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Game Theory-Based Supplementary Collection Strategy for Industrial Buyers in a Local Agricultural Biomass Market

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Abstract

To disclose the mechanism of supplementary collection strategy for industrial buyers in a local agricultural biomass market, this paper presents a framework of the economic behaviors, goals and interests of stakeholders in the market, including investors, industrial buyers and so on, and applies the game theory to investigate the willingness of the supplier and the buyer to seek strategies for common interests. In the supplementary collection strategy, special emphasis was laid to the sustainability of biomass supply. It is discovered that a buyer can reap more profits through the supplementary collection strategy; owing to the long transport distance, however, the strategy fails to achieve highly efficient biomass utilization.

Key words

Material competition, Agricultural residues, Game theory, Biomass.

1. Introduction

With the boom of renewable resources in recent years, agricultural residues have become a popular source of energy other than raw materials. The agricultural residues are often utilized as biofuels or biomass in various other industries, such as power generation and papermaking. The involvement of stakeholders from different industries has complicated the collection strategy of agricultural biomass, making it difficult to for decision-makers to make proper decisions (cooperation, competition, or co-opetition) in the rising market of biomass. The complexity is reflected in three aspects: the features of local biomass market, the features of related industries, and the collection strategy of biomass.

Whereas very few studies have simultaneously taken the three aspects into account, this paper attempts to disclose the formation and implementation of supplementary collection strategy by stakeholders in a local agricultural biomass market. For this purpose, the author built a framework to explain the strategy-making by stakeholders in the market, depict the contexts of their actions, and reveal the dynamics of the biomass market. The game theory, as a useful tool of economic analysis [1-3], was introduced to model the framework.

The remainder of this paper is organized as follows. Section 2 discusses the biomass material competitions between industrial buyers. Section 3 introduces the game model of biomass collection strategy. Section 4 examines the game equilibrium and its conditions. Section 5 explains the collection strategy by comparative analysis. Section 6 wraps up this research with some meaningful conclusions.

2. Model Construction

2.1 Basic Assumptions on Biomass Distribution

In reference to previous research, the biomass distribution is assumed to satisfy the following conditions:

(A1) There is a large-scale distribution of agricultural biomass thanks to uniformly distributed crops;

(A2) The biomass output varies insignificantly with crop species and planting conditions;

(A3) The ratio of planted to non-planted land and the crop density are constant within the biomass collection area, and the agricultural biomass output per unit area is denoted as q_s (kg/m^2);

(A4) The crop growth period plus the biomass collection period equals one year, and the crop seasonality and climate factors are negligible;

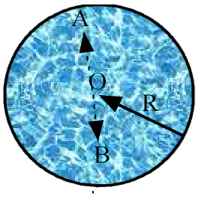
(A5) The transport cost is minimized by the circular shape of the biomass collection area; the radius and maximum radius of biomass collection are denoted as R and R^{max} (m), respectively; the equation $Q = kq_s\pi R^2$ (kg) holds, where $k(k \in [0,1])$ is the ratio of utilized biomass quantity to biomass output and Q is the collected biomass quantity.

The previous research on forest residues may provide some references to the systematic analysis on biomass supply. For instance, Gigler, Forsberg and Yoshioka [4-6] concluded that forest residues are more accessible than agriculture residues, and are often collected as industrial materials. As a promising energy source for rural households [7, 8], only part of agricultural residues is available for power generation and papermaking. Thus, the net availability of agricultural residues is much lower than that of forest residues. Although it is an important variable in the cost analysis of biomass material competition, the net availability does not need to be considered in the systematic analysis on biomass supply.

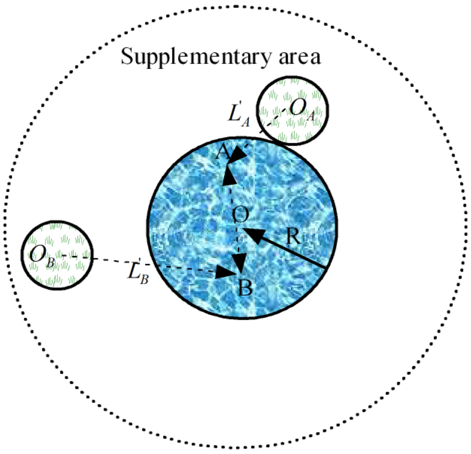
In addition to assumptions 1~5, another four assumptions were proposed for this research.

(A6) The transport cost is minimized by the circular shape of the two supplementary areas; the maximum radiuses of biomass collection of the two areas are denoted as $R_1^{\max}$ (m) and $R_2^{\max}$ (m), respectively.

In most countries, the biomass supply areas are distributed in a fragmented manner. The distributed is known as island distribution. The fragmented distribution must be considered in the modelling process, laying the basis of supplementary collection strategy.



(a) Main collection area



(b) Main collection area with Supplemetary collection

Legend: A,B - the locations of buyers in the main collection area
O, O_A, O_B -the central points of circular collection areas

Fig.1. Fragmented Distribution of Biomass Supply Areas

According to A5, the buyer prefers to buy the agricultural residues in a close range, and will not consider those in faraway places before the exhaustion of the close-range residues. As a result, the biomass collection area must be circular with a central storage facility at the centre to minimize the transport cost. The circular shape of the collection area not only offers an economic efficient operation flow, but also simplifies the transport of biomass from multiple storage facilities to the central storage facility and the mechanical/manual loading and unloading in the transport process. For convenience, it is assumed that the collection, transport and storage of the biomass in the circular collection area are undertaken by some large logistics firms (Figure 1(a)). Therefore, this research does not consider other complex or costly collection patterns.

2.2 Biomass Collection Cost and Pricing

The cost of a bioenergy system is incurred in the production, transport and energy conversion of biomass, and in the transmission of the bioenergy. The cost structure is generally site-specific, and connected with activities like forestry, forest industry, and agriculture.

The biomass collection should be priced in light of the four major costs of biomass collection:

(C1) The procurement cost of biomass: Each farm is a production unit of biomass. The biomass is procured at the same price from each farmer (excluding the transport cost). Because of the even distribution of agricultural residues across the region, the information is symmetric between the farmer and the buyer concerning the biomass price. The distance between the farm and the buyer has no impact on the procurement price of biomass. The equation $C_p = p_s \times Q$ holds, where P_s (\$/kg) is the unit procurement cost and C_p (\$) is the total procurement cost.

(C2) The transport cost from the farm to the central storage facility: the unit transport cost and the total transport cost are denoted as c_t (\$/ (kg·m)) and C_{TC} (\$), respectively.

(C3) The storage cost, including loading/unloading cost, labour remuneration and warehousing cost. The equation $C_0=c_0 \times Q$ holds, where c_0 is the unit storage cost (\$/ kg), and C_0 is the total storage cost.

(C4) The transport cost from the central storage facility to the buyer. This transport cost is linearly correlated with the demand, and is a part of the total biomass collection cost of the buyer Cc. The unit transport cost is still denoted as c_t (\$/ (kg·m)). The total biomass collection cost of the buyer is expressed as $C_c = C_p + C_{TC} + C_o = c_c \times Q$, where c_c is the per-unit total biomass collection cost of the buyer (\$/ kg).

Among the four costs of biomass collection, (C1)~(C3) lay the foundation for the pricing of biomass collection. (C2) and (C4) are primarily determined by the unit transport price and freight volume. The unit transport price is rarely affected by the competition between biomass suppliers and buyers in the local transport market. However, the proportion of the two transport costs (C2) and (C4) may vary with the freight forwarder, transport distance, road condition and transport mode. Suppose the biomass is transported in mini-vehicles from the farm to the central storage facility and in large vehicles from the central storage facility to the buyer. The transport distance is uncertain but within the biomass collection radius in the first segment, and constant in the second segment. Since the distances are rather stable, the biomass collection pricing is linearly correlated with the freight volume. Overall, there is little competition among (C1)~(C3), which are the bases for the pricing of biomass collection. Let a be the base price increment for selling biomass, and p be the inverse demand function, then the following lemma holds [8].

Lemma: According to the assumptions (A1)~(A5) and the total biomass collection cost (C1)~(C3), the inverse demand function is:

$$p = a + p_s + b\sqrt{Q} + c_o \tag{1}$$

□□□□

where b is defined as $\mathrm{b} = \frac{2c_t}{\sqrt[3]{\pi k q_s}}$.

□

2.3 Game Model Without Supplementary Collection

The game model without supplementary collection [3] was introduced to analyse the biomass collection strategy.

Suppose there is a supplier committed to collect, transport and store the biomass, and two buyers, a biomass power plant and a papermaking plant, willing to buy biomass in a local market. So, the biomass market is a monopoly in the upstream and a duopoly in the downstream. The game between the supplier and the buyers is based on price, while that between the two buyers is centred on volume. Because the product volume is linearly correlated with the biomass material, the buyers' decisions are limited to the choice of the volume of biomass material.

The profit functions of the supplier and the buyers involve the following variables.

$p_j, j = A, B$: The highest acceptable price of the buyers; $q_j, j = A, B$: The total volume of available biomass, provided that $q_A \geq 0, q_B \geq 0, q = q_A + q_B \geq 0$; $d_j, j = A, B$: The distance from the central storage facility to buyer j; $C'_{t,j}, j = A, B$ ($C'_{t,j} = c_t d_j q_j$): The transport cost from the central storage facility to the buyer j (\$); $\pi_j, j = A, B$: the profit function of the buyers.

Game model (1):

The profit function of the supplier is expressed as:

$$\pi_1 = a(q_A + q_B) \tag{2}$$

The profit functions of the buyers are expressed as:

$$\begin{aligned}\pi_A &= (p_A - p - C'_{t,A})q_A \\ &= (p_A - p_s - c_0 - a - b\sqrt{q_A + q_B} - c_t d_A)q_A \\ &= (p'_A - a - b\sqrt{q_A + q_B})q_A\end{aligned} \tag{3}$$

$$\begin{aligned}\pi_B &= (p_B - p - C'_{t,B})q_B \\ &= (p_B - p_s - c_0 - a - b\sqrt{q_A + q_B} - c_t d_B)q_B \\ &= (p'_B - a - b\sqrt{q_A + q_B})q_B\end{aligned} \tag{4}$$

where p'_A and p_p are defined as $p'_A = p_A - p_s - c_O - c_t d_A$ and $p'_B = p_B - p_s - c_O - c_t d_B$, respectively.

Definition 1:

$p'_A - a$ is defined as a fixed profit space for buyer A, and $p'_B - a$ as a fixed profit space for buyer B. Since $p'_A - a$ peaks at a=0, p'_A is the maximum fixed profit space for buyer A; Similarly, p'_B is the maximum fixed profit space for buyer B.

The above definition ignores the unit transport costs correlated with demand volumes.

The timing of the game:

Stage 1: Based on the given price increment, the buyers respectively seeks the Nash equilibrium of biomass volume under Cournot competition for the maximum profits.

Stage 2: The supplier seeks the Nash equilibrium of price increment under the Nash equilibrium solution in Stage 1.

2.4 Game Model with Supplementary Collection

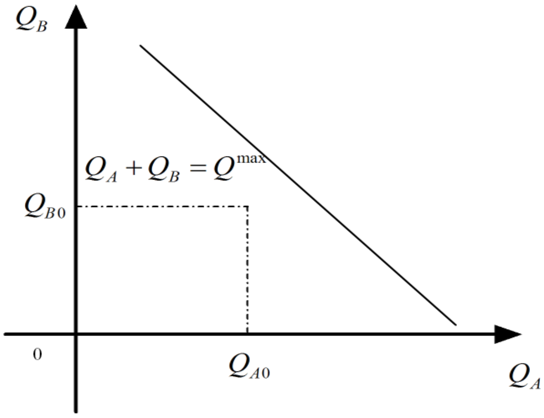
In order to model the game with supplementary collection, it is necessary to introduce the following assumptions of the goals of the buyers.

(A7) The buyers are competing to monopolize resources. The demand of each buyer is less than the maximum output of the main collection area, but the combined demand of the two buyers exceeds the said maximum output. This calls for supplementary collection from neighbouring areas.

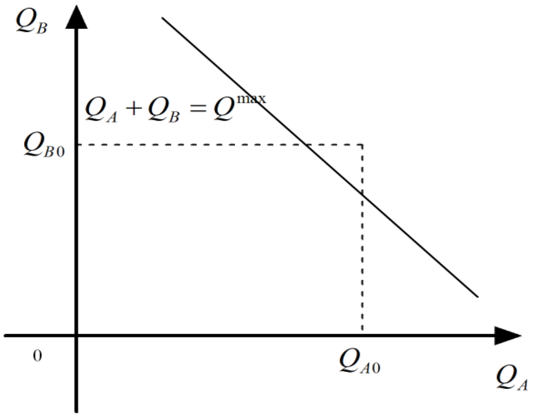
Then, assumption A7 was transformed into parameter constraints of the game model: $Q_{A0} \le Q^{Max}$, $Q_{B0} \le Q^{Max}$ and $Q_{A0} + Q_{B0} > Q^{Max}$.

Below are the variables related to the profit functions of the supplier and the buyers in the supplementary collection area.

$p_j, j = A, B$: The highest acceptable price of the buyers; $Q_j, j = A, B$: The total volume of available biomass, provided that $Q_A \ge 0, Q_B \ge 0, Q = Q_A + Q_B \ge 0$; $d_j, j = A, B$: The distance from the central storage facility to buyer j; $L'_j, j = A, B$: The distance from the supplementary storage facility to buyer j; $C'_j, j = A, B$ ($C'_j = c_t d_j Q_j$ for the main collection area; $c'_t L'_j$ for the supplementary collection area): The transport cost from the central storage facility to the buyer j (\$); $\pi_j, j = A, B$: The profit function of the buyers; a,l,m: The price increments for selling the biomass.



(a) Goal of sharing resource



(b) Goal of monopolizing resource

Fig.2. Goals of the Buyers

(A8) A longer distance has to be covered if the biomass is collected in the supplementary collection area instead of the main collection area: $L'_A \geq d_A$,and $L'_B \geq d_B$. The unit transport cost of biomass collected from the supplementary collection area is greater than that of biomass collected from the main collection area: $c'_t L'_A \geq c_t d_A$ and $c'_t L'_B \geq c_t d_B$.

It can be easily deduced that:

$$p_l = l + p_s + b' \sqrt{Q''_A} + c_o \tag{5}$$

$$p_m = m + p_s + b' \sqrt{Q''_B} + c_o \tag{6}$$

where $b' = \dfrac{2c_t'}{3\sqrt{\pi k q_s'}}$.

Game model (2):

The profit functions of the supplier are expressed as follows:

If the supplier is in the main collection area

$$\Pi_1 = a(Q'_A + Q'_B) \tag{7}$$

If the supplier is in the supplementary collection are of buyer A

$$\Pi_l = lQ''_A \tag{8}$$

If the supplier is in the supplementary collection are of buyer B

$$\Pi_m = mQ''_B \tag{9}$$

The profit functions of the buyers are:

$$\begin{aligned}\Pi_A &= (p_A - p - c_t d_A)Q'_A + (p_A - p_l - c_t' L'_A)Q''_A \\ &= (p_A - a - p_s - c_o - c_t d_A - b\sqrt{Q'_A + Q'_B})Q'_A + (p_A - l - p_s - c_o - c_t' L'_A - b'\sqrt{Q''_A})Q''_A \\ &= (p'_A - a - b\sqrt{Q'_A + Q'_B})Q'_A + (p''_A - l - b'\sqrt{Q''_A})Q''_A\end{aligned} \tag{10}$$

$$\begin{aligned}\Pi_B &= (p_B - p - c_t d_B)Q'_B + (p_B - p_m - c_t' L'_B)Q''_B \\ &= (p_B - a - p_s - c_o - c_t d_B - b\sqrt{Q'_A + Q'_B})Q'_B + (p_B - m - p_s - c_o - c_t' L'_B - b'\sqrt{Q''_B})Q''_B \\ &= (p'_B - a - b\sqrt{Q'_A + Q'_B})Q'_B + (p''_B - m - b'\sqrt{Q''_B})Q''_B\end{aligned} \tag{11}$$

where p'_A, p''_A, p'_B, p''_B are defined as $p'_A = P_A - P_s - c_0 - c_t d_A$, $p''_A = P_A - P_s - c_0 - c'_t L'_A$, $p'_B = P_B - P_s - c_0 - c_t d_B$ and $p''_B = P_B - P_s - c_0 - c'_t L'_B$.

The timing of the game:

Stage 1: Based on the given price increment, the buyers respectively seeks the Nash equilibrium of biomass volume under Cournot competition for the maximum profits.

Stage 2: The supplier seeks the Nash equilibrium of price increment under the Nash equilibrium solution in Stage 1.

Stage 3: The supplier in the supplementary collection area seeks the Nash equilibrium of price increment under the Nash equilibrium solution in Stage 1.

3. Game Equilibria and Conditions

If the optimal solution of $q_j, j = A, B$ is $q_j^*, j = A, B$ and the optimal solution of base price increment is a^*, it is possible to derive the following two propositions mentioned in previous research.

Proposition 1

If the biomass distribution satisfies (A1)~(A5) and the total biomass collection cost consists of (C1)~(C4), then there exists only one subgame perfect equilibrium solution of game model (1):

Buyer A:

$$q_A^* = \frac{4}{225b^2}(p_A^{'} + p_B^{'})(17p_A^{'} - 13p_B^{'}) \tag{12}$$

Buyer B:

$$q_B^* = \frac{4}{225b^2}(p_A^{'} + p_B^{'})(17p_B^{'} - 13p_A^{'}) \tag{13}$$

The supplier:

$$a^* = \frac{(p_A^{'} + p_B^{'})}{6} \tag{14}$$

Proposition 2

If the biomass distribution satisfies (A1)~(A5) and the total biomass collection cost consists of (C1)~(C4), then the profits of the supplier and the buyers under the equilibrium solution of game model (1) are as follows:

$$\pi_A^* = \frac{\pi k q_s}{750c_t^2}(p_A^{'} + p_B^{'})(17p_A^{'} - 13p_B^{'})^2 \tag{15}$$

$$\pi_B^* = \frac{\pi k q_s}{750c_t^2}(p_A^{'} + p_B^{'})(17p_B^{'} - 13p_A^{'})^2 \tag{16}$$

$$\pi_1^* = \frac{2\pi k q_s}{75 c_t^2}(p_A^{'} + p_B^{'})^3 \tag{17}$$

The total profit is:

$$\pi^* = \pi_1^* + \pi_A^* + \pi_B^* = \frac{\pi k q_s}{375 c_t^2}(p_A^{'} + p_B^{'})[239(p_A^{'})^2 - 422 p_A^{'} p_B^{'} + 239(p_B^{'})^2] \tag{18}$$

If the optimal solutions of $Q_j^{'}$ and $Q_j^{''}, j = A, B$ are $Q_j^{'*}$ and $Q_j^{''*}, j = A, B$, respectively, and the optimal solutions of base price increments are a^*, l^*, m^*, respectively, it is possible to derive the following propositions.

Proposition 3

If the biomass distribution satisfies (A1)~(A8) and the total biomass collection cost consists of (C1)~(C4), then there exists only one subgame perfect equilibrium solution of game model (2):

Buyer A:

$$Q_A^{'*} = \frac{4}{225 b^2}(p_A^{'} + p_B^{'})(17 p_A^{'} - 13 p_B^{'}) + \frac{16}{81(b^{'})^2}(p_A^{''})^2 \tag{19}$$

Buyer B:

$$Q_B^{'*} = \frac{4}{225 b^2}(p_A^{'} + p_B^{'})(17 p_B^{'} - 13 p_A^{'}) + \frac{16}{81(b^{'})^2}(p_B^{''})^2 \tag{20}$$

The supplier in the main collection area

$$a^* = \frac{(p_A^{'} + p_B^{'})}{6} \tag{21}$$

The supplier in the supplementary collection area of buyer A:

$$l^* = \frac{p_A^{''}}{3} \tag{22}$$

The supplier in the supplementary collection area of buyer B:

$$m^* = \frac{p_B^{''}}{3} \tag{23}$$

Proposition 3 implies that price increments of the supplier in the main collection area are dependent on both buyers, while those of the supplier in each supplementary area are dependent on the corresponding buyer. When the above-mentioned conditions are satisfied, the volumes demanded by the buyers are abound to increase. At the same time, the profits of the buyers will also grow, as per Proposition 4 below.

Proposition 4

If the biomass distribution satisfies (A1)~(A8) and the total biomass collection cost consists of (C1)~(C4), then the profits of the supplier and the buyers under the equilibrium solution of game model (2) are as follows:

$$\Pi_A^* = \frac{\pi k q_s}{750 c_t^2}(p_A^{'} + p_B^{'})(17 p_A^{'} - 13 p_B^{'})^2 + \frac{8\pi k q_s}{81(c_t^{'})^2}(p_A^{''})^3$$

$$\Pi_B^* = \frac{\pi k q_s}{750 c_t^2}(p_A^{'} + p_B^{'})(17 p_B^{'} - 13 p_A^{'})^2 + \frac{8\pi k q_s}{81(c_t^{'})^2}(p_B^{''})^3 \tag{24}$$

$$\Pi_1^* = \frac{2\pi k q_s}{375 c_t^2}(p_A^{'} + p_B^{'})^3 \tag{25}$$

$$\Pi_l^* = \frac{4\pi k q_s}{27(c_t^{'})^2}(p_A^{''})^3 \tag{26}$$

$$\Pi_m^* = \frac{4\pi k q_s}{27(c_t^{'})^2}(p_B^{''})^3 \tag{27}$$

The total profit is:

$$\Pi^* = \Pi_1^* + \Pi_l^* + \Pi_m^* + \Pi_A^* + \Pi_B^* = \frac{\pi k q_s}{375 c_t^2}(p_A^{'} + p_B^{'})[239(p_A^{'})^2 - 422 p_A^{'} p_B^{'} + 239(p_B^{'})^2] + \frac{20\pi k q_s}{81(c_t^{'})^2}[(p_A^{''})^3 + (p_B^{''})^3] \tag{28}$$

Propositions 3 and 4 imply more complex results than Proposition 1. There are three possible cases that the equilibrium demand volume is consistent with the production capacity of the buyers:

(1) $Q_A^* + Q_B^* \le Q^{Max} \le Q_{A0} + Q_{B0}$: the buyers can maximize the profit without supplementary collection of biomass.

(2) $Q^{Max} \le Q_A^* + Q_B^* \le Q_{A0} + Q_{B0}$: the buyers can maximize the profit with the biomass supply in the main collection area and the supplementary area. In this case, it is possible that the buyers reach the maximum profit before reaching the production capacity.

(3) $Q^{Max} \le Q_{A0} + Q_{B0} \le Q_A^* + Q_B^*$: the buyers can reach the production capacity before maximizing the profit.

Under a given production capacity, the buyers with supplementary collection is more likely to maximize the profit than those relying on the main collection only.

Corollary 1

If the biomass distribution satisfies (A1)~(A5) and the total biomass collection cost consists of (C1)~(C4), then the equilibrium conditions of the game is:

$$c_t \ge \frac{2}{5R^{\max}}[p_A^{'} + p_B^{'}] \tag{29}$$

Corollary 1 was mentioned in the previous research [3]. It implies that the minimum unit transport cost is positively correlated with the highest acceptable price of the buyers and negatively correlated with their locations in a circular collection area with the given radius R^{max}. The corollary is another feature of circular biomass market. If this condition is not satisfied, the game will not reach equilibrium.

(A9) The main collection area and the supplementary collection area have the same maximum radius: $R^{\max} = R_1^{\max} = R_2^{\max}$. This means the maximum supplementary supply of each buyer equals the maximum supply in the main collection area.

Corollary 2

If the biomass distribution satisfies (A1)~(A9) and the total biomass collection cost consists of (C1)~(C4), then the equilibrium conditions of the game is:

$$c_t^{'} \ge \frac{2\max(p_A^{''}, p_B^{''})}{3R^{\max}} \tag{30}$$

Corollary 2 implies that the minimum unit transport cost is positively correlated with the highest acceptable price of the buyers and negatively correlated with their locations in a circular collection area with the given radius R^{max}. The corollary is another feature of circular biomass market. If this condition is not satisfied, the game will not reach equilibrium.

The freight forwarders are not decision-makers in our model. In the completely competitive transport market, they have no reason to deviate from the game equilibrium. Hence, it is assumed that:

$$c_t = \frac{2[p_A^{'} + p_B^{'}]}{5R^{\max}} \tag{31}$$

$$c_t^{'} = \frac{2\max(p_A^{''}, p_B^{''})}{3R^{\max}} \tag{32}$$

Due to the competition in the main collection area, the transport price in the main collection area is generally higher than that in the supplementary collection area, indicating that $c_t \geq c_t'$ is a rational assumption. For instance, when $p_A' = p_B' = p_A'' = p_B''$, $c_t = \frac{4p_A^{'}}{5R^{\max}} > \frac{2p_A^{'}}{3R^{\max}} = c_t^{'}$.

The ratio of maximum fixed profit space between buyer A and buyer B is defined below.

$$n = \frac{p_A^{'}}{p_B^{'}} \tag{33}$$

The ratio reflects the degree of biomass price competition between buyers.

Corollary 3

If the biomass distribution satisfies (A1)~(A9) and the total biomass collection cost consists of (C1)~(C4) in the case of no supplementary collection, then we have:

$$n \in \left[\frac{13}{17}, \frac{17}{13}\right] \tag{34}$$

4. Downstream Competition Analysis

Corollary 4

If the biomass distribution satisfies (A1)~(A5) and the total biomass collection cost consists of (C1)~(C4) in the case of no supplementary collection, then we have:

$$\frac{\pi_A^*}{\pi_B^*} = \left(\frac{q_A^*}{q_B^*}\right)^2 < 1,\ \forall\ n \in (\frac{13}{17}, 1) \tag{35}$$

$$\frac{\pi_A^*}{\pi_B^*} = \left(\frac{q_A^*}{q_B^*}\right)^2 \geq 1,\ \forall\ n \in [1, \frac{17}{13}] \tag{36}$$

The maximum fixed profit spaces p'_A and p'_B are determined by the highest acceptable prices for the buyers, and the transport price. Although they are not variables for decision-makers in models (1) and (2), the two parameters enable the buyers and freight forwarders to influence the game equilibrium. As implied in Corollary 4, the buyer with the potential to enhance the highest acceptable prices, whether by technology improvement or management enhancement, is more likely to push up these prices, and increase the value n. In this scenario, the buyer cannot possess more biomass supply in the main collection area or enjoy faster profit growth than its competitor. As the ratio of maximum fixed profit space grows, the buyers will receive more profit than its competitor. However, if n reaches the bounds of the interval $\left[\frac{13}{17},\frac{17}{13}\right]$, the volume of a buyer will become zero and the market structure of the buyers will become a monopoly in reality.

Corollary 5

If the biomass distribution satisfies (A1)~(A9) and the total biomass collection cost consists of (C1)~(C4), then $q_A^* \le Q_A^*$, $q_B^* \le Q_B^*$, $\pi_A^* \le \Pi_A^*$ and $\pi_B^* \le \Pi_B^*$.

Corollary 5 implies that the equilibrium volume of the buyers with supplementary collection strategy is greater than that without the strategy, and the buyers reap more profits through the supplementary collection strategy.

Conclusions

In the agricultural biomass market, all stakeholders are pursuing efficient use of agricultural residues against fierce competition for raw materials. This calls for a sustainable and rational biomass collection. One of the viable options is the supplementary collection strategy. However, whether supplementary collection fits the local biomass market has long perplexed stakeholders like planners and investors.

To answer the question, this paper explores the competition mechanism in local biomass market by the game analysis, considering the goals and interests of industrial buyers. The theoretical conclusions are as follows. First, in an independent biomass market, the buyer with the potential to enhance the highest acceptable prices, whether by technology improvement or management enhancement, is more likely to push up these prices. Second, in a local market with supplementary collection area, the buyers can receive more profits than in an independent biomass market, but the strategy fails to achieve highly efficient biomass utilization owing to the long transport distance. The research findings shed new light on the features of biomass market, and provide meaningful references to investors and planners.

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