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Game Analysis of Low Carbonization for Urban Logistics Service Systems

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Abstract: To improve carbon efficiency for an urban logistics service system composed of a third-party logistics service provider (3PL) and an e-business enterprise, a 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, in total, five types of game scenarios were designed. Through analytical solution, Nash Equilibria under different scenarios were obtained. By analyzing these equilibria, four major propositions were given, in which some key variables and the system performance indexes 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 does not benefit the system performance improvement. E-business enterprise-leading game's performance overtook 3PL-leading ones.

Keywords: third-party logistics service provider; e-business enterprise; low carbonization; game theory; Nash Equilibria

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1. Introduction

The world greenhouse gas emission has been increasing rapidly in the past several decades. As a result, global warming poses a severe threat to the Earth's ecosystem and human beings [1]. Low carbon economy has attracted wide attention 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 pay more attention to a firm's environmental performance. More and more consumers are putting a big focus on a product's carbon footprints [2].

The urban logistics sector, as a fresh and flourishing industry, plays important roles in promoting urban economic development, improving inhabitants' living standards and, particularly, strengthening a city's overall competence. However, its externality has also received much attention, particularly its huge energy consumption and carbon emission. Green or low-carbon urban logistics is becoming a new trend. The third-party logistics service providers or 3PL, perfectly complying with such a tendency, represent larger scale, higher efficiency and lower cost in the urban logistics sector. Outsourcing of business logistics becomes a rational choice for e-business enterprises. However, when outsourcing booms in the urban logistics sector, for an e-business firm facing more carbon-sensitive customers, how should it achieve its lower footprint goals? Do its decisions impact its logistics partners? Why will 3PL invest in its own in low-carbon initiatives, but with its future benefits being enjoyed by e-business firms? How should we allocate low-carbon efforts' costs and benefits? For all the above questions, bargaining capabilities among 3PL and e-business firms, together with their coordination and cooperation mechanism are studied. Similar to relations among members of supply chains, in such a service chain composed of an e-business firm and a 3PL, game theory is an appropriate means to analyze their decision interactions and system balance. Greener product design, cleaner energy, and operation optimization can all help reduce carbon emission from manufacturing processes [3]. Bhaskaran et al. have studied cooperation among new product development members in a green supply chain background [4]. In the same context, Savaskan et al. have discussed manufacturer-leading waste goods recycling channels. In this research, selecting recycling channels corresponds to various strategies [5]. However, any internal emission reduction strategies for a single firm can hardly work effectively. The focus of carbon management should be put on a cooperation among partners of supply chains [6]. For example, 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 [7]. 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 [8]. To summarize, previous research seldom realized the low carbon effort motivation for the service system composed of an urban 3PL 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 should be better modeled. Meanwhile, except for 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 only cooperate in low carbon levels of their common logistics system.

The structure of this article is arranged as follows. The first part introduces as a whole the research background. In the second part, by introducing symbols for variables and parameters of the logistics system, its mathematical formulation is established. Subsequently, the third part discusses a total of five different game situations, including a partially cooperative game. Next, Nash Equilibria are found, analyzed and compared. The analytical results are presented in the fifth part. Finally, conclusions are formulated.

2. Notations and Mathematical Model

An urban 3PL and an e-business enterprise comprise the system that we studied. The marginal distribution cost for unit goods for the 3PL is c_1. It requires marginal profit of m_1. The outsourcing price the 3PL charged for its logistics service to the e-business enterprise is represented by p_1. 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.

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

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

Let us assume that the potential maximum market demand on the goods is D. From common economics theory, the actual demand of the goods relates to its price. As shown in Xie et al. [9], market demand q is assumed to be linearly related to market prices, just as the following Equation (3). Here d means market demand elasticity coefficient to price. 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 3PL tries to lower its carbon emissions to save costs and enhance company image in protecting the environment. Such an effort, obviously, belongs to a non-price element. It is often supposed to be nonlinearly related to market demand, just as in Savaskan et al. and Tsay et al. [10,11]. Generally speaking, the low-carbon levels of a distribution system shall rise gradually as policy guidance of governments and public environmental consciousness are strengthened. The low carbon level of the distribution system is l. Lower levels can benefit the 3PL due to better corporate image and customers' experiences. Sales will increase in return. For example, in Europe, a survey undertaken in 2008 shows that around 75% of customers are willing to pay more for environmentally-friendly products [12]. 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 ≥ 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 obtained, 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 that made by Bhaskaran et al. [4], and such an effect comes from diminishing returns of R & D activities of enterprises. Here we put it as a second-order equation [8]. It is assumed that only 3PL could improve the system's low carbon levels through its unilateral measures. The low carbon levels would not impact the 3PL's operation cost and marginal profit.

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

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

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

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, three types of non-cooperative game scenarios and two types of cooperative game scenarios will be discussed here.

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

In this scenario, the 3PL 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 opponent's profit function.

- 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 3PL firm is reduced to a follower. They decide their respective variables in the order of leader to follower.

- 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.

- 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 an active part in cooperation with the 3PL to improve 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 for the low carbon level of the system, they would return to the non-cooperative state again, deciding their respective marginal profit independently.

- 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 five 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.

4. Analytical Solution of Nash Equilibria

In this section, a total of five types of game playing scenarios will be discussed. There are three key endogenous variables, i.e., m_1, m_2 and l.

4.1.Scenario 1:LS Game

Backward induction is often applied to solve Stackelberg games. Namely, firstly the first-order and second-order derivative of the Equation (5) to variable m_2 are obtained as:

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

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

Obviously, it is concave in variable m_2. By letting the first-order derivative 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 value obtained from Equation (7).

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

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

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

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

The second-order principal minor of the Hessian matrix for Equation (4) on combined 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 combined variable (m_1, l). Therefore, let the two first order partial derivatives 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 are:

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

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

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 combined variable (m_2, l) are obtained.

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

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

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

When $4\tau d - a^2 > 0$, it is known that the Equation (4) is concave in (m_1, l). By letting the two first-order partial derivatives equal to 0, we obtain the following equations.

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

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

Combine them, and we obtain the following Equations (8) and (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 stricter constraint could be got $4d\tau - a^2 > 0$.

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

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

$$\frac{d^2 \Pi_l}{d{m_2}^2} = \frac{-4\tau d^2}{4d\tau - a^2} \leq 0$$

It can be seen that the Equation (5) in variable m_2 is concave. By letting its first-order derivative equal to 0, the optimal m_2 is obtained

$$m_2^{ES*} = \frac{D - dc_1 - dc_2}{2d}$$

Put it back into Equations (8) and (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 in scenario 2, firstly, partial derivatives of Equation (4) are solved to get Equations (8) and (9). Then as in scenario 1, Equation (7) is obtained by solving derivatives of Equation (5). Combining Equations (7)–(9), we get the optimal m_2.

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

Put it back into Equations (8) and (9), then we 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 derivative of Equation (4) to variable m_1 as follows.

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

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

Equation (4) is concave in variable m_1. Let its first-order partial derivative equal to 0 to get Equation (8). Next, as in Scenario 1, we solve the derivative of Equation (5) to m_2 to get Equation (7). Then by combining Equations (7) and (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 derivatives 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 derivative equal to 0, we get

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

Put it back into the above expressions 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 derivatives to united variables (m, l)

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

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

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

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 derivative equal to 0, we get

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

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

Combine the above two variables, it could easily be obtained as follows.

$$m^{FSCC*} = \frac{\tau((-d)(c_1 + c_2) + D)}{2d\tau - a^2/2} \tag{11}$$

$$l^{FSCC*} = \frac{a((-d)(c_1 + c_2) + D)}{4d\tau - a^2} \tag{12}$$

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

Table 1. Operational performance for the 3PL-e-business enterprise service system in five different game scenarios.

Variable	Scenario1	Scenario2	Scenario3	Scenario4	Scenario5
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	$\frac{\tau(D-c_2d-c_1d)}{4\tau d-\frac{a^2}{2}}$	$\frac{D-dc_1-dc_2}{2d}$	$\frac{\tau(D-dc_1-dc_2)}{3\tau d-\frac{a^2}{2}}$	$\frac{\tau(D-dc_1-dc_2)}{3\tau d-\frac{a^2}{3}}$	
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}	$\frac{4d\tau^2(D-dc_1-dc_2)^2}{(8\tau d-a^2)^2}$	$\frac{\tau(D-dc_1-dc_2)^2}{8\tau d-2a^2}$	$\frac{4d\tau^2(D-dc_1-dc_2)^2}{(6\tau d-a^2)^2}$	$\frac{9d\tau^2(D-dc_1-dc_2)^2}{(9\tau d-a^2)^2}$	–
$\Pi_{\mathrm{l+e}}$	$\frac{(12d\tau^2-\tau a^2)(D-dc_1-dc_2)^2}{(8\tau d-a^2)^2}$	$\frac{(12d\tau^2-3\tau a^2)(D-dc_1-dc_2)^2}{(8\tau d-2a^2)^2}$	$\frac{(8d\tau^2-\tau a^2)(D-dc_1-dc_2)^2}{(6\tau d-a^2)^2}$	$\frac{(18d\tau^2-\tau a^2)(D-dc_1-dc_2)^2}{(9\tau d-a^2)^2}$	$\frac{(4d\tau^2-\tau a^2)(D-dc_1-dc_2)^2}{(4\tau d-a^2)^2}$
q	$\frac{(a^2-6d\tau)(D-dc_1-dc_2)}{8\tau d-a^2}+D-dc_1-dc_2$	$\frac{(a^2-2d\tau)(D-dc_1-dc_2)}{8\tau d-2a^2}+\frac{D-dc_1-dc_2}{2}$	$\frac{(a^2-4d\tau)(D-dc_1-dc_2)}{6\tau d-a^2}+D-dc_1-dc_2$	$\frac{(a^2-6d\tau)(D-dc_1-dc_2)}{9\tau d-a^2}+D-dc_1-dc_2$	$\frac{(a^2-2d\tau)(D-dc_1-dc_2)}{4\tau d-a^2}+D-dc_1-dc_2$

5. Discussions and Several Propositions

Based on equilibria in the above table and constraints, through simple algebra calculations and comparisons, in total, four key propositions are obtained as follows.

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

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 the NA game. It is likely that in the LS game scenario, the 3PL shows even lower investment motivation for carbon reduction technologies.

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

It could be seen that each bargaining capability decides on their marginal profit, respectively. It would earn more if it could dominate the system. This well explains why in reality, either 3PL 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 in other games, or they will not choose to fully cooperate.

For the e-business firm, if it cannot 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 learn that 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 3PL is $\prod_l^{NA} < \prod_l^{LCNA} < \prod_l^{LS} < \prod_l^{FSCC}$; For thee-business enterprise, it is $\prod_e^{LS} < \prod_e^{LCNA} < \prod_e^{NA} \leq \prod_e^{ES} < \prod_e^{FSCC}$.

There is no doubt that the FSCC game scenario offers 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, the LCNA game scenario is inferior to pure NA game and therefore, in response to partial cooperation requests from the 3PL, 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 3PL-e-business firm service system. However, if the cooperation fails to achieve, the system shall evade the situation in which the 3PL 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 the fully non-cooperative situation, namely, the NA game scenario.

6. Conclusions

Considering the sales expansion effect brought about by low carbonization of the urban 3PL-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, a total of five types of game mechanisms are designed, particularly, including a partial cooperative situation. Not only are all Nash equilibria for five scenarios analytically solved, but through algebra calculation, four important propositions are obtained. From these propositions, the following conclusions are drawn.

Firstly, the system reaches its upmost performance under both sides' fully strategic cooperation scenario. When such a cooperation fails to fulfill, the second best choice is the e-business enterprise-leading Stackelberg game, which is superior to the other three game scenarios. Among all game scenarios, the 3PL-leading asymmetric game is the worst because of 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 the key propositions we obtained 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.

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