Research on Quality Investment and Pricing Decision Sequence of Complex Equipment Supply Chain Considering Manufacturer’s Incentive Strategy

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Abstract: For the demand uncertainty of complex equipment two-stage supply chain, the influence of different quality investment and pricing decision sequence on expected revenue and demand, with the consideration of incentive strategy between manufacturers to suppliers, manufacturer determines the basic quality and compensation for suppliers, suppliers determine the parts wholesale price and quality investment, then manufacturer decides the complex equipment product price. This paper set up two quality investment and price decentralized decision sequence: a Stackelberg game model, a vertical Nash game. Conditions of suppliers decisions are obtained, and the changes of pricing, quality investment, demand and profit of supply chain members are analyzed. It shows that making quality investment and wholesale price decisions simultaneously is best for manufacturers and integrated supply chain; determining quality investment and then set the wholesale price at the same time is the best choice for the whole suppliers. For individual suppliers, there is no absolutely dominant decision-making sequence. By comparing the model and different parameters, the paper provides a management basis for improving the quality and performance of supply chain subjects.

1. Introduction

Product price and quality play an important role in the market competition and affect the market competitiveness of enterprises and supply chains. Nowadays, the market competition is increasingly fierce, and the quality investment and pricing cooperation among supply chain members will affect the competitiveness of the whole supply chain and individual members, so the pricing strategy and quality investment decision are particularly important. In the "suppliers-main manufacturer" complex equipment supply chain, the enterprise improves market demand and maximizes profits through competition and cooperation. Strategies include technology investment in improving product quality, parts quality, shortening procurement cycle and other investments in supplier relationship management. Therefore, manufacturers not only need to pay attention to their own production and development process, but also need to encourage suppliers to increase the quality of the production of key components. This paper adopts the form of incentive contract, in which the manufacturer subsidizes the part of suppliers that is higher than the basic quality investment, and penalizes the part that is lower than the basic quality investment, the quality of the suppliers have mutual influence between decision-making, manufacturer produces the complex equipment and determines price; Product quality level is affected by the quality of different components. A Stackelberg game model, a Nash game model are established and compared in the decentralized decision are established for analyzing and comparing the influences of quality investment and pricing decision sequence on the optimal decision and expected profit of suppliers, manufacturers and the whole supply chain.

As for the research of quality investment, Rohit et al. [1] use fuzzy game theory to study four kinds of decentralized supply chain cases. For the research on incentive strategies, Meina et al. [2] established an effective reverse logistics system in a two-stage supply chain composed of pharmaceutical enterprises and retailers based on game theory. Alex et al. [3] establish a model that
takes into account the uncertainty of the source of returns and the supplier of new components. Wang et al. [4] establish a set and separate incentive equilibrium model for the supply chain system, analyze the influence of the model on the performance of supply chain. Charles et al. [5] study two main incentives for retailers from manufacturers. Pietro et al. [6] study retailers' efforts to provide a common maximization incentive for manufacturers to promote green activity plans. In the pricing decision making and quality improvement research, most consider manufacturers or suppliers and retailers, and retailers in the supply chain of complicated product supply chain. Therefore, this paper set up two quality investment and price decentralized decision sequence to reveal how to adopt the optimal decision-making in order to improve itself and the performance of the supply chain as a whole with optimization theory.

2. Notation definition

This paper studies the two-stage supply chain of "suppliers-main manufacturer", in which the two core parts of the product are supplied by two different suppliers respectively. The demand of products decreases with the increase of product price and improves with the improvement of product quality. Let $e_1$, $e_2$ be the quality investment of supplier 1 and supplier 2, and $w_1$, $w_2$ be the wholesale price of components determined by the suppliers, let $p$ be the product price determined by the main supplier. We normalize the manufacturer demand expression $D$ to be:

$$D = a + b(e_1 + e_2) - \phi$$

Where $a$ is the size of the market, $b$ is the impact factor of quality input of supply chain members on the market demand, $d$ is the impact factor of product price on the market demand.

The quality investment is directly proportional to the fixed quality cost:

$$Q (e) = (q e^2)/2, q_i$$ is the fixed quality investment cost coefficient; $c_i$ is the supplier's fixed production cost of components, $V_i$ is the supplier's variable unit cost related to quality level, $v(e) = c_i + v e_i$; $C = c_0 + c_1 + c_2$, where $C$ is the fixed total production cost of unit product in the supply chain, $c_0$ is the manufacturer's assembly cost, and $c_1$ and $c_2$ are the fixed production costs of components of supplier 1 and 2.

3. Decentralized decision-making

In the decentralized decision, the two suppliers as the decision-making leaders, first decide the quality investment of their production components and the wholesale price to the suppliers. The suppliers' decision sequence in decentralized decision-making. The objective function of the manufacturer is:

$$\max \left[ \Pi_i(p, w_i, e_i, e_2, r, t) \right] = \left[ a + b(e_1 + e_2) - \phi \right] \left[ p - c_i - w - w_j - r(e_1 - t) - r(e_2 - t) \right]$$

the manufacturer's optimal pricing can be expressed as a function of $e_1$, $e_2$, $w_1$ and $w_2$:

$$p_i(w_i, w_j, e_i, e_2) = \frac{a + d(c_i + w_i + w_j) + b(e_1 + e_2)}{2}$$

the market demand in decentralized decision-making is:

$$D_i(w_i, w_j, e_i, e_2) = \frac{a - d(c_i + w_i + w_j) + b(e_1 + e_2)}{2}$$

the expected profit of the manufacturer in decentralized decision-making is:

$$E \left[ \Pi_i(w_i, w_j, e_i, e_2, r, t) \right] = \left[ a - d(c_i + w_i + w_j) + b(e_1 + e_2) \right]^2 - 4d(e_1 + e_2 - 2)$$

the expected profit of supplier 1 and 2 in the decentralized decision is:

$$E \left[ \Pi_i(w_i, w_j, e_i, e_2, r, t) \right] = \left[ a - d(c_i + w_i + w_j) + b(e_1 + e_2) \right]^2 - 4d(e_1 + e_2 - 2)$$

the overall expected revenue of the supply chain in decentralized decision-making is:
The optimal pricing of the manufacturer's products increases with the increase of the manufacturer's fixed production cost (c_i), supplier's quality input (e_i) and the wholesale price of parts (w_i), and decreases with the increase of the influence coefficient (d) of product price on market demand.

### 3.1 Vertical Nash game model (Supplier determine quality investment (e_i) simultaneously)

Suppliers as the leaders of the supply chain, first independently make decisions on quality investment, and then make decisions on the wholesale price of spare parts after making commitments on the quality of spare parts. In the solution of the model, the reverse method is adopted to solve the problem, that is, p^* is solved first, then w_i^* is solved, and finally e_i^* is solved.

The expected profit function is:

\[
E[\Pi_i(e_i, w_i, r_i)] = \frac{[a - d(C_i + w_i + c_i) + b w_i + r(e_i + e_q)]}{2} - r(e_i + e_q) - \frac{a r_c e_i^2}{2} + \frac{a r_c w_i^2}{2}
\]

(8)

The optimal pricing of the manufacturer's products increases with the increase of the manufacturer's fixed production cost (c_i), supplier's quality input (e_i) and the wholesale price of parts (w_i), and decreases with the increase of the influence coefficient (d) of product price on market demand.

### 3.2 Stackelberg non-cooperation model

Supplier 1 as a leader in the supply chain first to determine the quality investment and wholesale price, supplier 2 as a follower and then determine the quality investment and wholesale price, in this case assumes that the two suppliers are in demand uncertainty is resolved before make decisions quality and wholesale price. After the supplier is determined, the uncertainty of demand is resolved, and the manufacturer then determines the price of the product. Expected profit of supplier 1:

\[
E[\Pi_1(e_1, w_1, r_1)] = \frac{[a - d(C_i + w_i + c_i) + b w_i + r(e_i + e_q)]}{2} - r(e_i + e_q) - \frac{a r_c e_i^2}{2} + \frac{a r_c w_i^2}{2}
\]

(9)

The expected profit function is:

\[
E[\Pi_1(e_1, w_1, r_1)] = \frac{[a - d(C_i + w_i + c_i) + b w_i + r(e_i + e_q)]}{2} - r(e_i + e_q) - \frac{a r_c e_i^2}{2} + \frac{a r_c w_i^2}{2}
\]

(10)

Substitute equation (9) - (15) into equation (4) - (8), the equilibriums are:

\[
E[\Pi_{12}] = \frac{9[a - d(C_i + w_i + c_i) + r(6b - d - d_v)]}{36 [9d q q_a - (b - d_v)^2 q_a - (b - d_v)^2 q_a]}
\]

(11)
$e_{i,j} = \left( a - c - r\beta v_i + rbdv_j \right) \left( b - dv_j \right) q_i + 4rdv_j q_i^2 \beta d q_i q_j + \frac{c_i}{2d q_i^2 q_j} - b - dv_j)$

$w_i = \frac{a - dC}{\beta d q_i q_j} - \frac{b - dv_j}{2} - \frac{c_i}{\beta d q_i^2 q_j}$

$e_{i,\cdot} = \frac{a - dC - r\beta v_i + rbdv_j \left( b - dv_j \right) q_i + 4rdv_j q_i^2 \beta d q_i q_j + \frac{c_i}{2d q_i^2 q_j} - b - dv_j)$

$w_i = \frac{a - dC}{\beta d q_i q_j} - \frac{b - dv_j}{2} - \frac{c_i}{\beta d q_i^2 q_j}$

$p_{i,j} = \left( a - dC \right) \left( b - dv_j \right) q_i + \left( b - dv_j \right) \left( b - dv_j \right) q_i - 2b - dv_j)^q_i + \frac{c_i}{2d q_i^2 q_j} - b - dv_j)$

$\eta_{i,j} = \left( a - dC \right) \left( b - dv_j \right) q_i - \frac{b - dv_j}{2} - \frac{c_i}{\beta d q_i^2 q_j}$

$\eta_{i,j} = \left( a - dC \right) \left( b - dv_j \right) q_i - \frac{b - dv_j}{2} - \frac{c_i}{\beta d q_i^2 q_j}$

$\eta_{i,j} = \left( a - dC \right) \left( b - dv_j \right) q_i - \frac{b - dv_j}{2} - \frac{c_i}{\beta d q_i^2 q_j}$

The supplier's quality investment equilibrium is related to the product total fixed cost $C$, when $C$ is fixed, the optimal value of quality investment and the product price have nothing to do with $C$, and the $c_i$ of the supply chain members; when $C$ changes, the optimal value of quality investment decreases with the increase of $C$, and product pricing increases with the increase of $C$. For the integrated supply chain, the expected profit is related to $r$ for suppliers, and has nothing to do with $t$ determined in the incentive strategy. The manufacturer's expected profit with the basic quality increase with the increase of $t$, the supplier's expected profit with the increase of $t$; Since $b-dv_j > 0$ (i.e., $t$), and the manufacturer design incentive contract, encourage suppliers to adopt for manufacturers and integrated supply chain decisions, and find out the dominant strategy from each subject. The sequence of quality investment and wholesale price decision affects the quality input level of suppliers and the expected earnings of enterprises. The second decision sequence is the best choice for suppliers as a group. However, the dominant strategy of suppliers as a group is not the best choice for manufacturers and integrated supply chains. This article does not take into account different main body coordination in supply chain system assembly, the future can consider manufacturers design contracts as leader of the supply chain to coordinate decentralized assembly system, in addition, this article does not consider the manufacturer's quality investment, the future can add the manufacturer's quality investment as a variable model are discussed.

4. Conclusion

The decision sequence of component pricing and quality investment may affect the supplier's quality effort, thus affecting product quality and product pricing, and ultimately affecting market demand. In this paper, two models of different decision sequences are established by vertical Nash game, and the optimal solution of the decision sequence is analyzed from the perspective of each subject of the supply chain. This paper studies the supply chain decision-making sequence from different subjects of integrated supply chain, manufacturers and suppliers of quality investment, product price and expected return, the influence of by the manufacturer design incentive contract, encourage suppliers to adopt for manufacturers and integrated supply chain decisions, and find out the dominant strategy from each subject. The sequence of quality investment and wholesale price decision affects the quality input level of suppliers and the expected earnings of enterprises. The second decision sequence is the best choice for suppliers as a group. However, the dominant strategy of suppliers as a group is not the best choice for manufacturers and integrated supply chains. This article does not take into account different main body coordination in supply chain system assembly, the future can consider manufacturers design contracts as leader of the supply chain to coordinate decentralized assembly system, in addition, this article does not consider the manufacturer's quality investment, the future can add the manufacturer's quality investment as a variable model are discussed.
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