand from origin to destination for rail system
q_R	Transportation demand for road system
q_L	Transportation demand for rail system
π_R	Profit function for road system
π_L	Profit function for rail system
π_{gov}	Profit function for government
μ_R	External cost imposed to government for carrying one unit of demand within one unit of distance by road
μ_L	External cost imposed to government for carrying one unit of demand within one unit of distance by rail
A	Rail access charge

2. Description of the Problem

In this study, a game-theoretic approach is followed in order to concurrently maximize the profits of two competing freight transportation systems. Each transportation system has its own demand function. This study has two variables including final transportation prices of two competing modes. A constant demand must be carried between a fixed origin and destination. Each transportation mode seeks to absorb available freight demand as much as possible. Therefore, proposing a model which can simultaneously maximize profit functions of both systems is the main objective of current study. In order to solve this problem, Nash game approach is followed.

As mentioned earlier, road and rail systems are the two competing modes selected for this study. Road transportation costs include a fixed cost and fuel consumption cost. Rail transportation costs include a corresponding fixed and fuel costs besides access charge. Two different transportation routes including road and rail are denoted as D_R and D_L respectively.

To support this approach, the following assumptions are made.

- All involved parameters are non-negative.
- Demand of each mode is more sensitive to its own price than price of the competing mode.

3. The Model Formulation

In this section, first, the competition model of the two competing freight transportation systems is introduced. Subsequently, the government profit function and the corresponding optimal access charge which maximizes government profit are represented. Demand functions of road and rail modes are represented in Eq. (1) and Eq. (2).

$$q_R[p_R, p_L] = \alpha - \beta_p p_R + \gamma_p p_L \tag{1}$$

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$$q_L[p_R,p_L] = Q - (\alpha - \beta_p p_R + \gamma_p p_L) \quad (2)$$

Cost functions for two competing systems are introduced in Eq. (3) and Eq. (4).

$$c_{\mathrm{R}} = \bar{c}_R + D_{\mathrm{R}}\theta_R f \quad (3)$$

$$c_{\mathrm{L}} = \bar{c}_L + D_{\mathrm{L}}\theta_L f + A_L D_{\mathrm{L}} \quad (4)$$

$$\Pi_R[p_R,p_L] = (p_R - c_R).q_R[p_R,p_L] \quad (5)$$

$$\Pi_L[p_R,p_L] = (p_L - c_L).q_L[p_R,p_L] \quad (6)$$

By inserting Eqns. (1-4) into Eqns. (5&6), the profit functions can be rewritten as follows:

$$\Pi_R[p_R,p_L] = (\alpha - p_R\beta_p + p_L\gamma_p)(+p_R - \bar{c}_R - fD_R\theta_R) \quad (7)$$

$$\Pi_L[p_R,p_L] = (Q - \alpha + p_R\beta_p - p_L\gamma_p)(p_L - \bar{c}_L - D_L(A + f\theta_L)) \quad (8)$$

In addition to the aforementioned problem, a government profit function is developed in which rail access charge is considered as the main variable. In this case, two parameters are defined which denotes for environmental, economic and social costs of road and rail transportation for the government. Optimal rail access charge is determined by Stackelberg game approach. These two parameters are denoted as μ_R and μ_L. The government profit function is illustrated in Eq. (9).

$$\Pi_{gov}[p_R,p_L,A] = A.D_L.q_L[p_R,p_L] - \mu_R.D_R.q_R[p_R,p_L] - \mu_L.D_L.q_L[p_R,p_L] \quad (9)$$

Where, the first term reflects the government profit gained by the imposed access charge and the second and third terms reflect the environmental, economic, and social costs of each transportation mode incurred by the government.

4. Equilibrium Solutions

In Nash game approach, the competing systems act at the same level. The model of Nash game approach for this competition is as follows:

$$\begin{cases} \max\limits_{p_{\mathrm{R}}} \pi_{\mathrm{R}}(p_{\mathrm{R}},p_{\mathrm{L}}) \\ \max\limits_{p_{\mathrm{L}}} \pi_{\mathrm{L}}(p_{\mathrm{R}},p_{\mathrm{L}}) \end{cases} \quad (10)$$

Theorem 1.

The equilibrium transportation prices, transportation demands, and profits of road and rail systems is represented in Eq. (11) to Eq. (16).

In Stackelberg game approach, access charge of the government acts as the leader and prices of two competing mode act as the followers of the model.

The Stackelberg's game structure is modeled as in Eq. (17).

Theorem 2.

The equilibrium government profit and optimal access charge are calculated as in Eqns. (18&19):

5. Numerical Example

Following numerical example has been assumed in order to realize the effects of different parameters on the final results. The set of data that are assumed for this case are presented in Table 2. Figure 2 to Figure 4 illustrate equilibrium prices, demands, and

Table 2. Data for the example problem

$\beta_p = 2$	$\gamma_p = 1$	$f = 1(\frac{\$}{lit})$	$\theta_R = 0.0445\ (\frac{lit}{Km.m^3})$
$\theta_L = 0.0072\ (\frac{lit}{Km.m^3})$	$Q = 1000\ (\frac{m^3}{hr})$	$\alpha = 1300\ (\frac{m^3}{hr})$	$\bar{c}_M = 2.5\ (\frac{\$}{m^3})$
$\bar{c}_R = 3.4\ \left(\frac{\$}{m^3}\right)$	$D_M = 1100\ Km$	$\mu_R = 0.02(\frac{\$}{Km.m^3})$	$\mu_L = 0.004(\frac{\$}{Km.m^3})$
$D_R = 1100\ Km$	$\mathrm{A} = 0.5(\frac{\$}{Km.m^3})$		

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$$p_{\mathrm{R}} = \frac{Q + \alpha + \gamma_p(\bar{c}_L + D_L(A + f\theta_L)) + 2\beta_p(\bar{c}_R + fD_R\theta_R)}{3\beta_p} \tag{11}$$

$$p_{\mathrm{L}} = \frac{2Q - \alpha + 2\gamma_p(\bar{c}_L + D_L(A + f\theta_L)) + \beta_p(\bar{c}_R + fD_R\theta_R)}{3\gamma_p} \tag{12}$$

$$q_R[p_R, p_L] = \frac{1}{3}(Q + \alpha + \gamma_p(\bar{c}_L + D_L(A + f\theta_L)) - \beta_p(\bar{c}_R + fD_R\theta_R)) \tag{13}$$

$$q_L[p_R, p_L] = \frac{1}{3}(2Q - \alpha - \gamma_p(\bar{c}_L + D_L(A + f\theta_L)) + \beta_p(\bar{c}_R + fD_R\theta_R)) \tag{14}$$

$$\Pi_R[p_R, p_L] = \frac{(Q+\alpha+\gamma_p(\bar{c}_L+D_L(A+f\theta_L))-\beta_p(\bar{c}_R+fD_R\theta_R))^2}{9\beta_p} \tag{15}$$

$$\Pi_L[p_R, p_L] = \frac{(-2Q + \alpha + \gamma_p(\bar{c}_L + D_L(A + f\theta_L)) - \beta_p(\bar{c}_R + fD_R\theta_R))^2}{9\gamma_p} \tag{16}$$

$$\begin{cases} \mathit{Optimizing}\ \text{ government model } (p_R^*, p_L^*, A) \\ \text{where } (p_R^*, p_L^*) \text{ are simultaneously obtained by solving:} \\ \begin{cases} \max\limits_{p_{\mathrm{R}}} \pi_{\mathrm{R}}(p_R^*, p_L^*) \\ \max\limits_{p_{\mathrm{L}}} \pi_{\mathrm{L}}(p_R^*, p_L^*) \end{cases} \end{cases} \tag{17}$$

$$\begin{aligned} \pi_{gov} = \frac{1}{3}(&-D_L(-2Q + \alpha + \gamma_p(\bar{c}_L + D_L(A + f\theta_L)) - \beta_p(\bar{c}_R + fD_R\theta_R))(A - \mu_L) \\ &- D_R(Q + \alpha + \gamma_p(\bar{c}_L + D_L(A + f\theta_L)) - \beta_p(\bar{c}_R + fD_R\theta_R))\mu_R) \end{aligned} \tag{18}$$

$$A = \frac{2Q - \alpha + \beta_p(\bar{c}_R + fD_R\theta_R) - \gamma_p\big(\bar{c}_L + D_L(f\theta_L - \mu_L)\big) - D_R\gamma_p\mu_R}{2D_L\gamma_p} \tag{19}$$

profit functions with respect to fuel price variations. It can be concluded that as the fuel price increases, equilibrium demand and profit of road transportation system decline, contrary to the rail transportation system. Figure 5 represents a three dimensional illustration of profit functions with respect to distance variations of both systems.

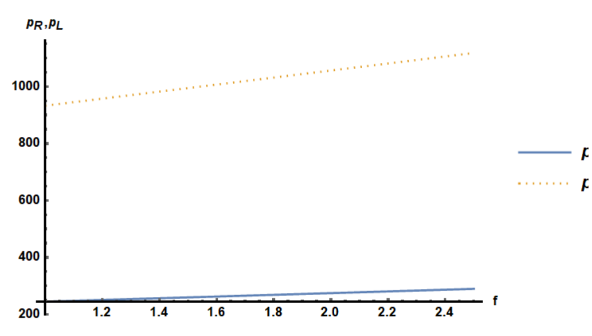

Figure 2. Equilibrium prices with variations of fuel price

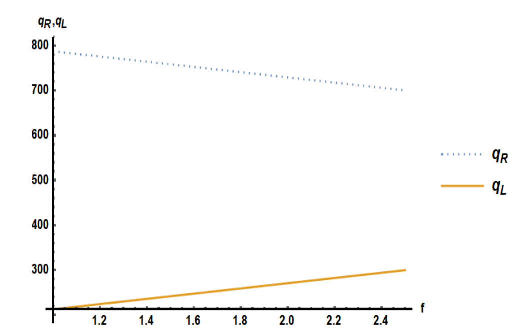

Figure 3. Equilibrium demands with variations of fuel price

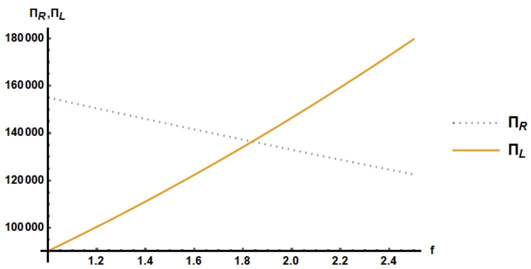

Figure 4. Equilibrium profits with variations of fuel price

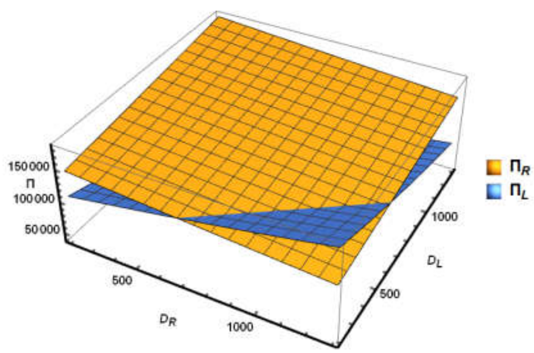

Figure 5. Relationship between profit functions and transportation distances

6. Conclusions

Rail system is considered as the green mode of freight transportation which affords sustainability, compared to road transportation, which is considered less sustainable. However, accessibility to the railway infrastructure does not guarantee the utilization of the rail system for freight transportation. Therefore, the other policy- making strategies must be considered to make the railway system appealing for the freight shippers and customers. It can be concluded that the impacts of other transportation factors such as road and rail final transportation prices, as well as rail access charge are prominent. The results of current research can contribute to the policy makers and managers who wish to optimize freight carriage system. In addition, governmental authorities can apply optimal access charge calculated in current study in order to maximize their profits.

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