Peer-reviewed version available at Math. Comput. Appl. 2017, 22, 12; doi:10.3390/mca22010012

Article

Game Analysis of Low Carbonization for Urban Logistics Service Systems

Jidong Guo [1,*] and Shugang Ma [2]

[1] Department of Economics and Management, Institute of Disaster Prevention Science and Technology, Beijing 101601, China
[2] Business School, Hebei University of Economics and Business, Shijiazhuang 050061, Hebei Province, China; mashugang@126.com
* Correspondence: guojidong@sina.com; Tel.: +86-10-52645764

Abstract: To improve carbon efficiency for urban logistics service system composed of a third-party logistics service provider (3PLs) and an e-business enterprise, low-carbon operation game between them was studied. Considering low carbon technology investment cost and sales expansion effect of low carbon level, profit functions for both players were constituted. Based on their different bargaining capabilities, totally 5 types of game scenarios were designed. Through analytical solution, Nash Equilibria under varied scenarios were obtained. By analyzing these equilibria, 4 major propositions were given, in which, some key variables and system performance index were compared. Results show that the best system yields could only be achieved under the fully cooperative situation; limited cooperation only for carbon emission reduction would not benefit the system performance improvement; E-business enterprise-leading game's performance overtook 3PLs-leading ones.

Keywords: 3PLs; E-business enterprise; low carbonization; game theory; Nash Equilibria

1. Introduction

The world greenhouse gas emission has been increasing rapidly in the past several decades. As a result, the global warming poses a severe threat to the earth ecosystem and human beings [1]. Low carbon economy has attracted all-around attentions both from business and academia. The whole market environment, to which industrial players have to adapt themselves, is also changing quickly. Low carbon policies from the government, customers' environmental consciousness or preferences will impact a firm's operational costs, goods prices and competition strategies too. Currently consumers and investors now pay more attentions to a firm's environmental performance. More and more consumers are putting a big focus on a product's carbon footprints [2].

Urban logistics sector, as a fresh and flourishing industry, play important roles in promoting urban economic development, improving inhabitants' living standard and particularly strengthening a city's overall competence. However, its externality has also received much more attention, particularly its huge energy consumption and carbon emission. Green or low-carbon urban logistics becomes a new trend. The 3rd-party logistics service providers or 3PLs, perfectly complying with such a tendency, represents larger scale, higher efficiency and lower cost in urban logistics sector. Outsourcing of business logistics becomes a rational choice for e-business enterprises. However, when outsourcing booms in urban logistics sector, for an e-business firm facing more carbon-sensitive customers, how to achieve its lower footprint goals? Do its decisions impact its logistics partners? Why will 3PLs invest on its own in low-carbon initiatives, but with its future fruits enjoyed by e-business firms? How to allocate low-carbon efforts costs and benefits? For all the above questions, bargaining capabilities among 3PLs and e-business firms, together with their coordination and cooperation mechanism shall be studied. Similar to relations among members of supply chains, in such a service chain composed of an e-business firm and a 3PLs, game theory is well proper to analyze their decision interactions and system balance. Bhaskaran et al. have studied cooperation among new product development members in green supply chain background [3]. In the same backdrop, Savaskan et al. have discussed manufacturer-leading waste goods recycling channels. In this research, selecting recycling channels corresponds to various strategies [4]. By analyzing different cooperation forms for a supplier and a manufacturer in environmental protection, Vachon et al. investigate their influence on the manufacturer's performance. Much like this research, Debabrata et al. studied the games between one manufacturer and one retailer with different market power in green efforts of supply chains [5]. To summarize, previous research seldom realized the low carbon effort motivation for the service system composed of an urban 3PLs and an e-business enterprise. Actually, such an effort could benefit all members of the system. Therefore, the relation between customers' demand and low carbon level shall be better modeled. Meanwhile, except full cooperation and asymmetric games, another game scenario, probably much closer to the actual situation, or at least it seemingly is, shall be considered, i.e., game members would cooperate in low carbon levels of their common logistics system only.

The structure of this article is arranged as follows. The first part would introduce as a whole the research background. In the second part, by introducing symbols for variables and parameters of the logistics system, its mathematical formulation would be established. Subsequently, the third part discussed totally five different game situations, including a partially cooperative game. Next, Nash Equilibria would be found, analyzed and compared. The analytical results would specially be put into the fifth part. Conclusions would occur at last.

2. Notations and Mathematical Model

An urban 3PLs and an e-business enterprise comprise the system we studied. The marginal distribution cost for unit goods for the 3PLs is c_1. It requires marginal profit of m_1. p_1 represents outsourcing price the 3PLs charged for its logistics service to the e-business enterprise. For the e-business firm, the purchasing price of the unit goods is c_2. Its required marginal profit is m_2. Unit retail price is set at p_2. The following equations could be established accordingly.

$$p_1 = c_1 + m_1 \quad m_1 \ge 0, c_1 > 0 \tag{1}$$

$$p_2 = c_2 + p_1 + m_2 \quad m_2 \ge 0, c_2 > 0 \tag{2}$$

Let's assume the potential maximum market demand on the goods is D. From common economics theory, the actual demand of the goods shall, meanwhile, relate to its price. As the same as Xie et al. [6], market demand is assumed to be linearly related to market prices, just as the following equation (3). Here d means market demand elasticity coefficient to prices. Moreover, a is demand expansion coefficient to the low-carbon levels of the distribution system, which is also positively proportional to market demand. Similar to other efforts to improve product quality or technical upgrades measures, the 3PLs tries to lower its carbon emissions to save costs and enhance company image in protecting environment. Such an effort, obviously, belongs to non-price element. It is often supposed to be nonlinearly related to market demand, just the same as Savaskan et al. and Tsay et al. [7,8]. Generally speaking, the low-carbon levels of a distribution system shall rise gradually as policy guidance of governments and public environmental consciousness are strengthened. l is the low carbon level of the distribution system. Lower levels can benefit the 3PLs due to better corporate image and customers' experiences. Sales will increase in return. For example, in Europe, around 75% customers are willing to pay more for environment-friendly products. The number was only 31% 3 year ago in 2005 [9]. Now we could well put the total market demand as below.

$$q = D - dp_2 + al \quad D > 0, d > 0, a > 0, l > 0 \tag{3}$$

It could be deduced easily that $D \ge dp_2$, i.e., the potential market demand would be lower than zero. Combining equations (1-3), another important inequality $D - dc_1 - dc_2 > 0$ could be got, which will often be used in the subsequent game procedures.

Furthermore, τ is the investment cost coefficient for low-carbon efforts. The relation between the investment cost and low carbon levels takes on higher order function relations. This assumption is the same as Bhaskaran et al. [3], and such an effect comes from diminishing returns of R & D activities of enterprises. Here we put it as a second-order equation [10]. It is assumed only 3PLs could improve the system's low carbon levels through its unilateral measures. The low carbon levels would not impact the 3PLs's operation cost and marginal profit.

Based on above hypotheses and analysis, the complete profit functions both for the 3PLs and the e-business enterprise could be written below respectively.

$$\Pi_l(m_1,t) = qm_1 - \tau l^2 = (D - d(c_1 + c_2 + m_1 + m_2) + al)m_l - \tau l^2 \qquad \tau > 0 \tag{4}$$

$$\Pi_e(m_2) = qm_2 = (D - d(c_1 + c_2 + m_1 + m_2) + al)m_2 \tag{5}$$

Therefore, the total profit for both game players, or for the whole service system, could be put as follows.

$$\Pi_{l+e} = \Pi_l + \Pi_e = q(m_1 + m_2) - \tau l^2 = (D - d(c_1 + c_2 + m_1 + m_2) + al)(m_1 + m_2) - \tau l^2 \tag{6}$$

3. Game scenarios

According to different market power, or bargaining capability for both game players, 3 types of non-cooperative game scenarios and 2 types of cooperative game scenarios will be discussed here.

(1) Scenario 1: 3PLs leading Stackelberg game (LS game for brief)

In this scenario, the 3PLs firm plays a leading role in the system. Through the reaction function of the e-business firm, it would decide the low carbon level of the system and its marginal profit at first. The e-business firm is a follower and it would decide its own marginal profit by referring to its match's one.

(2) Scenario 2: E-business-enterprise-leading Stackelberg game (ES game for brief)

Contrary to the Scenario 1, in such a system, the e-business firm dominates the whole game, and the 3PLs firm is reduced to a follower. They decide their respective variables in the order of leader to follower.

(3) Scenario 3: Fine Nash game (NA game for brief)

In such a scenario, there are lots of potential partners for both game players. Nobody can dominate the whole system and two sides are well matched in strength. Both make decisions independently based on their opponent's reaction functions.

(4) Scenario 4: Cooperation only in low carbon level decision Nash game (LCNA game)

Enhancing low carbon levels of the logistics distribution system can benefit sales of goods. Therefore, in reality, the e-business firm takes active part in cooperation with the 3PLs to improving the system's greening levels. However, both are not yet willing to negotiate allocation of the whole profit in the service system. So their cooperation is only partial. After they decide together the low carbon level of the system, they would back to the non cooperative state again, deciding their respective marginal profit independently.

(5) Scenario 5: Fully strategic cooperation game (FSCC game for brief)

In this scenario, both sides are strategic partners. Their common goal is to maximize the total profit of the whole service system. The allocation of the total profit is beyond this research. Both players will try to avoid opportunism in the system by making all related decisions together.

In the following section, all Nash equilibria under the above 5 types of scenarios will be obtained. Furthermore, according to equations (1-6), other related endogenous variables, such as total profit of the system, profits for both of them respectively, optimal sales, etc. can also be obtained.

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 9 January 2017 doi:10.20944/preprints201701.0034.v1

Peer-reviewed version available at Math. Comput. Appl. 2017, 22, 12; doi:10.3390/mca22010012

4. Analytical solution of Nash Equilibria

In this section, totally 5 types of game playing scenarios will be discussed. There are 3 key endogenous variables, i.e., m_1,m_2 and l.

4.1 Scenario 1:LS Game

In Stackelberg games, backward induction is often applied to solve them. Namely, firstly the first-order and second-order derivative of the equation (5) to variable m_2 could be got.

$$\frac{d\Pi_e}{dm_2} = -d(c_1 + c_2 + m_1 + 2m_2) + al + D$$

$$\frac{d^2\Pi_e}{dm_2^{\,2}} = -2d < 0$$

Obviously, it is concave in variable m_2. Let the first-order derivate equal to zero. It could be inferred as equation (7).

$$m_2 = \frac{-d(c_1 + c_2 + m_1) + al + D}{2d} \tag{7}$$

Replace m_2 in equation (4) with the above equation (7).

Next, the first-order and second order partial deviations to variable m_1 could be got as follows.

$$\frac{\partial\Pi_l}{\partial m_1} = \frac{-d(c_1 + c_2 + 2m_1) + al + D}{2}$$

$$\frac{\partial^2\Pi_l}{\partial m_1^{\,2}} = -d \qquad \frac{\partial\Pi_l}{\partial l} = \frac{am_1}{2} - 2l\tau$$

$$\frac{\partial^2\Pi_l}{\partial l^2} = -2\tau \qquad \frac{\partial^2\Pi_l}{\partial m_1 \partial l} = \frac{a}{2}$$

The second-order principal minor of the Hessian matrix for equation (4) on united variables (m_1,l) is $2\tau d - \frac{a^2}{4}$.

When $2\tau d - \frac{a^2}{4} > 0$, i.e., when $8\tau d - a^2 > 0$, the Hessian matrix is negative definite. That is to say, the equation (4) is concave in the united variable (m_1,l). Therefore, let the two first order partial derivates equal to 0, then

$$m_1 = \frac{al - c_1 d - c_2 d + D}{2d}$$

$$l = \frac{am_1}{4\tau}$$

Combining the above two equations, the optimal solutions for variable m_1 and l

$$m_1^{LS*} = \frac{\tau(D - c_2 d - c_1 d)}{2\tau d - \frac{a^2}{4}}$$

$$l^{LS*} = \frac{a(D - c_2 d - c_1 d)}{8\tau d - a^2}$$

Because $m_1 \geq 0$, $8\tau d - a^2 > 0$ can easily hold. Then

$$m_2^{LS*} = \frac{\tau(D - c_2 d - c_1 d)}{4\tau d - \frac{a^2}{2}}$$

4.2 Scenario 2:ES Game

Firstly, the first-order and second-order partial derivative of the equation (4) to united variable (m_2,l)could be got.

$$\frac{\partial\Pi_l}{\partial m_1} = -d(2m_1 + m_2 + c_1 + c_2) + al + D \quad \frac{\partial^2\Pi_l}{\partial m_1^{\,2}} = -2d \qquad \frac{\partial\Pi_l}{\partial l} = am_1 - 2l\tau$$

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 9 January 2017 doi:10.20944/preprints201701.0034.v1

Peer-reviewed version available at Math. Comput. Appl. 2017, 22, 12; doi:10.3390/mca22010012

$$\frac{\partial^2\Pi_l}{\partial l^2}=-2\tau \qquad \frac{\partial^2\Pi_l}{\partial m_1\partial l}=a$$

The second-order principal minor of its Hessian matrix is $4d\tau-a^2$.

When $4\tau d-a^2>0$, it could be known that the equation (4) is concave in (m_1,l). Let the two first-order partial derivates equal to 0, and then we get

$$m_1=\frac{-d(m_2+c_1+c_2)+la+D}{2d}$$

$$l=\frac{am_1}{2\tau}$$

Combine them, we get the following equations (8-9)

$$m_1=\frac{\tau((-d)(m_2+c_1+c_2)+D)}{2d\tau-\frac{a^2}{2}} \tag{8}$$

$$l=\frac{a((-d)(m_2+c_1+c_2)+D)}{4d\tau-a^2} \tag{9}$$

Because m_1>0 and l>0, another more strict constraint could be got $4d\tau-a^2>0$.

Substitute equation (8-9) for corresponding variables in the equation (5), now we get its first-order and second-order derivates to m_2.

$$\frac{d\Pi_l}{dm_2}=m_2((-d)(\frac{d\tau}{-2d\tau+\frac{a^2}{2}}+1)+\frac{da^2}{a^2-4d\tau})-d(\frac{\tau(-d(m_2+c_1+c_2)+D)}{2d\tau-\frac{a^2}{2}}+c_1+c_2+m_2)+\frac{a^2((-d)(m_2+c_1+c_2)+D)}{4d\tau-a^2}+D$$

$$\frac{d^2\Pi_l}{dm_2^{\,2}}=\frac{-4\tau d^2}{4d\tau-a^2}\le 0$$

It can be seen that the equation (5) in variable m_2 is concave. Let its first-order derivate equal to 0, the optimal m_2 is obtained

$$m_2^{ES*}=\frac{D-dc_l-dc_2}{2d}$$

Put it back into equation (8-9), then we get

$$m_1^{ES*}=\frac{\tau(D-dc_1-dc_2)}{4d\tau-a^2}$$

$$l^{ES*}=\frac{a(D-dc_1-dc_2)}{8d\tau-2a^2}$$

4.3 Scenario 3:NA Game

As the Scenario 2, firstly, partial derivates of equation (4) are solved to get equation (8-9). Then as in the Scenario 1, equation (7) is obtained by solving derivates of equation (5). Combine (7-9), we get the optimal m_2.

$$m_2^{NA*}=\frac{\tau(D-dc_l+dc_2)}{2d}$$

Put is back into equation (8-9), then get

$$m_1^{NA*}=m_2^{NA*}=\frac{\tau(D-dc_1+dc_2)}{2d}$$

$$l^{NA*}=\frac{a(D-dc_1-dc_2)}{a^2-6d\tau}$$

4.4 Scenario 4:LCNA Game

Firstly, we only solve the partial derivate of equation (4) to variable m_1 as follows.

$$\frac{d\Pi_l}{dm_1}=-d(2m_1+m_2+c_1+c_2)+al+D$$

$$\frac{d^2\Pi_l}{dm_1^{\,2}}=-2d<0$$

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 9 January 2017 doi:10.20944/preprints201701.0034.v1

Peer-reviewed version available at Math. Comput. Appl. 2017, 22, 12; doi:10.3390/mca22010012

Equation (4) is concave in variable m_1. Let its first-order partial derivate equal to 0 to get equation (8). Next, as in Scenario 1, we solve the derivate of equation (5) to m_2 to get equation (7). And then Combining equation (7-8) to get

$$m_1 = m_2 = \frac{D+la}{3d} - \frac{c_1}{3} - \frac{c_2}{3}$$

Put the above m_2, m_1 into equation (4). Solve its partial derivates to l as follows

$$\frac{d\Pi_l}{dl} = \frac{2Da + 2la^2}{9d} - \frac{2ac_1}{9} - \frac{2ac_2}{9} - 2l\tau$$

$$\frac{d^2\Pi_l}{dl^2} = \frac{2a^2}{9d} - 2\tau$$

Because $9d\tau - a^2 > 4d\tau - a^2 > 0$, therefore $\frac{2a^2}{9d} - 2\tau < 0$ and equation (4) is concave in variable l. Now let its first-order derivate equal to 0, we get

$$l^{LCNA*} = \frac{dac_2 + dac_1 - Da}{a^2 - 9d\tau}$$

Put it back into above expression of m_1 and m_2, the optimal solutions of them are

$$m_1^{LCNA*} = m_2^{LCNA*} = \frac{\tau(D - dc_1 - dc_2)}{3\tau d - a^2/3}$$

4.5 Scenario 5:FSCC Game

Firstly, expand the expression of the whole profit function.

$$\Pi_{l+e} = \Pi_l + \Pi_e = q(m_1 + m_2) - \tau l^2 = (D - d(c_2 + c_1 + m_1 + m_2) + al)(m_1 + m_2) - \tau l^2$$

Let $m=m_1+m_2$ and then

$$\Pi_{l+e} = (D_2 - d_2(c_2 + c_1 + m) + al)m - \tau l^2 \tag{10}$$

Solve its first and second-order partial derivates to united variable (m,l)

$$\frac{\partial\Pi_{l+e}}{\partial m} = -d(m + c_1 + c_2) + la - dm + D$$

$$\frac{\partial^2\Pi_{l+e}}{\partial m^2} = -2d \qquad \frac{\partial\Pi_{l+e}}{\partial l} = ma - 2l\tau$$

$$\frac{\partial^2\Pi_{l+e}}{\partial m^2} = -2\tau \qquad \frac{\partial^2\Pi_{l+e}}{\partial m\partial l} = a$$

The second order principal minor of its Hessian matrix is $4d\tau - a^2 > 0$.

Therefore, equation (10) is concave in the united variable.

Let its first-order derivate equal to 0, we get

$$m = \frac{-d(c_1 + c_2) + la + D}{2d}$$

$$l = \frac{ma}{2\tau}$$

Combine the above two variable, it could easily be got as follows.

$$m^{FSCC*} = \frac{\tau((-d)(c_1 + c_2) + D)}{2d\tau - a^2/2}$$

$$l^{FSCC*} = \frac{a((-d)(c_1 + c_2) + D)}{4d\tau - a^2}$$

Beside the above optimal values of major independent variables, profit for each of them, the whole profit and goods sales are also obtained, and put in the following Table 1.

Peer-reviewed version available at *Math. Comput. Appl.* **2017**, *22*, 12; doi:10.3390/mca22010012

Table 1. Operational performance for 3PLs-e-business enterprise service system under 5 types of game scenarios.

Variable	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
l	$\frac{a(D-dc_2-dc_1)}{8\tau d-a^2}$	$\frac{a(D-dc_2-dc_1)}{8\tau d-2a^2}$	$\frac{a(D-dc_2-dc_1)}{6\tau d-a^2}$	$\frac{a(D-dc_2-dc_1)}{9\tau d-a^2}$	$\frac{a(D-dc_2-dc_1)}{4\tau d-a^2}$
m_1	$\frac{\tau(D-dc_2-dc_1)}{2\tau d-\frac{a^2}{4}}$	$\frac{\tau(D-dc_2-dc_1)}{4\tau d-a^2}$	$\frac{\tau(D-dc_2-dc_1)}{3\tau d-\frac{a^2}{3}}$	$\frac{\tau(D-dc_2-dc_1)}{3\tau d-\frac{a^2}{3}}$	$\frac{\tau(D-dc_2-dc_1)}{3\tau d-\frac{a^2}{2}}$
m_2	$\frac{\tau(D - c_2 d - c_1 d)}{4\tau d - \frac{a^2}{2}}$	$\frac{D-dc_1-dc_2}{2d}$	$\frac{\tau(D-dc_1-dc_2)}{3\tau d-\frac{a^2}{2}}$	$\frac{\tau(D-dc_1-dc_2)}{3\tau d-\frac{a^2}{3}}$	
Π_l	$\frac{(8d\tau^2-\tau a^2)(D-dc_1-dc_2)^2}{(8\tau d-a^2)^2}$	$\frac{(4d\tau^2-\tau a^2)(D-dc_1-dc_2)^2}{(8\tau d-2a^2)^2}$	$\frac{(4d\tau^2-\tau a^2)(D-dc_1-dc_2)^2}{(6\tau d-a^2)^2}$	$\frac{(9d\tau^2-\tau a^2)(D-dc_1-dc_2)^2}{(9\tau d-a^2)^2}$	--
Π_e	$\frac{4d\tau^2\ (D-dc_1-dc_2)^2}{(8\tau d-a^2)^2}$	$\frac{\tau\ (D-dc_1-dc_2)^2}{8\tau d-2a^2}$	$\frac{4d\tau^2\ (D-dc_1-dc_2)^2}{(6\tau d-a^2)^2}$	$\frac{9d\tau^2\ (D-dc_1-dc_2)^2}{(9\tau d-a^2)^2}$	--
Π_{l+e}	$\frac{(12d\tau^2-\tau a^2)(D-dc_1-dc_2)^2}{(8\tau d-a^2)^2}$	$\frac{(12d\tau^2-3\tau a^2)(D-dc_1-dc_2)^2}{(8\tau d-2a^2)^2}$	$\frac{(8d\tau^2-\tau a^2)(D-dc_1-dc_2)^2}{(6\tau d-a^2)^2}$	$\frac{(18d\tau^2-\tau a^2)(D-dc_1-dc_2)^2}{(9\tau d-a^2)^2}$	$\frac{(4d\tau^2-\tau a^2)(D-dc_1-dc_2)^2}{(4\tau d-a^2)^2}$
q	$\frac{(a^2-6d\tau)(D-dc_1-dc_2)}{8\tau d-a^2}+D-dc_1-dc_2$	$\frac{(a^2-2d\tau)(D-dc_1-dc_2)}{8\tau d-2a^2}+\frac{D-dc_1-dc_2}{2}$	$\frac{(a^2-4d\tau)(D-dc_1-dc_2)}{6\tau d-a^2}+D-dc_1-dc_2$	$\frac{(a^2-6d\tau)(D-dc_1-dc_2)}{9\tau d-a^2}+D-dc_1-dc_2$	$\frac{(a^2-2d\tau)(D-dc_1-dc_2)}{4\tau d-a^2}+D-dc_1-dc_2$

4. Discussions and Several Propositions

Based on equilibria in the above table and constraints, through simple algebra calculations and comparisons, totally 4 key propositions could be got as follows.

Proposition 1: Low carbon levels of the logistics distribution service system are listed in the following order $l^{\mathrm{LCNA}} < l^{\mathrm{LS}} < l^{\mathrm{ES}} < l^{\mathrm{FSCC}}$; $l^{\mathrm{LS}} < l^{\mathrm{NA}} < l^{\mathrm{FSCC}}$.

It is interesting to find that LCNA game scenario proposes the lowest low carbon level. That is to say, the system will get the lowest carbon efficiency if both players could only cooperate in decisions of low carbon levels but not in decisions of system's whole profit. Of course, fully strategic cooperation relation would mostly benefit the system performance including system carbon efficiency. Another finding is that carbon efficiency in ES game scenario is higher than in LS game scenario, which is even lower than in NA game. It is much likely that in LS game scenario, the 3PLs has even lower investment motivation for carbon reduction technologies.

Proposition 2: The marginal profit for the 3PLs is in the following order $m_1^{\mathrm{LCNA}} < m_1^{\mathrm{NA}} < m_1^{\mathrm{LS}}$; For the e-business enterprise, it is in the order $m_2^{LS} < m_2^{\mathrm{LCNA}} < m_2^{\mathrm{NA}}$; $m_2^{\mathrm{LS}} < m_2^{\mathrm{ES}}$.

It could be seen that bargaining capability decides on their marginal profit respectively. It will earn more if it could dominate the system. It well explain why in reality, either 3PLs or e-business firm tries their best to strengthen themselves so as to acquire more voices or pricing power on the service system. Theoretically, in FSCC game scenario, each of them could obtain more profit than any other games, or they will not choose to fully cooperate.

For the e-business firm, if it can not dominate the service system, it shall turn to look for outsourcing logistics partners with nearly equal market force to get its corresponding benefit in NA game. Furthermore, from proposition 2, we could know the e-business enterprise will not actively join in low carbon level cooperation for its lower marginal profit.

Proposition 3: The order for profit of the 3PLs is $\prod_l^{NA} < \prod_l^{LCNA} < \prod_l^{LS} < \prod_l^{FSCC}$; For the e-business enterprise, it is $\prod_e^{LS} < \prod_e^{LCNA} < \prod_e^{NA} \leq \prod_e^{ES} < \prod_e^{FSCC}$.

It is no doubt that FSCC game scenario would offer the optimal benefit for both players. If full cooperation is impossible, each of them will be in pursuit of control of the service system. For the e-business firm, LCNA game scenario is inferior to pure NA game and therefore, in response to partial cooperation requests from the 3PLs, the best choice for the firm is to refuse joint decision only in carbon efficiency.

Proposition 4: For the whole profit of the service system, it follows the order $\prod_{l+e}^{LS} < \prod_{l+e}^{LCNA} < \prod_{l+e}^{NA} < \prod_{l+e}^{FSCC}$; The whole sales of the system follow the same order.

It is necessary to accomplish full strategic cooperation for the urban 3PLs-e-commer firm service system. However, if the cooperation fails to achieve, the system shall evade the situation in which the 3PLs will dominate, because it will yield the worst result for the whole system. Such a conclusion could also be drawn from the previous three propositions. Furthermore, profit for partial cooperation in carbon efficiency only is not as large as fully non-cooperative situation, namely, the NA game scenario.

5. Conclusions

Considering sales expansion effect brought about by low carbonization of the urban 3PLs-e-business enterprise service system, a game model is established. The model has two players, an urban third party logistics service provider and an e-business firm. Based on bargaining capability of both players, totally 5 types of game mechanisms are designed, particularly, including a partial cooperative situation. Not only are all Nash equilibria for 5 scenarios analytically solved, but through algebra calculation, 4 important propositions are obtained. From these propositions, the following conclusions could safely be drawn.

Firstly, the system performance reaches its upmost under both sides' fully strategic cooperation scenario. When such a cooperation fails to fulfill, the second best choice is e-business enterprise-leading Stackelberg game, which is superior to other three game scenarios. Among all game scenarios, the 3PLs-leading asymmetric game is the worst, for its lowest benefit for the whole system and for each player.

Secondly, the new cooperation mode, namely, the partial cooperation only in carbon efficiency, is far beyond our initial expectations. It never behaves better than even the completely non-cooperative situation.

Thirdly, besides key propositions we got in the above section, sensitivity analysis were also done on major coefficients of the system, including the investment cost coefficient for low-carbon efforts τ and demand expansion coefficient to the low-carbon levels α. It is found that the system's low carbon level has strong negative correlation with τ, and the system's benefit has the same strong positive correlation with α. Therefore, it is recommended that city management shall actively participate in the low carbon technologies and facilities investment, so as to decrease enterprises' costs in improving their low carbon levels. Furthermore, city management is proposed to issue incentive measures and further promote citizens' green consumption consciousness, so as to increase customers' demand to low carbon services and goods.

Acknowledgments: This study is financially supported by the Hebei Province Social Science Funds (No. HB16GL006).

Author Contributions: Jidong Guo proposed the research idea and established the mathematical model. Shugang Ma was responsible for all analytically solving the model and analyzing the results under various scenarios. Jidong Guo wrote this paper.

Conflicts of Interest: The authors declare no conflict of interest.

 doi:10.20944/preprints201701.0034.v1

Peer-reviewed version available at *Math. Comput. Appl.* **2017**, *22*, 12; doi:10.3390/mca22010012

References

1. IPCC. Climate change 2007: Impacts, adaptation and vulnerability. Intergovernmental Panel on Climate Change, Available online: http://www.ipcc.ch/publications_and_data/publications_ipcc_fourth_assessment_report_wg2_report_impacts_adaptation_and_vulnerability.htm (accessed on 8 July 2016).
2. Stein, J. Following the footprints. The Econ: Technol. Quart. 2011, pp. 13-15.
3. Bhaskaran, S. R.; Krishnan, V. Effort, revenue and cost Sharing mechanisms for collaborative new product development. Manage. Sci. 2009, 55, pp. 1152-1169.
4. Savaskan, C; Van Wassenhove, L. N. Reverse channel design: the case of competing retailers, Manage. Sci. 2006, 48, pp. 1196-1212.
5. Vachon, S; Klassen, R. D. Environmental management and manufacturing performance: the role of collaboration in the supply chain. Int. J. Prod. Econ. 2008, 111, pp. 299-315.
6. Xie, J; Neyret, A. Co-op advertising and pricing models in manufacturer-retailer supply chains. Comput. Int. Eng. 2009, 56, pp. 1375–1385.
7. Savaskan, C; Bhattacharya, S; Van Wassenhove, L. N. Closed-loop supply chain models with product remanufacturing. Manage. Sci. 2004, 50, pp. 239-252.
8. Tsay, A.; Agrawal, N. Channel dynamics under price and service competition. Manuf. Serv. Op. 2000, 2, pp. 372–391.
9. European Commission. Europeans' attitudes towards the issue of sustainable consumption and production [online]. Available online: http://www.ec.europa.eu (accessed on 12 Aug 2016).
10. Debabrata, G.; Janat, S. A comparative analysis of greening policies across supply chain structures. Int. J. Prod. Econ 2002, 135, pp. 568–583.