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# Choice Game of Collection Strategies in Agricultural Biomass Supply Market

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**Abstract:** This study studies the difference among three collection strategies for agricultural biomass, i.e., commitment strategy, pure competition strategy and vertical integration strategy. Unlike existing research that is much reported research on qualitative analysis, this study use the method of mathematical analysis and further explain the interaction of the players and its impact on the benefits, which can be offered by game theory. The study of collection strategies for industrial buyers is of critical importance to realize the development potentials of agricultural biomass and its related industries. Firstly, the assumptions of biomass distribution, cost structure and market structure are applied to describe the agricultural biomass market, this lead to a monotonous increasing inverse demand function that is different from the past research. Secondly, commitment strategy, pure competition strategy and vertical integration strategy are modeled with game theory to explore equilibrium quantities and profits. Thirdly, equilibrium quantities and profits among the three collection strategies are compared to show the co-existence conditions of market structure and their differences. As a result, pure competition strategy is the most efficient strategy among the three; commitment strategy will bring the most aggregate biomass supply but is less efficient than pure competition strategy; vertical integration will bring secure biomass supply for integrated industrial buyer but it is at the sacrifice of aggregate profits of all decision makers, especially the profit of non-integrated industrial buyer.

**Key words:** Agricultural biomass, collection strategic choice, supply chain market

## INTRODUCTION

In the agriculture sector, the supply of biomass resources for industrial buyers may help to alleviate rural poverty especially in developing regions (Verdonk *et al.*, 2007; Altman and Johnson, 2008). But agricultural biomass supply exchanges are less mature than other biomass market (Altman and Johnson, 2008) and if many invested projects using biomass as inputs are involved in local biomass supply market, the resource competition will take place (Narodoslawsky *et al.*, 2008; Korhonen, 2001), meaning there is possibly more than one industrial buyers in the market.

It is widely accepted that players in biomass supply market, such as farmers, biomass suppliers, biomass power plants, social planners and transporters, will benefit from the formulation and operation of a local biomass market (Illsley *et al.*, 2007). Here are five types of players in the biomass supplying market, among which biomass suppliers and industrial buyers (e.g. biomass power plants) have direct interests and market power, thus be regarded as decision-makers in the market, farmers, social planners and transporters are regarded as general participants because they have little impact on the market price of biomass supply. It is concluded that each player would seek profit maximization in agricultural biomass supply market, but only the decision makers are able to maximize their profits (Sun and Hou, 2009).

Simply there are three types of profit maximization principles for decision makers in agricultural biomass supply market, i.e., individual maximization, allied maximization and overall maximization, which are corresponding to three kinds of biomass collection strategies for industrial buyers, i.e. competition strategy, vertical integration strategy (price alliance strategy) and commitment strategy. These collection strategies, which interact with the formulation of agricultural biomass market (abbr. ABM), have great impacts on adequate biomass supply and profit maximization of industrial buyers and can be figured out in three perspectives.

Firstly, there are large supply and demand potentials of agricultural biomass, but barriers to formulate biomass market are also many (Huacuz, 2005; Sherrington *et al.*, 2008). To induce investment by producers, processors could be required to offer more committed relationship. Observability means that each downstream industrial buyer knows the quantity offered to the other firm when deciding accept its own contract (Baake *et al.*, 2002). This implies that the priority of government who aims to maximize the social welfare by selling adequate agricultural biomass to every industrial buyer is feasible, while profit maximizations of suppliers and industrial buyers would be secondly arranged. The viewpoint usually prevails when biomass utilization is introduced and commitment strategy is proper collection strategy for the market formulation.

Secondly, because the agricultural biomass transaction, with many unknown producers, can involve higher transaction costs than in other more established markets, a competitive market framework that is fit to agricultural biomass supply is required to assure the equivalence of price and marginal cost (Klevas *et al.*, 2009). Biomass producers will prefer to utilize spot market, so they are free to sell or use the product depending on the highest value. Competition strategy is viable collection strategy for industrial buyers when the market is formulated and operated. This is also evidenced by the research that around 25% bio power plants get fuels completely from spot market.

Thirdly, the monopolizing resource goals of downstream industrial players will exert great impact on the raw material competition. Some researchers select organizational economic theory demonstrate the organizational perspective applied to future agro-bioenergy industries, for example, vertical integration strategy is recommended to industrial buyers for cooperation between upstream supplier downstream buyers in the research (Downing, *et al.*, 2005), which is a more effective approach for is an alternative for monopolizing resource goals than competition strategy. There leaves some problems to the players in ABM. Why commitment strategy is proper for the market formulation? What are the conditions for efficient competition strategy? What are the conditions for adopting vertical integration strategy?

There is much reported research on qualitative analysis and further mathematical analysis is needed to explain the interaction of the players and its impact on the benefits, which can be offered by game theory. The study of collection strategies for industrial buyers is of critical importance to realize the development potentials of agricultural biomass and its related industries.

To address the limitations described above, a methodology is presented in the research which: (1) Incorporates the commitment theory and industrial organization theory in agricultural biomass supply, including quantities and prices in material competition, to depict the main feedstock collection approaches, (2) Introduces game theory to model the local supply market of agricultural biomass, (3) Compares the total equilibrium quantities, total equilibrium profits among commitment, competition and vertical integration strategies for industrial buyers in ABM.

This research aims to reveal the conditions for main biomass collection strategies of industrial buyers in agricultural biomass supply market.

In Section 2, the basic assumption on biomass distribution and cost structure are made, the model of three collection strategies are introduced; the first model is constructed on the basis of profit maximization for all the decision makers, which is an approximate measurement of social welfare; the second model on competition strategy is constructed as a game among one upstream supplier and two downstream industrial buyers; the third model describes the integration between one supplier and one industrial buyer, while the other industrial buyer get the supply from spot market. In Section 3, the equilibrium results on biomass quantities, decision-makers' profits are compared. In Section 4, conclusions are made.

## MODEL CONSTRUCTIONS

**Assumptions and variables:** Consider a market with one upstream supplier U and two downstream industrial buyers $D_j$, j = A, B and suppose that downstream buyers compete in quantities. $Q_j$ is the agricultural biomass demand of the industrial buyer j.

Biomass distribution is assumed to satisfy the following assumption.

**Assumption 1:** There is quite a large-scale distribution of agricultural biomass; the variety of crops and planting conditions resulting in differences in biomass outputs are not significant; crops are uniformly distributed; the ratio of planted land to non-planted land and the density of the crops are not variable within the collection area, agricultural biomass output in unit area is described as $q_s$ (kg $m^{-2}$); the crop growth period and the corresponding collection period of agricultural biomass is one year, therefore the seasonality of different kinds of crops and climate factors are not considered in the model; the biomass collection area should be circular in order to minimize transportation costs, maximum radius of straw collection is $R^{max}$ (m) and radius of straw collection is R (m); if ratio of utilized biomass quantity to biomass output is k ($k \in [0, 1]$) and collected quantity of biomass is Q, then it holds that $Q = kq_s\pi R^2$ (kg).

Pricing is based on different kinds of collection costs, which are comprised of four parts listed in the following assumption:

**Assumption 2:** The procurement cost of biomass from farmers $C_p$ (RMB Yuan). $C_p = p_s \times Q$, wher $p_s$ (RMB Yuan kg$^{-1}$) represents procurement price for biomass from farmers; the transportation cost from farms to the storage facility.

Let $\alpha$ be base price increment for selling biomass and p be the inverse demand function, the following Lemma holds.

**Lemma 1:** If the assumptions on biomass distribution and agricultural biomass suppliers' costs are satisfied, the inverse demand function is:

$$p = a + p_s + b\sqrt{Q} + c_0 \tag{1}$$

where, b is defined as:

$$b = \frac{2c_t}{3\sqrt{\pi k q_s}}$$

Lemma 1 means that circular area assumptions on ABM lead to a monotonous increasing inverse demand function, which does not belong to those cost functions discussed in the research (Klevas *et al.*, 2009), including convex cost function, linear cost function and linear-quadratic cost function.

**Definition 1:** $p_{j'} = p_j\text{-}p_s\text{-}c_0\text{-}c_t{}'d_j$, j = A, B are defined as profit space. $p_{j'}\text{-}\alpha$,j = A, B are defined as fixed profit space.

**Assumption 3:** $p_{j'}>0$, j = A, B. To measure the competitiveness of the two industrial buyers in cost structure, the following definition is introduced.

**Definition 2:** The maximum fixed profit space ratio of downstream buyer A to buyer B is defined as follows and can be used to measure the degree of downstream price competition for agricultural residues:

$$n = \frac{p_A^{'}}{p_B^{'}} \tag{2}$$

**Game model with commitment strategy:** A simple commitment device is observable contracts proposed in the research [5], which implies that each $D_j$ knows the quantity offered to the other buyer when deciding whether to accept its own contract. Hence, in a sub game perfect equilibrium, $D_j$ will accept any offer ($Q_j$, $\pi_j^{CM}$) which have been similarly mentioned in the research (Klevas *et al.*, 2009). U is committed to choose ($Q_j$, $\pi_j^{CM}$) such that total industry profit $\pi^{CM}$ are maximized. The common cost assumptions for downstream buyers imply that U offers equal quantity to both $D_j$ = A, B, , i.e., $Q_A = Q_B$ in commitment case and $Q^{CM} = Q_A+Q_B$.

The profit function for biomass material supplier is:

$$\pi_U^{CM} = a(Q_A + Q_B) \tag{3}$$

The profit functions of the biomass power plant and study mills are:

$$\pi_j^{CM} = (p_j - p - C_{t,j}^{'})Q_j = (p_j^{'} - a - b\sqrt{Q_A + Q_B})Q_j,\ j = A,B \tag{4}$$

$$\pi^{CM} = \pi_U^{CM} + \pi_A^{CM} + \pi_B^{CM} = \left(\frac{p_A^{'} + p_B^{'}}{2} - b\sqrt{Q^{CM}}\right)Q^{CM} \tag{5}$$

$$\begin{gathered}\frac{\partial \pi^{CM}}{\partial Q^{CM}} = \frac{p_A^{'} + p_B^{'}}{2} - b\sqrt{Q^{CM}} - \frac{b}{2}\sqrt{Q^{CM}} = 0 \\ Q^{CM*} = \frac{(p_A^{'} + p_B^{'})^2}{9b^2}\end{gathered} \tag{6}$$

The maximum of all the decision makers is:

$$\pi^{CM*} = \frac{(p_A^{'} + p_B^{'})^3}{54b^2} = \frac{\pi k q_s}{24c_t^2}(p_A^{'} + p_B^{'})^3 \tag{7}$$

**Game model with pure competition strategy:** In pure competition case, contracts are not observable, i.e. ($Q_{j,\ \pi j}{}^{PC}$) is secretly offered to $D_j$, j = A, B, which is a game of incomplete information. The rival of $D_j$ is assumed to be offered the equilibrium contract independently of its own contract. With secret contracts and incomplete information, $D_j$, j = A, B accept ($Q_j$, $\pi_j^{PC}$) with $\pi_j^{PC} \leq \pi_j^{PC}$ ($Q_i^{PC*}$, $Q_j$), i≠j, U and $D_j$, j = A, B maximize their profits through a two-stage game.

The profit function for biomass material supplier is:

$$\pi_U^{PC} = a(Q_A + Q_B) \tag{8}$$

The profit functions of the biomass power plant and study mills are:

$$\pi_j^{PC} = (p_j - p - C_{t,j}^{'})Q_j = (p_j^{'} - a - b\sqrt{Q_A + Q_B})Q_j,\ j = A,B \tag{9}$$

**Timing of game:**

- **Stage 1:** The downstream buyers seek individual Nash equilibrium biomass quantity under Cournot game based on the any given price increment for the maximum profits
- **Stage 2:** The upstream supplier seeks Nash equilibrium price increment under Nash equilibrium solution in Stage 1

The equilibrium quantities and profits for the above game are listed as follows:

- For biomass buyer A:

$$Q_A^{PC*} = \frac{4}{225b^2}(p'_A + p'_B)(17p'_A - 13p'_B) \tag{10}$$

- For biomass buyer B:

$$Q_B^{PC*} = \frac{4}{225b^2}(p'_A + p'_B)(17p'_B - 13p'_A) \tag{11}$$

- For biomass material supplier:

$$Q^{PC*} = Q_A^{PC*} + Q_B^{PC*} = \frac{16}{225b^2}(p'_A + p'_B)^2 \tag{12}$$

$$a^* = \frac{(p'_A + p'_B)}{6} \tag{13}$$

$$\pi_A^{PC*} = \frac{\pi k q_s}{750c_t^2}(p'_A + p'_B)(17p'_A - 13p'_B)^2 \tag{14}$$

$$\pi_B^{PC*} = \frac{\pi k q_s}{750c_t^2}(p'_A + p'_B)(17p'_B - 13p'_A)^2 \tag{15}$$

$$\pi_U^{PC*} = \frac{2\pi k q_s}{375c_t^2}(p'_A + p'_B)^3 \tag{16}$$

$$\begin{aligned}\pi^{PC*} &= \pi_U^{PC*} + \pi_A^{PC*} + \pi_B^{PC*} \\ &= \frac{\pi k q_s}{375c_t^2}(p'_A + p'_B) \times [231(p'_A)^2 - 217p'_A p'_B + 231(p'_B)^2]\end{aligned} \tag{17}$$

The results imply that the critical parameters of the profits, $p'_A$ and $p'_B$ are positively related to the total profit, while $c_t$ is negatively related to the total profit.

**Game model with vertical integration strategy:** The vertical integration is assumed between U and $D_A$, the profit maximization is prior to that of non-integrated buyer $D_B$.

The profit function for biomass material supplier is:

$$\pi_U^{VI} = xQ_A + aQ_B \tag{18}$$

The profit functions of the biomass power plant and study mills are:

$$\pi_A^{VI} = (p_A - p_x - C'_{t,A})Q_A = (p'_A - x - b\sqrt{Q_A + Q_B})Q_A \tag{19}$$

$$\pi_B^{VI} = (p_B - p - C'_{t,B})Q_B = (p'_B - a - b\sqrt{Q_A + Q_B})Q_B \tag{20}$$

We have:

$$Q^{VI} = \frac{4}{25b^2}\left(p'_A + p'_B - a\right)^2 \tag{21}$$

$$Q_A^{VI*} = \frac{4}{25b^2}\left(p'_A + p'_B - a\right)\left(3p'_A - 2p'_B + 2a\right) \tag{22}$$

$$Q_B^{VI*} = \frac{4}{25b^2}\left(p'_A + p'_B - a\right)\left(3p'_B - 2p'_A - 3a\right) \tag{23}$$

The profit of allied downstream buyer and supplier is:

$$\pi_{U+A}^{VI} = \frac{4}{125b^2}\left(p'_A + p'_B - a\right)\left[-11a^2 + \left(2p'_A + 7p'_B\right)a + \left(3p'_A - 2p'_B\right)^2\right]$$

By differentiating the profit of alliance:

$$\frac{\partial \pi_{U+A}^{VI}}{\partial a} = \frac{4}{125b^2}\left[33a^2 - \left(26p'_A + 36p'_B\right)a + \left(-7(p'_A)^2 + 21p'_A p'_B + 3(p'_B)^2\right)\right] = 0$$

Considering:

$$\frac{\partial^2 \pi_{U+A}^{VI}}{\partial a^2} < 0$$

for any $\alpha^* \in [0, +\infty)$, We have:

$$a^* = \frac{13p'_A + 18p'_B - 5\sqrt{16(p'_A)^2 - 9p'_A p'_B + 9(p'_B)^2}}{33} \tag{24}$$

$$\begin{aligned}Q^{VI*} &= \frac{4}{25b^2}\left(p'_A + p'_B - a^*\right)^2 \\ &= \frac{4}{1089b^2}\left(4p'_A + 3p'_B + \sqrt{16(p'_A)^2 - 9p'_A p'_B + 9(p'_B)^2}\right)^2\end{aligned} \tag{25}$$

$$\begin{aligned}\pi_{U+A}^{VI*} = {} & \frac{4}{125b^2}\left(\frac{20p'_A + 15p'_B + 5\sqrt{16(p'_A)^2 - 9p_A p_B + 9(p'_B)^2}}{33}\right) \\ & \times \left[\begin{aligned} & -11\left(\frac{13p'_A + 18p'_B - 5\sqrt{16(p'_A)^2 - 9p'_A p'_B + 9(p'_B)^2}}{33}\right)^2 + \\ & \left(2p'_A + 7p'_B\right)\left(\frac{13p'_A + 18p'_B - 5\sqrt{16(p'_A)^2 - 9p'_A p'_B + 9(p'_B)^2}}{33}\right) + \left(3p'_A - 2p'_B\right)^2 \end{aligned}\right]\end{aligned}$$

$$\pi_B^{VI*} = \frac{4}{125b^2}\left(p'_A + p'_B - a^*\right)\left(3p'_B - 2p'_A - 3a^*\right)^2$$

The maximum of all the decision makers is:

$$\pi^{VI*} = \pi_{U+A}^{VI*} + \pi_B^{VI*} \tag{26}$$

## COMPARATIVE ANALYSIS

**Conditions for industrial coexistence:** For comparative research, the market structure with one upstream supplier and two downstream industrial buyers must be maintained. In reality, players' expected benefits, which are represented by equilibrium quantities for industrial buyers and equilibrium price for supplier, must not be negative. For simplifying the discussion, we introduce following definitions.

**Definition 3:** Industrial coexistence is defined as the case that all the variables of decision-makers are no less than zero, i.e. $Q_j^*\geq 0$, j = A, B and $\alpha\geq 0$.

Apparently, the negative equilibrium $Q_A^*<0$ or $Q_B^*<0$ May also appear, but these cases are not included in our research.

**Proposition 1:** If Assumption 1 and 2 are satisfied, then the condition for industrial coexistence for $D_j$, j = A, B is:

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

In pure competition strategy

- $$n\in\left[\frac{8}{17},1\right]$$

in vertical integration strategy

**Proof of Proposition 1(omit):** It is noted that for commitment strategy industrial coexistence holds unconditionally.

**Comparisons on quantities:** Comparative results on quantity are listed in the following proposition.

**Proposition 2:** If Assumption 1, Assumption 2 and conditions for industrial coexistence are satisfied, then the following inequalities hold:

- $Q^{PC*}<Q^{CM*}$ f or any:

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

- $Q^{CM*}\leq QV^{I*}$ for any:

$$n\in\left[\frac{8}{17},1\right]$$

- $Q^{PC*}\leq Q^{CM*}\leq Q^{VI*}$ for any:

$$n\in[\frac{13}{17},1]$$

**Proof of proposition 2:** The inequality (I) can be easily derived by formula (6) and (12); inequality (II) by Eq. 6 and 25; inequality (III) holds because:

$$n\in\left[\frac{13}{17},\frac{17}{13}\right]\cap\left[\frac{8}{17},1\right]=[\frac{13}{17},1]$$

**Q.E.D.:** The above results can be illustrated by the following figure

**Comparisons on profits:** Comparative results on profits of $\pi^{CM*}$ and $\pi^{PC*}$ are listed in the following proposition.

**Proposition 3:** If Assumption 1 and 2are satisfied, then $\pi^{CM*}<\pi^{PC*}$ for any:

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

## CONCLUSION

We analyze commitment strategy, pure competition strategy and vertical integration strategy etc. three collection strategies for industrial buyers in the research. Agricultural biomass markets are assumed to be circular area, this leads to a monotonous increasing inverse demand function which is different from the similar researches on industrial organizations.

As a result, pure competition strategy is the most efficient strategy among the three collection strategy; commitment strategy will bring the most aggregate biomass supply among the three strategies but is less efficient than pure competition strategy; vertical integration will bring secure biomass supply for integrated industrial buyer that is at the sacrifice of aggregate profits of all decision makers, especially the profit of non-integrated industrial buyer.

Our results suggest that commitment collection strategy will bring the most equilibrium biomass supply for the industrial buyers and will be helpful to formulate ABM. After market formulation, commitment strategy may be replaced by pure competition strategy because it is less efficient. The powerful industrial buyer prefers vertical integration strategy to the others, which will bring the secure biomass supply, even if it is not the most efficient strategy and will decrease the aggregate equilibrium profits of all decision makers.

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