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Study on Collection Strategic Choice for Industrial Buyers in Agricultural Biomass Supply Chain Market

Fan Zhang
School of Economics and Finance, Xi'an Jiaotong University, Xi'an, 710061, China

Abstract: This research aims to clarify the difference among three collection strategies for agricultural biomass, i.e., commitment strategy, pure competition strategy and vertical integration strategy. 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

Biomass is the most abundant renewable energy resource in developing countries such as India and China. 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). 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), meaning there is possibly more than one industrial buyers in the market.

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.

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?

In order to answer these questions, 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.

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

Let α be base price increment for selling biomass and p be the inverse demand function, the following Lemma holds(Huacuz, 2005).

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

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

where, b is defined as:

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

Definition 1: $p_j^{'} = p_j\text{-}p_s, c_0\text{-}c_t^{'}d_j, p'_j > 0$, j = A, B are defined as profit space. $P^{'}j\text{-}\alpha$, j = A, B, are defined as fixed profit space.

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:

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

Game model with commitment strategy: A simple commitment device is observable contracts proposed in the research (Sherrington *et al.*, 2008), 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 subgame perfect equilibrium, D_j will accept any offer (Q_j , π_j^{CM}) which have been similarly mentioned in the research (Klevas *et al.*, 2009). U is committed to choose (Q_j , π_j^{CM}) such that total industry profit π^{CM} are maximized. The common cost assumptions for downstream buyers imply that U offers equal quantity to both D_j, 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:

$$\pi_U^{CM} = a(Q_A + Q_B) \tag{1}$$

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

$$\begin{aligned} &\pi_j^{CM} = (p_j^{'} - a - b\sqrt{Q_A + Q_B})Q_j, \\ &\pi^{CM} = \pi_U^{CM} + \pi_A^{CM} + \pi_B^{CM}, j = A,B \\ &\frac{\partial \pi^{CM}}{\partial Q^{CM}} = \frac{p_A^{'} + p_B^{'}}{2} - b\sqrt{Q^{CM}} - \frac{b}{2}\sqrt{Q^{CM}} = 0, \\ &Q^{CM*} = \frac{(p_A^{'} + p_B^{'})^2}{9b^2} \end{aligned} \tag{2}$$

The maximum of all the decision makers is:

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

Game model with pure competition strategy: In pure competition case, contracts are not observable, i.e., (Q_j π_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, π_i^{PC}) with $\pi_j^{PC} \leq \pi_j^{PC}$ (Q_i^{PC*}, Q_j), $i \neq j$, U and D_j, j = A, B maximize their profits through a two-stage game.

The profit function for biomass material supplier is:

$$\pi_U^{PC} = a(Q_A + Q_B) \tag{4}$$

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

$$\pi_j^{PC} = (p_j - p - C_{t,j}^{'})Q_j = (p_j^{'} - a - b\sqrt{Q_A + Q_B})Q_j, j = A,B \tag{5}$$

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:

$$Q_A^{PC*} = \frac{4}{225b^2}(p'_A + p'_B)(17p'_A - 13p'_B),$$
$$Q_B^{PC*} = \frac{4}{225b^2}(p'_A + p'_B)(17p'_B - 13p'_A) \qquad (6)$$

For biomass material supplier:

$$Q^{PC*} = Q_A^{PC*} + Q_B^{PC*} = \frac{16}{225b^2}(p'_A + p'_B)^2,$$
$$a^* = \frac{(p'_A + p'_B)}{6} \qquad (7)$$

$$\pi_A^{PC*} = \frac{\pi k q_s}{750c_t^2}(p'_A + p'_B)(17p'_A - 13p'_B)^2$$
$$\pi_B^{PC*} = \frac{\pi k q_s}{750c_t^2}(p'_A + p'_B)(17p'_B - 13p'_A)^2 \qquad (8)$$

$$\pi_U^{PC*} = \frac{2\pi k q_s}{375c_t^2}(p'_A + p'_B)^3$$
$$\pi^{PC*} = \pi_U^{PC*} + \pi_A^{PC*} + \pi_B^{PC*} \qquad (9)$$

$$\frac{\pi k q_s}{375c_t^2}(p'_A + p'_B)[231(p'_A)^2 - 217p'_A p'_B + 231(p'_B)^2] \qquad (10)$$

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:

$$\pi_U^{VI} = xQ_A + aQ_B \qquad (11)$$

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

$$\pi_A^{VI} = (p'_A - x - b\sqrt{Q_A + Q_B})Q_A$$
$$\pi_B^{VI} = (p'_B - a - b\sqrt{Q_A + Q_B})Q_B \qquad (12)$$

We have:

$$Q^{VI} = \frac{4}{25b^2}(p'_A + p'_B - a)^2$$
$$Q_A^{VI*} = \frac{4}{25b^2}(p'_A + p'_B - a)(3p'_A - 2p'_B + 2a) \qquad (13)$$

$$Q_B^{VI*} = \frac{4}{25b^2}(p'_A + p'_B - a)(3p'_B - 2p'_A - 3a) \qquad (14)$$

The profit of allied downstream buyer and supplier is:

$$\pi_{U+A}^{VI} = \frac{4}{125b^2}(p'_A + p'_B - a)\times$$
$$\left[-11a^2 + (2p'_A + 7p'_B)a + (3p'_A - 2p'_B)^2\right] \qquad (15)$$

By differentiating the profit of alliance:

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

Considering:

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

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

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

$$Q^{VI*} = \frac{4}{1089b^2}\left(\begin{matrix}4p'_A + 3p'_B + \\ \sqrt{16(p'_A)^2 - 9p'_A p'_B + 9(p'_B)^2}\end{matrix}\right)^2$$
$$\pi_B^{VI*} = \frac{4}{125b^2}(p'_A + p'_B - a^*)(3p'_B - 2p'_A - 3a^*)^2 \qquad (17)$$

$$\pi_{U+A}^{VI*} = \frac{4}{125b^2}\times$$
$$\left(\frac{20p'_A + 15p'_B + 5\sqrt{16(p'_A)^2 - 9p_A p_B + 9(p'_B)^2}}{33}\right) \qquad (18)$$

The maximum of all the decision makers is:

$$\pi^{VI*} = \pi_{U+A}^{VI*} + \pi_B^{VI*} \qquad (18)$$

Comparative analysis: For comparative research, the market structure with one upstream supplier and two downstream industrial buyers must be maintained. 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 that 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:

(I)

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

in pure competition strategy:
(II)

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

in vertical integration strategy.

Proof of Proposition 1 is omitted.

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

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

(I) $Q^{PC*} < Q^{CM*}$ for any:

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

(II) $Q^{CM*} < Q^{VI*}$ for any:

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

(III) $Q^{PC*} \leq Q^{CM*} \leq Q^{VI*}$ for any:

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

Proof of proposition 2 is omitted.

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

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

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

Proof of proposition 3 is omitted.

CONCLUSION

We analyze three collection strategies for industrial buyers in the research. 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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