Dynamic Game on Carbon Emission Reduction in Intermodal Supply Chain

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Abstract. With the development of international trade, intermodal operations have become more and more important in goods transportation, in order to show the effect of carbon emission tax on a marine-land intermodal supply chain, this paper use dynamic game theory to get a sub-game Nash equilibrium, and the result of this paper show that the carbon emission tax will lead to sea transport and land transport to reduce the carbon emission of every goods, But the carbon tax is not necessarily guaranteed to reduce the total amount of carbon emissions. meanwhile, one part’s reduction of carbon emission may incentive the other part to reduce carbon emission.

Introduction

With the development of electronic commerce and international trade, intermodal transport has become an inevitable trend of supply chain. There were so many studies about intermodal transportation, but most of the article is confined to path planning and terminal location problem, an optimal rail-truck container terminal locations problem on the European network is studied in S. Limbourg[1]. Meisel[2] presents a model and solution approach for combining production and transportation planning in an intermodal network. Some studies have also been combined intermodal with other topics, Xie[3] proposes an intermodal location and routing model for hazardous materials transportation. Kim[4] studies the break-even distance of intermodal freight transport systems. The intermodal transport is so popular not only because economics, efficiency but also due to its ecological friendliness, the combination of various modes of transport has retained eco advantages of different kinds of transportation.

Few studies have explored carbon emission in intermodal transport. Bouchery studied carbon emissions and modal shift in intermodal network[5], Chun-Hsiung Liao Compared carbon dioxide emissions of trucking and intermodal container, It is proved that the intermodal transport is more ecofriendly[6]. In order to urge the supply chain reduce carbon emission, the government will develop a series of measures, such carbon emission tax[7], Green supply chain is the product of these measures, Bruno analyzed the composition of the green supply chain of automobile industry[8]. Lhoussaine integrate logistics outsourcing with green supply chain design and proposed a multi-objective multi-period programming model to solve the problem[9]. Xing K He explores the carbon footprint of the green supply chain[10].

The above researches about carbon emissions in intermodal transport are from the outside, but ignore the decision made by various parts in the supply chain, and the interaction between each parts were seldom mentioned So, We aim to explore the game results between different parts in intermodal supply chain about carbon emission reduction, and get excellent emission reduction plans to provide reference for the enterprise.

Methods

We assume that goods will be sent to consumers by the supplier, but the only means for transportation is the land transportation by truck. They need outsourcing providers to provide marine transportation by ship, so the intermodal supply chain in this paper is a two stages supply
chain consists of marine transportation and land transportation, at the first stage, goods will be transported by boat from one dock to another dock and then it will be delivered to customers through trucks. The government will impose a carbon tax on carbon emissions from the whole transport process. Supplier's revenue comes from selling goods to consumers, but it has to pay the cost of shipping by the outsourcing provider and the carbon emission tax of the land transportation part, outsourcing provider’s profits comes from supplier’s payment, they also need to pay for carbon tax of the marine part.

Through making comparison between the profits of the two successive parts in the intermodal transportation, we use the reverse induction to carry on the dynamic game to get the factors that influence the emission reduction and the mutual influence between marine transportation and land transportation, and finally highlight how the carbon emissions tax effect carbon emission.

At first we need to introduce carbon tax, consumer preferences, Abatement cost and other factors to get the profit of two transportation modes respectively, then according to the Nash equilibrium principle to get the corresponding reduction range of land transport, and whether marine transport’s reduction of carbon emissions will impact land transport’s emission reduction, and what measures the land transport will eventually take.

And then, in the foundation of the best transportation volume and carbon reduction volume, we could get the marine transportation profits, and we will find out the relationship between the marine transportation’s optimal carbon emission and land transport emissions reduction technology, and what measures the marine transport will finally take.

Considering the marginal abatement costs rise, the cost of emission reduction increases with the growth of the emission reduction quantity. We assume that the Abatement cost of marine transportation is \( r_1 \frac{m^2}{2} \), and the emissions reduction amount is \( m \), for land transport they are \( r_2 \frac{n^2}{2} \) and \( n \), with the emission reduction, Unit cargo’s carbon emissions will be reduced, and carbon tax will also be reduced, while consumers in favor of low carbon products, so emission reduction will lead to increased demand. We set demand function as \( p = a - bX + k(m + n) \)

The parameters are set as follows:

**Network:**
- \( c \) : The government’s tax rate on carbon emissions
- \( X \) : The transportation amount in the whole supply chain
- \( m_1 \) : Carbon emissions from marine transport unit products
- \( m_2 \) : Carbon emissions from land transport unit products
- \( w \) : the income brought by transportation one unit goods in marine transportation
- \( d_1 \) : Marine transportation cost of unit product
- \( d_2 \) : land transportation cost of unit product
- \( p = a - bX \) : Consumer linear inverse demand function, \( a \) and \( b \) are constant.
- \( r_1 \) : The emission reduction cost coefficient of marine transportation.
- \( r_2 \) : The emission reduction cost coefficient of land transportation.
- \( m \) : The emission reduction amount of marine transportation.
- \( n \) : The emission reduction amount of land transportation.
- \( k \) : Consumer preference coefficient
\[ \pi_1: \text{The profit of outsourcing provider.} \]

\[ \pi_2: \text{The profit of supplier.} \]

Dynamic game means the actions of the participants is in the order, the latter can observe the former’s action and make choices depend on it, in this article, marine transportation will determine whether to reduce emissions firstly, and then land transport will determine their own transport volume and reduce emissions volume according to the information they’ve got.

![Decision process of outsourcing provider and supplier.](image)

Figure 1. Decision process of outsourcing provider and supplier.

Picture 1 depicts the 4 scenarios that we need to consider.

We take scenario1 as an example, in scenario1 both marine transportation and land transportation don’t reduce carbon emission.

The profit of outsourcing provider includes the income brought by transportation and transportation cost and carbon emission tax.

\[ \pi_1 = (w - d_i)X - cm_i = (w - d_i - c_m)X \]

After supplier’s goods will be sold to customers, but suppliers must pay boat rent fee, so the profit they can get is:

\[ \pi_2 = (P - w - d_z)X - cm_z \]

And it can be transfer to \( \pi_2 = (a - w - d_z - cm_z)X - bX^2 \).

In order to get the maximum benefit, we take this formula as a function of \( X \).

\[ \frac{d\pi_2}{dX} = a - w - d_z - cm_z - 2bX = 0 \]

So the best transportation amount is

\[ X = \frac{(a - w - d_z - cm_z)}{2b} \]

Then we let \( a - w - d_z - cm_z = A \), \( w - d_i - c_m = B \), we can get \( X = \frac{A}{2b} \).
So the profit of outsourcing provider is \( \pi_1 = BX = \frac{AB}{2b} \), and the profit of land transportation or supplier is \( \pi_2 = AX - bX^2 = \frac{A^2}{4b} \).

Scenario 2: the carbon emission reduction of marine transportation is 0, and the carbon emission reduction of marine transportation is \( n \).

The profit of marine transportation or outsourcing provider:

\[
\pi_1 = (w - d_1)X - cm_1X = (w - d_1 - cm_1)X
\]

The profit of land transportation or suppliers:

\[
\pi_2 = (p - w - d_2)X - c(m_2 - n)X - \frac{r_n^2}{2}
\]

Insert \( p = a - bX + kn \) into the formulation we can get:

\[
\pi_2 = (a - w - d_2 - cm_2 + kn + cn)X - bX^2 - \frac{r_n^2}{2}
\]

\[
X = A + \frac{(k + c)n}{2b}
\]

\[
\pi_1 = \frac{B[A + (k + c)n]}{2b}, \quad \pi_2 = \frac{[A + (k + c)n]^2 - r_n^2}{4b} - \frac{r_n^2}{2}
\]

We can get profits of outsourcing provider and land transportation or supplier of four scenarios in this way and put it in Table 1.

<table>
<thead>
<tr>
<th>Marine Emission reduction</th>
<th>Land Emission reduction</th>
<th>No Emission reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emission reduction</td>
<td>( \frac{AB}{2b}, \frac{A^2}{4b} )</td>
<td>( \frac{B[A + (k + c)n]}{2b} ), ( \pi_2 = \frac{[A + (k + c)n]^2 - r_n^2}{4b} - \frac{r_n^2}{2} )</td>
</tr>
<tr>
<td>No Emission reduction</td>
<td>( \frac{(B + mc)(A + km)}{2b} - \frac{r_m^2}{2} ), ( \frac{(A + km^2)}{4b} )</td>
<td>( \frac{(B + mc)[A + km + (k + c)n]}{2b} - \frac{r_m^2}{2} ), ( \frac{[A + (k + c)n + km^2]}{4b} - \frac{r_n^2}{2} )</td>
</tr>
</tbody>
</table>

Both of them desire to find the best way to pursue their interests in the game matrix, the transportation cost per unit commodity, the rate of carbon emission, and carbon emission reduction cost coefficient are fixed, but the emission reduction amount could change for both sides.

**Results**

The government hopes Outsourcing provider and supplier will have a prisoner's dilemma to reduce carbon emission together. By analyzing the above profit table, according to the principle of Nash equilibrium, we could find out that:
In the case of the government imposed carbon tax, whether marine emission reduction or not, the optimal transportation volume after the reduction of land transport transportation volume is larger than the one for no reduction, supply chain must pursue more transportation amount to achieve higher efficiency, so the outsourcing provider hope supplier reduce emissions to get more transportation and bring more profit for themselves; in order to get higher benefit, supplier also want outsourcing provider reduce carbon emission.

No matter outsourcing provider reduce emission or not, supplier will take emission reduction, but due to technical constraints, they have to reduce emission in a certain range to ensure the increase their own profits, when the outsourcing provider don’t reduce emissions reduction, the interval is

\[ (0, \frac{2A(k+c)}{[2br_2 -(k+c)^2]}) \]

and the optimal transport volume, and the optimal emission reduction volume

\[ \frac{r_2 A}{A(k+c)} \]

and \[ \frac{[2br_2 -(k+c)^2]}{[2br_2 -(k+c)^2]} \], when the outsourcing provider reduce emissions, the interval is

\[ (0, \frac{2(A+km)(k+c)}{[2br_2 -(k+c)^2]}) \]

the optimal transport volume and the optimal emission reduction volume are

\[ \frac{r_2 A}{[2br_2 -(k+c)^2]} \]

\[ \frac{[2br_2 -(k+c)^2]}{[2br_2 -(k+c)^2]} \].

If government imposes carbon tax on supply chain, meanwhile, emission reduction technology is still very low, the outsourcing provider will choose emission reduction in order to ensure their profits and the reduction range is

\[ 0 < m < \frac{2(Bl+Ac)r_2}{r_1[2br_2 -(k+c)^2]-2kcr_2} \]

the optimal emission reduction volume is

\[ m = \frac{(Ac + Bk)r_2}{r_1[2br_2 -(k+c)^2]-2kcr_2} \].

The emission reduction amount of outsourcing provider is closely related to the optimal emission reduction of land transport, and the smaller the emission reduction cost coefficient of supplier, the greater the emission reduction amount of out sourcing provider.

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References


