Study on the Decision of Supply Chain Considering Asymmetric Information and Quality Competition

Chao Zhao¹, Jing Zhao², Gang Wu², Fan Zhang²⁺

¹ Dolink School of Economics and Management, University of Science and Technology Beijing, Beijing, China
² China National Institute of Standardization, Beijing, China
⁺Corresponding author
Email: zhangfan@cnis.ac.cn

Abstract. Product quality is a fundamental factor for supply chain to obtain a competitive advantage. This paper studies the decisions of supply chain under asymmetry information of quality effort cost, considering the quality competition of manufacturers. Transfer payment contract is introduced by comparing the Stackelberg model between symmetry information and asymmetry information. At the same time, this paper analyzes the impact of quality competition and false information strategy on supply chain quality decision. The research shows that the quality competition can improves products quality, and manufacturers tend to choose strategy of false information. Moreover, after the introduction of contract, the manufacturers will convey the true quality information and reduce the competition to optimize their own profits.

1. Introduction
To make quality an advantage of supply chain competition, it is necessary to coordinate the quality competition decisions among supply chain members and optimize the whole benefit of the supply chain. In actual life, each member enterprise tends to ignore the benefits of the supply chain and maximize its own benefits. The competition among the members will have a significant impact on the decision-making of the supply chain. At the same time, information asymmetry in the supply chain is widespread. Therefore, it is of great theoretical value and practical significance to study the problem of retailers improving quality and promoting the information sharing in the supply chain based on the quality competition. By reviewing the literatures, some studies are based on the quality improvement of the manufacturer or retailer, and a few researchers consider the factors of information asymmetry. However, few literatures consider the impact of quality efforts by retailers and manufacturers in the context of information asymmetry. On the basis of the existing results, this paper studies the supply chain decision problem of quality competition under the condition of information asymmetry. Considering the quality decision problem of the two manufacturers and one retailer who exist the competition relationship, by introducing the transfer payment contract optimize supply chain benefits.
2. Model building and solving

2.1. Problem description and symbolic description
Retailers and manufacturers carry out Stackelberg master-slave game. The product market demand function of the product \( i (i=1,2) \) is \( d_i = (\alpha_i - \beta_i p + \varphi \theta) (\epsilon e_i - e_i) \), \( (j,i=1,2; j \neq i) \), \( \alpha_i \) is the potential demand for the two manufacturers' products. \( \beta p \) and \( \varphi \theta \) are the impact of retail price and quality on the market demand. \( p \) is the selling price. \( \theta \) is the retailer's decision variable. \( \epsilon e_i - e_i \) is the influence of the quality competition of the manufacturer on the market demand, and \( \epsilon e_i \) is the quality of the manufacturer's efforts. The impact of market demand, \( \epsilon \) is the sensitivity of the market demand for the quality of the manufacturer's efforts. \( e_i \) shows the quality. \( \gamma \) is the quality competition between the manufacturers, and \( 0 < \gamma < \epsilon \).

Other symbols are as follows: \( w_p \), manufacturer's product wholesale price; \( c \), production cost per unit of product; \( c_M \), manufacturer's quality effort cost, \( \gamma c_M = \eta e^2 \gamma / 2 \); \( c_R \), retailer quality effort cost, \( \gamma c_R = \delta \theta^2 / 2 \); \( \eta_i \), information in the case of asymmetric circumstances, the manufacturer to the retailer to provide the quality of the effort cost coefficient declared value.

2.2. Consider the quality of the effort to competition in the supply chain decision

2.2.1 Supply chain decision making under asymmetric information. The asymmetric information situation, in order to maximize their own interests, manufacturers and retailer often conceal their own private information (quality cost coefficient \( \eta_i \)), which makes retailers can't make a decision according to the real quality cost. Assume that the quality effort cost coefficients provided by the manufacturers to the retailer under asymmetric information are \( \eta_1 \) and \( \eta_2 \), respectively.

**Step1** According to \( \eta_1 \) and \( \eta_2 \), retailers determine the optimal quality level of effort \( \theta \).

The manufacturer believes that the profit function of the two retailers is:

\[
\begin{align*}
\Pi_{1m1} &= d_1(w_1 - c) - \frac{\eta_1 e_1^2}{2} \\
\Pi_{1m2} &= d_2(w_2 - c) - \frac{\eta_2 e_2^2}{2}
\end{align*}
\]

(1)

(2)

By using the inverse solution method, the first order derivative of Eq. (1) and Eq. (2) with respect to \( e_1 \) and \( e_2 \) is equal to 0. The retailer considers the quality effort levels of the two manufacturers is:

\[
\begin{align*}
\bar{e}_1 &= \frac{(w_1 - c)(\epsilon + \gamma)(\alpha_1 + \varphi \theta - \beta p)}{\eta_1} \\
\bar{e}_2 &= \frac{(w_2 - c)(\epsilon + \gamma)(\alpha_2 + \varphi \theta - \beta p)}{\eta_2}
\end{align*}
\]

(3)

(4)

Replace \( \bar{e}_1, \bar{e}_2 \) into the retailer's profit function:

\[
\Pi_{1e} = d_1(p - w_1) + d_2(p - w_2) - \frac{\delta \theta^2}{2}
\]

(5)

Get formula:

\[
\Pi_{1e} = I_1 \left( \gamma \left( \frac{G}{\eta_1} - \frac{H}{\eta_2} \right) - \frac{\epsilon H}{\eta_1} \right) - I_2 \left( \gamma \left( \frac{G}{\eta_1} - \frac{H}{\eta_2} \right) + \frac{\epsilon G}{\eta_2} \right) - \frac{\delta \theta^2}{2}
\]

(6)

Among them, \( I_1 = (p - w_1)(\alpha_1 + \varphi \theta - \beta p) \) \( I_2 = (p - w_2)(\alpha_2 + \varphi \theta - \beta p) \), \( G = (\epsilon + \gamma)(c - w_1)(\alpha_1 + \varphi \theta - \beta p) \), \( H = (\epsilon + \gamma)(c - w_2)(\alpha_2 + \varphi \theta - \beta p) \)

The first order derivative of Eqs. (6) with respect to \( \theta \), and make it equal to 0. we can get the information asymmetry in the case of retailers the best quality effort:

\[
\theta^*_1 = -\frac{K_1 \left( \gamma (J_1 - J) + J_i \right) - K_2 \left( \gamma (J_i - J) - J_1 \right) + \varphi (p - w_1)(\gamma (L_i - L) + \epsilon L) - \varphi (p - w_2)(\gamma (J_1 - J_i) - \epsilon L_i)}{\delta + 2 \varphi (p - w_1)(\gamma (J_i - J) + J_i) - 2 \varphi (p - w_2)(\gamma (J_1 - J_i) - J_1)}
\]

(7)
Among them, \( J_1 = \frac{\varphi(c + \gamma)(c - w_1)}{\eta_1} \), \( J_2 = \frac{\varphi(c + \gamma)(c - w_2)}{\eta_2} \), \( K_i = (p - w_i)(\alpha_i - \beta p) \),
\[
K_2 = (p - w_2)(\alpha_2 - \beta p) \quad L_2 = \frac{(e + \gamma)(c - w_2)(\alpha_2 - \beta p)}{\eta_2}
\]

**Step 2** The manufacturers determine their respective best quality effort levels based on \( \theta^*_1 \) and \( \eta \).

The real profits of the two manufacturers are:
\[
\Pi_{AM1} = \varphi \theta^*_1 (w_1 - c)(\alpha_1 - \beta p + \epsilon \alpha_1 - \gamma_1 (e_1 - e_2)) - \frac{\eta e_1^2}{2}
\]
\[
\Pi_{AM2} = \varphi \theta^*_2 (w_2 - c)(\alpha_2 - \beta p + \epsilon \alpha_2 - \gamma_2 (e_1 - e_2)) - \frac{\eta e_2^2}{2}
\]

According to Eqs. (8) and Eqs. (9) we obtain the manufacturers’ optimal quality:
\[
\hat{e}_1 = \frac{(e + \gamma)(c - w_1)\beta p - \alpha_1 - \varphi(K_1(\gamma(J_1 - J_2) + \epsilon J_1) - K_2(\gamma(J_1 - J_2) - \epsilon J_1) + \varphi(p - w_1)(\gamma(J_1 - J_2) - \epsilon J_1)(\gamma(J_1 - J_2) - \epsilon J_1))}{\delta + 2\varphi(p - w_1)(\gamma(J_1 - J_2) + \epsilon J_1) - 2\varphi(p - w_1)(\gamma(J_1 - J_2) - \epsilon J_1)}
\]
\[
\hat{e}_2 = \frac{(e + \gamma)(c - w_2)\beta p - \alpha_2 - \varphi(K_1(\gamma(J_1 - J_2) + \epsilon J_1) - K_2(\gamma(J_1 - J_2) - \epsilon J_1) + \varphi(p - w_1)(\gamma(J_1 - J_2) + \epsilon J_1)(\gamma(J_1 - J_2) - \epsilon J_1))}{\delta + 2\varphi(p - w_1)(\gamma(J_1 - J_2) + \epsilon J_1) - 2\varphi(p - w_1)(\gamma(J_1 - J_2) - \epsilon J_1)}
\]

Substituting \( \theta^*_1, e_{A1}^*, e_{A2}^* \) into Eq.(5), Eq.(8) and Eq.(9) yields the optimal profit \( \Pi_{AM},\Pi_{AM1},\Pi_{AM2} \) of the manufacturer and the retailer in the case of information asymmetry.

### 2.2.2 Supply Chain Decision under Transfer Contract

Asymmetry information has a negative impact on retailers, so retailers tend to take some measures to promote the manufacturers to deliver real private information. In this paper, retailers push manufacturer deliver real quality effort costs by developing transfer payment contracts.

**Step 1** The retailer determines the optimal quality effort level \( \theta \) and the transfer payment amount \( T(\eta_1), T(\eta_2) \), and \( T(\eta_1) > 0, T(\eta_2) > 0 \), according to \( \eta_1 \) and \( \eta_2 \).

After introducing the transfer payment contract, the retailer considers the profit function of the two manufacturers:
\[
\Pi_{AM1} = d_1(w_1 - c) - \frac{\eta e_1^2}{2} - T(\eta_1)
\]
\[
\Pi_{AM2} = d_2(w_2 - c) - \frac{\eta e_2^2}{2} - T(\eta_2)
\]

According to Eqs. (12) and (13), the retailer considers the quality effort level of manufacturers is:
\[
\hat{e}_1 = \frac{(w_1 - c)(e + \gamma)(\alpha_1 + \varphi \theta - \beta p)}{\eta_1}
\]
\[
\hat{e}_2 = \frac{(w_2 - c)(e + \gamma)(\alpha_2 + \varphi \theta - \beta p)}{\eta_2}
\]

Replace \( \hat{e}_1, \hat{e}_2 \) into the retailer’s profit function:
\[
\Pi_{Ar} = d_1(p - w_1) + d_2(p - w_2) - \frac{\delta \theta^2}{2} + T(\eta_1) + T(\eta_2)
\]

Then we obtain:
\[
\Pi_{Ar} = O_1(\gamma(N_1 - N_2) - \epsilon N_1) - O_2(\gamma(N_1 - N_2) - \epsilon N_1) - \frac{\delta \theta^2}{2} + T(\eta_1) + T(\eta_2)
\]
Among them, \( N_1 = \frac{(c + \gamma)(c - w_1)(\alpha_1 + \varphi \theta - \beta p)}{\eta_1} \) and \( N_2 = \frac{(c + \gamma)(c - w_2)(\alpha_2 + \varphi \theta - \beta p)}{\eta_2} \),

\( O_1 = (p - w_1)(\alpha_2 + \varphi \theta - \beta p) \), \( O_2 = (p - w_1)(\alpha_2 + \varphi \theta - \beta p) \).

In order for manufacturer to deliver the true information, it must be met: when the manufacturer delivers the true information, its profit can be maximized. so Eq(18) should be met:

\[
\max_{\eta \in \eta} \Pi_m \\
\text{s.t.} \quad \Pi_{m1} = \max_{\eta} \Pi_{m1} \\
\Pi_{m2} = \max_{\eta} \Pi_{m2} \\
\]

From the extreme correlation theory can be seen when the \( \frac{\partial \Pi_{m1}}{\partial \eta_1} = 0 \), \( \frac{\partial \Pi_{m2}}{\partial \eta_2} = 0 \), the two manufacturers can maximize their profits by delivering the real information, that is:

\[
\left( \frac{N_1^2}{2} - (c - w_1)(\alpha_1 + \varphi \theta - \beta p) \left( \frac{\varepsilon N_1}{\eta_1} + \gamma N_1 \right) - \frac{\partial T(\eta)}{\partial \eta_1} \right)_{\eta = \eta_1} = 0 \quad (19)
\]

\[
\left( \frac{N_2^2}{2} - (c - w_2)(\alpha_2 + \varphi \theta - \beta p) \left( \frac{\varepsilon N_2}{\eta_2} + \gamma N_2 \right) - \frac{\partial T(\eta)}{\partial \eta_2} \right)_{\eta = \eta_2} = 0 \quad (20)
\]

Integrate Eq. (19) and Eq. (20) to get:

\[
T(\eta_1) = \frac{\eta_1 (c + \gamma)^2 (c - w_1)^2 \left( \alpha_1 + \varphi \theta - \beta p \right)^2}{2\eta_1} + R_1
\]

\[
T(\eta_2) = \frac{\eta_2 (c + \gamma)^2 (c - w_2)^2 \left( \alpha_2 + \varphi \theta - \beta p \right)^2}{2\eta_2} + R_2
\]

When \( \theta = \theta', x_1 = x_1', x_2 = x_2', \eta_1 = \eta_2 = \eta \), there are \( T(\eta) = 0 \), substituting them into Eqs. (21) and (22) can solve \( R_1 \) and \( R_2 \), so \( T(\eta_1) \) and \( T(\eta_2) \) formula is:

\[
T(\eta_1) = \frac{(c + \gamma)^2 \eta_1 - (c - w_1)^2 \left( \alpha_1 + \varphi \theta - \beta p \right)^2}{2\eta_1}
\]

\[
T(\eta_2) = \frac{(c + \gamma)^2 \eta_2 - (c - w_2)^2 \left( \alpha_2 + \varphi \theta - \beta p \right)^2}{2\eta_2}
\]

And then get the profit function of the retailer:

\[
\Pi_s = O_1 \left( \gamma (N_1 - N_2) - \varepsilon N_1 \right) - O_2 \left( \gamma (N_1 - N_2) - \varepsilon N_1 \right) - \frac{\partial \theta^2}{2} \left[ (c + \gamma)^2 \left( \eta_1 - (c - w_1)^2 \left( \alpha_1 + \varphi \theta - \beta p \right)^2 \right) \right] \]

\[
- \frac{(c + \gamma)^2 \left( \eta_2 - (c - w_2)^2 \left( \alpha_2 + \varphi \theta - \beta p \right)^2 \right)}{2\eta_2}
\]

The retailer’s optimal quality effort level \( \theta' \) is:

\[
\theta' = \left( \frac{\gamma K_2 \left( J_1 - J_2 \right) - \gamma K_1 \left( J_1 - J_2 \right) - \varphi (p - w_1) \left( (L_2 - L_1) + \varphi p (p - w_1) \right) (J_1 - J_2) - \delta (\alpha_1 - \beta p) P_1 + (\alpha_2 - \beta p) P_2}{2p (p - w_1) \left( (J_1 - J_2) - \varepsilon L_1 \right) - 2p (p - w_1) \left( (J_1 - J_2) + \varepsilon L_1 \right) - \delta P_1 + P_2} \right)
\]

Among them, \( P_1 = \frac{\varphi (c + \gamma)^2 \left( \eta_1 - (c - w_1)^2 \left( \alpha_1 + \varphi \theta - \beta p \right)^2 \right)}{2\eta_1} \), \( P_2 = \frac{\varphi (c + \gamma)^2 \left( \eta_2 - (c - w_2)^2 \left( \alpha_2 + \varphi \theta - \beta p \right)^2 \right)}{2\eta_2} \)

Step2 The manufacturers determine their best quality effort levels based on \( \theta' \) and \( \eta \). The real profits of the two manufacturers are:

\[
\Pi_{m1} = d_1 (w_1 - c) - \frac{\eta_1^2}{2} \left[ (c + \gamma)^2 \left( \eta_1 - (c - w_1)^2 \left( \alpha_1 + \varphi \theta - \beta p \right)^2 \right) \right]
\]

(27)
\[ \Pi_{M_2} = d_2 \left( w_2 - c \right) - \frac{\eta_1 e_2^2}{2} - \left( e + \gamma \right)^2 \left( \eta - \eta_1 \right) \left( c - w_2 \right)^2 \left( \alpha_1 + \varphi \theta - \beta p \right)^2 \]  

(28)

After introducing the transfer payment contract, the optimal quality effort is:

\[ e_1^* = \frac{\left( w_1 - c \right) \left( e + \gamma \right) \left( \alpha_1 + \varphi \theta - \beta p \right)}{\eta} \]  

(29)

\[ e_2^* = \frac{\left( w_2 - c \right) \left( e + \gamma \right) \left( \alpha_2 + \varphi \theta - \beta p \right)}{\eta} \]  

(30)

The formulas (17), (29) and (30) are obtained by introducing \( \theta', e_1', e_2' \) into the optimal profit \( \Pi_{r_1}, \Pi_{m_1}, \Pi_{m_2} \) in the case of introducing the transfer payment contract. As Eqs. (27) and (28) shown, when \( \eta = \eta_1, \Pi_{m_1} \) and \( \Pi_{m_2} \) have the maximum, that is, only when two manufacturers strive to deliver real information, they can obtain the maximum profit, indicating that the transfer payment contract can prompt the manufacturer to deliver real information.

3. Numerical analysis

The model is analyzed by Matlab software. The parameters in the model are given as follows: \( \alpha_1=140, \alpha_2=120, \beta=0.8, \varphi=1.5, w_1=w_2=15, \alpha_1=140, \alpha_2=120, \beta=0.8, \varphi=1.5, w_1=w_2=15. \)

After the introduction of the contract, increased degree of competition among manufacturers affects total profit of manufacturers, retailers and supply chains. As Figures 1-4 shown, the more intense the competition between manufacturers, the faster the profits of the two manufacturers decline, and the faster the total profits of retailers and supply chains rise. Figure 1 and Figure 2 show the trend of competition for the profit changes of two manufacturers before and after the contract. The competition between manufacturers will reduce the profit of the manufacturer. After the introduction of the contract, the degree of competition will drop the profit of the manufacturer. For example, when the competition intensity \( \gamma \) is increased from 0.1 to 1, the profit before the introduction is reduced by 291.2 yuan, and the profit after the introduction is reduced by 432.7 yuan, which is 48.59%.

![Figure 1](image1.png)  
Figure 1 The impact of manufacturer’s quality competition on manufacturers’ 1 profit

![Figure 2](image2.png)  
Figure 2 The impact of manufacturer’s quality competition on manufacturers’ 2 profits
From the above analysis, it can be seen from the above analysis that the manufacturer's decision to misrepresent the information has adversely affected the retailer and the supply chain. In order to avoid damage to their own interests, the dominant retailer will adopt the strategy of introducing the transfer payment contract. The following analysis of the impact of the transfer contract to the supply chain, before the introduction of transfer payments before and after the supply chain member profit and supply chain total profit were compared. Regardless of the kind of misreporting information strategy adopted by the manufacturer, the profit of the retailer and the total profit of the supply chain will increase after the introduction of the contract, and the profit of the manufacturer who misrepresents the information will decrease before the introduction of the contract, indicating that the retailer's contract strategy can effectively avoid itself. Loss of profits and increase the total profit of the supply chain.

4. Conclusion
Based on the quality competition of the manufacturer, this paper constructs the supply chain decision model of the manufacturer's quality effort information asymmetry, and analyzes the manufacturers strategy and its impact. The introduction of transfer payment contracts enabled retailers to avoid the losses caused by manufacturers' false information, and also increased the total profit of the supply chain, and conducted sensitivity analysis on quality competition and quality effort cost factors. The following conclusions are drawn: In order to avoid loss of profits, retailers introduce a transfer payment contract, the contract can increase the total profit of retailers and supply chain, reduce the profits of manufacturers who provide false information. After the introduction of the contract, the manufacturer will pass on the true quality effort information and adopt a strategy to reduce the quality competition between each other to increase profits.

Acknowledgments
This paper is supported by grants from National Key R&D Program of China (522016Z-4973) and China National Institute of Standardization (522019Y-6781, 522018Y-5948, 522018Y-5941).

References
[1] Hsieh C C, Liu Yute. Quality investment and inspection policy in a supplier manufacturer supply chain[J]. European Journal of Operational Research, 2010, 202(3):717-729.
[2] B C Giri, A Chakraborty, T Maiti. Quality and pricing decisions in a two-echelon supply chain under multi-manufacturer competition [J]. Int J Adv Manur Technol, 2015, 44(78): 1927-1941.
[3] Federgruen A. Competition under generalized attraction models: Applications to quality competition under yield uncertainty[J]. Management Science, 2009, 55(12):2028-2043.
[4] Estampe D, Lamouri S, Paris J L, et al. A framework for analyzing supply chain performance
evaluation models[J]. International Journal of Production Economics, 2013, 142(2):247-258

[5] Xie Gang, Wang Shougang, Lai K K. Quality improvement in competing supply chains[J]. International Journal of Production Economics, 2011,134(1):262-270

[6] Tsay A, Agrawal N. Channel dynamics under price and service competition [J]. Manufacturing & Service Operations Management, 2000, 2(4):372-391.

[7] Boyaci T, Gallego G. Supply chain coordination in a market with customer service competition[J]. Production and Operations Management, 2004, 13(01): 3-22.

[8] Lim Wei Shi. Producer-supplier contracts with incomplete information[J]. Management Science, 2001,47(5):709-715.