The Optimal Consignment Policy for the Retailer Facing Multiple Manufacturers

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Abstract - Consignment is becoming an increasingly popular practice to supply chain management. We consider the optimal consignment policy for the retailer facing multiple manufacturers. We model the decision making of the retailer and the manufacturers as a Stackelberg game: The retailer, acting as the leader, offers the manufacturers a uniform consignment contract, which specifies the slotting fee and the percentage. The manufacturers, acting as the follower, choose whether to use the retailer. We formulate the retailer’s decision process as a mixed integer programming (MIP) problem and solve it by graphical method. We propose the algorithm to determine the optimal consignment policy for the retailer. This policy and each manufacturer’s corresponsive behavior to it constitute the Stackelberg equilibrium. The numerical example shows that this optimal policy can improve the retailer’s total charge.

Keywords – Consignment policy, game, optimization, supply chain management

I. INTRODUCTION

Consignment policy is a new approach to supply chain management. Major retailers such as Wal-Mart, Carrefour, Amazon.com and Tmall.com are among the users of the consignment [1]. Taking the example of Amazon.com, it applies a special fee structure and provides a revenue sharing contract with consignment to its manufacturers. In such a business model, the manufacturer retains the ownership of the goods and provides a fixed fee (called slotting allowance) to the retailer. The retailer deducts a percentage of the selling price for each item sold and remits the balance to the manufacturer. This arrangement has many advantages [2-4]. It favors the retailer. Since no payment to the manufacturer is made until the item is sold, the retailer has no money tied up in inventory and bears no risk associated with demand uncertainty [5]. Furthermore, it has been proved that the revenue sharing contract with consignment contract coupled with slotting fee will perfectly coordinate the channel and lead to Pareto improvements among channel participants [6]. Prior research highlighted the coordination mechanism in designing the consignment contracts. Cachon and Lariviere [7] study a VMI contract with revenue sharing and demonstrate that the decentralized system provides less capacity than the integrated system. Li and Hua [8] propose a cooperative game model to describe the payment bargaining process between the manufacturer and the retailer, and determine a new consignment contract with revenue sharing attached with the equilibrium payment scheme. However, no study explored the matching process between the consignment retailers and manufacturers before they become supply chain partners. In fact, the retailer can attract a quantity of manufacturers and select the right partners by designing appropriate consignment policy, while the manufacturers can compare different policies to determine which retailer to enter. This matching process is effective for resource allocation. This study focuses on the matching process between one retailer and multiple manufacturers, and develops a model for the retailer of how to design the optimal consignment policy. The paper proceeds as follows. Section II proposes a MIP model. Section III solves the model through graphical method and presents an algorithm to determine the optimal policy. A numerical example is placed in Section IV, followed by concluding remarks.

II. MODEL DESCRIPTION

Consider an environment comprised of N number of manufacturers, each producing a single product, and one retailer, which may carry one to N products. The manufacturers sell their products through consignment. The retailer charges a yearly slotting fee and a percentage of revenue whenever a product is sold. Assume the retailer use the same consignment policy for all of his manufacturers. We model the decision making of the retailer and the manufacturers as a Stackelberg game: The retailer, acting as the leader, offers the manufacturers a take-it-or-leave-it consignment contract, which specifies the slotting fee and the percentage. The manufacturers, acting as the follower, choose whether to use the retailer. In this game, the manufactures need to balance between the consignment charges and the benefit, while the retailer needs to balance the charges and the number of manufacturers to serve.

The following notations are used to formulate the mathematical model:

- x Sloting allowance, a fixed fee paid yearly by the manufacturer to the retailer.
- y The retailer’s share of revenue generated from each unit; 0 ≤ y < 1.
- \( p_i \) Per-unit selling price for product \( i \) produced by manufacturer ; \( i = 1,2,...N \).
- \( c_i \) Per-unit manufacturing cost for product \( i \) ; \( i = 1,2,...N \).
- \( z_i \) Binary variables;
represents a very large as the horizontal axis of the

\[ z_i = \begin{cases} 1, & \text{if manufacturer } i \text{ uses the retailer} \\ 0, & \text{otherwise} \end{cases}; i = 1,2...N \]

\[ q_i \] Product \( i \)'s quantity of sales through consignment when manufacturer uses the retailer; \( i = 1,2...N \).

\[ \pi_i^m \] Manufacturer \( i \)'s profit; \( i = 1,2...N \).

\[ \pi^r \] The retailer's total consignment charge.

In this dynamic game, the retailer offers all the manufacturer's a revenue-sharing contract with a uniform consignment policy \((x,y)\). Given this policy, each manufacturer computes his profit and determines whether to take the contract (see Fig.1).

![Fig.1. Channel structure](image)

The profit of manufacturer \( i \) can be expressed as

\[ \pi_i^m = q_i(p_i - c_i) - x - q_ip_iy. \]

If \( \pi_i^m \geq 0 \), manufacturer \( i \) chooses to take the contract then uses the retailer, and the binary variable \( z_i = 1 \); otherwise, he chooses not to use the retailer, and \( z_i = 0 \). The retailer's revenue is the sum of what she charges to those manufacturers who determine to take the contract. Her revenue function can be written as \( \pi^r = \sum_{i=1}^{N} z_i(x + q_ip_iy). \)

To formulate the retailer's decision process as a mixed integer programming (MIP) problem, we identify the objective function and the constraints as follows:

MIP Model:

\[
\text{maximize } \pi^r = \sum_{i=1}^{N} z_i(x + q_ip_iy) \\
\text{subject to: } M(1 - z_i) + q_i(p_i - c_i)z_i - (x + q_ip_iy) \geq 0 \\
Mz_i - q_i(p_i - c_i)(1 - z_i) + (x + q_ip_iy) \geq 0 \\
x \geq 0, y \geq 0, z_i = 0 \text{ or } 1
\]  

(1)

In this model, the letter \( M \) represents a very large negative number. The first two constraints represent mathematical relationships between the value of \( z_i \) and the profit of manufacturer \( i \). If manufacturer \( i \)'s benefit \( q_i(p_i - c_i) \) is greater than or equal to the consignment charge \( x + q_ip_iy \), both constraints are satisfied when \( z_i = 1 \), while the equation \( z_i = 0 \) would violate the second constraint. If manufacturer \( i \)'s benefit is less than the charge, both constraints are satisfied when \( z_i = 0 \), while the equation \( z_i = 1 \) would violate the first constraint. Using these constraints, we incorporate the manufacturer's decision problem into the retailer's decision model. The solution to this MIP Model would not only provide the retailer with an optimal consignment policy, but also provide the manufacturers with optimal responsive strategies. Therefore, it is the Stackelberg equilibrium of this game.

### III. GRAPHICAL METHOD

There are some computer programs that are capable of solving this MIP problem, such as LINGO, MATLAB. We use the graphical method to solve it as there are two decision variables in a consignment policy. The graphical procedure is invaluable in providing us with insights into how the model works. For that reason alone, it is worthwhile to spend the rest of this section exploring graphical solutions as an intuitive basis for the analysis.

We plot the variable \( x \) as the horizontal axis of the graph and the variable \( y \) as the vertical axis. If we graph the linear equation \( q_i(p_i - c_i) - x - q_ip_iy = 0 \) in the first quadrant, we can get \( N \) critical lines where each manufacturer's profit is equal to zero. Without loss of generality, we draw two manufacturers' critical lines in the graph. There are two possibilities for the position of these two lines. First, the two critical lines have an intersection point in the first quadrant. As shown in Fig.2, manufacturer 1’s horizontal intercept is smaller than that of manufacturer 2, but its vertical intercept is larger. This shows manufacturer 1’s total profit is smaller than that of manufacturer 2, i.e. \( q_1(p_1 - c_1) < q_2(p_2 - c_2) \) , but its profit rate is larger than that of manufacturer 2, i.e. \( \frac{p_1-c_1}{p_1} > \frac{p_2-c_2}{p_2} \). Second, the two lines have no intersection in the first quadrant (see Fig.3). This is because both the total profit and the profit rate of manufacturer 1 are larger than those of manufacturer 2. In such a case, we call manufacturer 1 the strong one and manufacturer 2 the weak one.

![Fig.2. The two critical lines with an intersection point](image)