Quality improvement in a supply chain with horizontal competition

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Abstract
Supply quality management is becoming an important part of a manufacturer’s work with suppliers, and has recently received significant attention from researchers. This paper focuses on a supply chain system that consists of a supplier and two competing manufacturers, examines quality strategies in different cooperative mechanisms and investigates the effects of different cooperative mechanisms on channel members’ profits. A modified Nerlove-Arrow model is employed to describe quality levels on goodwill and sales of products. Utilizing differential game theory, we calculate and compare the equilibrium quality decisions and profits of all channel members in three different scenarios; that is, (i) each channel member makes decisions with a non-cooperative program; (ii) each channel member makes decisions with a cooperative program; (iii) the supplier cooperates with a manufacturer as a joint venture. Our analysis reveals that the traditional cooperative mechanism is not very effective in the horizontal competitive market. Finally, it is noted that each channel member can obtain an extra benefit if a transfer payment exists.

Keywords: Supply chain management, Quality improvement, Goodwill, Differential games
1. Introduction

Today, the public is paying more attention to product quality. A survey in the auto industry showed that product quality is becoming the second most important factor affecting consumers’ purchase decisions after product price (J.D. Power and Associates, 2004). In a number of industries, competition is shifting from price to quality in specific segments of the market (Gans, 2002; Ren and Zhou, 2008). Thus, firms are turning to the tactic of increasing their product quality as a powerful competitive tool in the market.

For most product, the procedure from raw materials to final product is not within a single firm but throughout a supply chain, therefore, the manufacturer’s final product quality depends on not only its own quality efforts but also on the quality of the component supplied by its supplier (Reyniers and Tapiero, 1995; Robinson and Malhotra, 2005; Foster Jr, 2008; Hsieh and Liu, 2010). In fact, there are many quality incidents caused by low component quality. For instance, Ford reported that 76% of the company’s quality problems stem from its suppliers (Sherefkin, 2002). In practice, supply quality management is becoming an important part of a manufacturer’s work with suppliers (El Ouardighi and Kim, 2010), and the supply chain quality becomes a key component in achieving competitive advantage (Xie et al., 2011). Intel chose some of its suppliers to participate in its quality improvement programs (Roos, 2001). GE offered an annual budget of $200 to $400 million for its Six Sigma program, a significant portion of which is for the sole purpose of improving its suppliers’ component quality (Snee and Hoerl, 2003). It is becoming a common practice that the manufacturer shares a part of the supplier’s quality cost to stimulate the supplier do more on the quality improvement (Balachandran and Radhakrishnan, 2005). Surveys showed that manufacturers are more willing to involve suppliers during the product development process in the auto industry (Kisiel, 2007).

The supply quality management has also received significant attention from researchers. In operations management, a group of papers discussed quality improvement from a supply chain perspective. Reyniers and Tapiero (1995) studied the effect of a contract on a supplier’s quality improvement effort in both a non-cooperative and a cooperative game under the assumption of complete information. Lim (2001) extended the work of Reyniers and Tapiero (1995) into a supply chain with incomplete information. Balachandran and Radhakrishnan (2005) modeled the fixed share rate contract for allocating the costs of internal failures. Tapiero (2007) adopted the traditional Neyman-Pearson theory to the control of quality in a supply chain system. Zhu et al. (2007) explored the roles of different channel members in quality improvement and how firms can coordinate the supply chain. Different from the work of Zhu et al. (2007), Chao et al. (2009) looked at a setting where the manufacturer’s effort affects the final quality of the product and discussed the cost sharing contracts to coordinate the supply chain. Hsieh and Liu (2010) investigated the quality investment decisions of the supplier and the manufacturer in four non-cooperative games with different degrees of information available. Xie et al. (2011) investigated quality investment and price decision of a make-to-order supply chain with uncertain demand. Xiao et al. (2011) developed a
game theoretic model to explore how the manufacturer coordinates the supply chain with a quality assurance policy via a revenue sharing contract. Lee et al. (2013) considered a supply chain with quality uncertainty, and proposed the quality compensation contract to coordinate the supply chain. Ma et al. (2013) investigated the equilibrium quality and marketing efforts of the manufacturer and the retailer under three supply chain structures.

The above literature is mainly focused on a “single upstream firm and single downstream firm” framework. The significant contribution of this paper is that it generalizes existing supply quality management work on “single-supplier single-manufacturer” framework to the “single-supplier two-manufacturer” framework. This generalization has provided new analytical results about how the decision makers choose the quality strategies in the horizontal competitive market. In detail, the supply chain system considered in this paper consists of a supplier and two competing manufacturers, where the two manufacturer produce/sell similar final product that consists of two components (e.g., one is provided by the supplier and the other is offered by the manufacturer), which is a fairly common assumption in the relevant literature (Chao et al., 2009). Utilizing differential game theory, the equilibrium quality decisions for all channel members are calculated in three different scenarios: (i) each channel member makes decisions with a non-cooperative program; (ii) each channel member makes decisions with a cooperative program, and (iii) the supplier cooperates with a manufacturer as a joint venture.

The remainder of this paper is structured as follows. Section 2 develops the general models for the three scenarios. The equilibrium quality decisions for the all channel members in three different scenarios are discussed in Section 3. Section 4 offers a numerical analysis. Concluding remarks are in Section 5.

2. The model

The supply chain system considered here includes one supplier and two competing manufacturers, where the manufacturer produces a final product that consists of two components, one is provided by the supplier, the other is provided by the manufacturer. In addition, the two manufacturers produce/sell the similar products with different brands which are denoted as \( i, i \in \{1,2\} \). Denote \( x_i(t) \) as the quality level of the component that offered by the supplier over time \( t \), \( x_{m1}(t) \) and \( x_{m2}(t) \) as the quality levels of the components that provided by the two manufacturers over time \( t \) respectively. Based upon the model of Nerlove and Arrow (1962), the changing of the stock of goodwill for the supplier is given by Eq. (1),

\[
\frac{dG_s(t)}{dt} = x_i(t) - \delta G_s(t), \quad G_s(0) = G_s^0 \geq 0,
\]

where \( \delta > 0 \) is the diminishing rate of goodwill, and the item \( G_s^0 \) implies the initial goodwill level of the supplier.

Due to the “brand halo” effect (Bendixen et al., 2004; Zhang et al., 2013), the supplier’s goodwill can be partly transferred to the manufacturer’s goodwill, and thus the changing of the stock of goodwill of two manufacturers are given by Eq. (2),

\[
\frac{dG_{mi}(t)}{dt} = \lambda_{si} x_i(t) + \lambda_{mu} x_{m1}(t) + \beta G_i(t) - \delta G_{mi}(t), \quad G_{mi}(0) = G_{mi}^0 \geq 0, \quad i \in \{1,2\}.
\]

where \( \lambda_{si}, \lambda_{mu}, \) and \( \beta \) are all positive constants, the expression \( \lambda_{si} x_i(t) + \lambda_{mu} x_{m1}(t) \) indicates the quality of the final product \( i \). The item \( \beta G_i(t) \) gives the “brand halo” effect on the manufacturer’s goodwill.

In this paper, the competition is based primarily on the use of non-price
competitive strategies, thus we assume that the price of the final product \( p_i(t) \) is kept constant. Further, we assume that the sales of the final products \( S_i(t) \) are determined by the goodwill levels of both manufacturer and the quality of the two final products, which is given by the Eq. (3),

\[
S_i(t) = k_i \alpha + G_{m_i}(t) + \lambda_{m_i} x_i(t) + \lambda_{m_m} x_{m_i}(t) - \chi G_{m_{m_i}}(t)
\]

where \( k_i, i = 1, 2 \) are positive constants, and \( k_1 + k_2 = 1 \). Here, \( k_i \alpha \) is the potential intrinsic demand for firm \( i, i = 1, 2 \), which is irrespective of product quality. In Eq. (3), \( G_{m_i}(t) \) represents the manufacturer’s goodwill on sales, which is long-term effect, while the expression \( \lambda_{m_i} x_i(t) + \lambda_{m_m} x_{m_i}(t) \) implies the effect of the final product \( i \)’s own quality on the sales. The parameter \( \chi(\theta) \) denotes the sales responsiveness to the competitor’s brand (quality), and \( 0 < \chi, \theta < 1 \) are both constants, which implies that firm’s own efforts have a greater impact on sales than that of its competitor’s efforts, which is a fairly common assumption in the relevant literature (Banker et al., 1998; Nair and Narasimhan, 2006).

The quality cost function is quadratic with respect to quality level, specified by:

\[
C(x_i(t)) = \mu_i x_i^2(t), \quad C(x_{m_i}(t)) = \mu_{m_i} x_{m_i}^2(t), \quad i \in \{1, 2\}
\]

where \( \mu_i, \mu_{m_i} \) are positive cost parameters, and the cost parameter is scaled to 1 for the sake of simplicity. Then, we denote the marginal profit of the supplier as \( \rho_{s_i} \), and the manufacturer’s marginal profit as \( \rho_{m_i} \). Thus, the profit function for the supplier is given by Eq. (5),

\[
\pi_s(t) = \rho_{s_i} S_i(t) + \rho_{s_2} S_2(t) - x_i^2(t),
\]

and the profit function for the manufacturer \( i \) is

\[
\pi_{m_i}(t) = \rho_{m_i} S_i(t) - x_{m_i}^2(t), \quad i \in \{1, 2\}.
\]

Then, we will calculate the equilibrium quality decisions for all channel members in three different scenarios.

3. Equilibria

We start by analyzing the first scenario (benchmark scenario), and use the subscript “N” to signify this “non-cooperative scenario”. In the second scenario, players make decisions with a cooperative program, and we use subscript “C” to signify this scenario. The third scenario characterizes a joint venture, and we use subscript “J” to signify “joint venture scenario”.

3.1 Scenario I: Each channel member makes decisions with a non-cooperative program.

In this benchmark scenario, we focus on the decentralized setting of the game in which each player aims to maximize his own objective function. And the profit functions for all channel members are given by Eqs. (5) and (6). With a common discount rate \( r > 0 \) and for the sales \( S_i(t) \geq 0 \), we have

\[
\max_{x_i \geq 0} J_s^N = \int_0^{\infty} e^{-rt} \pi_s(t) dt,
\]

and for the manufacturer \( m_i \), we have

\[
\max_{x_{m_i} \geq 0} J_{m_i}^N = \int_0^{\infty} e^{-rt} \pi_{m_i}(t) dt,
\]

Using the necessary conditions for equilibrium, we obtain the following results:
Proposition 1. When each channel member makes decisions with a non-cooperative program, the equilibrium quality level for the supplier along time \( t \) is constant, i.e.,
\[
x_i^N(t) = \frac{1}{2} \left[ \lambda_{s1}(\rho_{s1} - \theta\rho_{s2}) + \lambda_{s2}(\rho_{s2} - \theta\rho_{s1}) \right] + \frac{\beta(1 - \chi)(\rho_{s1} + \rho_{s2})}{2(r + \delta)^3} + \frac{\lambda_{s1}(\rho_{s1} - \chi\rho_{s2}) + \lambda_{s2}(\rho_{s2} - \chi\rho_{s1})}{2(r + \delta)},
\]
(9)
the equilibrium quality level for the manufacturer \( m_i \) along time \( t \) is constant, i.e.,
\[
x_m^N(t) = \frac{1}{2} \left( \lambda_{m1}\rho_{mi} + \frac{\lambda_{m2}\rho_{mi}}{r + \delta} \right), \quad i \in \{1, 2\}.
\]
(10)
According to the Eq. (9), we find that when the conditions \( \theta \leq \min\{\rho_{s1}, \rho_{s2}, \rho_{s2} / \rho_{s1}\} \) and \( \chi \leq \min\{\rho_{s1}, \rho_{s2}, \rho_{s2} / \rho_{s1}\} \) are both satisfied, the equilibrium quality level for the supplier is always a largest possible constant compared to that the conditions are not satisfied. Further, we analyze the factors that the supplier mainly considers when determining the equilibrium quality level: (i) The first factor is the supplier’s marginal profits \( \rho_{s1} \) and \( \rho_{s2} \). Differentiating \( x_i^N \) from \( \rho_{s1} \) and \( \rho_{s2} \), we have \( \partial x_i^N / \partial \rho_{s1} > 0 \). Under this situation, as the supplier’s marginal profits \( \rho_{s1} \) and \( \rho_{s2} \) increase, the supplier will spend more on the quality improvement. (ii) The second factor is the diminishing rate of goodwill \( \delta \), if the goodwill diminishes quickly, the equilibrium quality level of the supplier would drop. (iii) The third factor is the discount rate \( r \), when the discount rate is large, namely, the decision makers do not feel confident in future, the supplier would spend less on the quality improvement. (iv) The fourth factor is the “brand halo” effect coefficient \( \beta \), if the consumers sensitive to supplier’s brand (i.e., a large \( \beta \)), the supplier will do more on the quality improvement to enhance the company brand. (v) The last factor is the competition intensity \( \theta(\chi) \), when the competition intensity is small, the supplier will spend more on his quality improvement, and once the conditions \( \theta, \chi = 0 \) are satisfied, the quality level of the supplier will reach the maximum, which also means the component which is provided by the supplier is suitable to different industries.

According to the Eq. (10), we can obtain the following management implications: (i) When the manufacturer’s marginal profit increases, the manufacturer will do more on his quality improvement. (ii) The manufacturer’s equilibrium quality level does not depend on competitive intensity. (iii) The equilibrium quality level of the manufacturer is determined by two parts: \( \lambda_{m1}\rho_{mi} \) and \( \lambda_{m2}\rho_{mi} / (r + \delta) \). The first item implies the instant effect of quality on the sales; the latter specifies the long-term effect of quality on sales through the brand effect. (iv) Specifically, the second item decreases sharply when the diminishing rate of goodwill becomes very large or the managers are shorter sighted. Thus, if the managers do not feel confident in the future, or the goodwill diminishes quickly, they will do less on their quality improvement.

Substituting Eqs. (9)-(10) into Eqs. (7) and (8) respectively, we get the current value of all channel members’ profits (i.e., \( J_s^N, J_m^N, J_{m2}^N \)).

3.2 Scenario II: Each channel member makes decisions with a cooperative program.

In this scenario, the supplier cooperates with one of the manufacturers, we assume this manufacturer is \( m1 \), then each channel member makes decisions with a cooperative program, where the cooperative program has the manufacturer provide a
subsidy rate $\phi(0 \leq \phi \leq 1)$ for the supplier’s quality improvement cost. With a fixed subsidy rate, the profit function for the supplier in Eq. (5) is then changed into

$$\pi^C_s(t) = \rho_{s1}S_1 + \rho_{s2}S_2 - (1 - \phi)x^2_s,$$

and the profit function for the manufacturer $m1$ in Eq. (6) is then changed into

$$\pi^C_m(t) = \rho_{mi}S_1 - x^2_m - \phi x^2_s,$$

while the profit function for the manufacturer $m2$ is not changed.

Using the necessary conditions for equilibrium, we obtain the following results:

**Proposition 2.** When each channel member makes decisions with a cooperative program, the equilibrium quality level for the supplier along time $t$ is constant, i.e.,

$$x^C_s(t) = \frac{1}{2(1 - \phi)} \left( (\rho_{s1} - \theta\rho_{s2})\lambda_{s1} + (\rho_{s2} - \theta\rho_{s1})\lambda_{s2} \right) + \frac{\beta(1 - \chi)(\rho_{s1} + \rho_{s2})}{2(1 - \phi)(r + \delta)} + \frac{(\rho_{s1} - \chi\rho_{s2})\lambda_{s1} + (\rho_{s2} - \chi\rho_{s1})\lambda_{s2}}{2(1 - \phi)(r + \delta)},$$

the equilibrium quality level for the manufacturer $m_i$ along time $t$ is constant, i.e.,

$$x^C_{mi} = \frac{1}{2} \left( \lambda_{mi}\rho_{mi} + \frac{\lambda_{mi}\rho_{mi}}{r + \delta} \right), ~ i \in \{1, 2\}.$$

Compared with the results of Proposition 1, we find that, under the cooperative program, the equilibrium quality levels of all channel members have a similar structure to that under the non-cooperative program. However, the equilibrium quality level of the supplier is higher than that under a non-cooperative program, and as the subsidy rate $\phi$ increases, the supplier will do more on its quality improvement. But for the manufacturers, their equilibrium quality levels are not changed if the supplier cooperates with the manufacturer $m1$ with a cooperative program, which implies that manufacturers’ equilibrium quality levels do not depend on the cooperation between the supplier and the manufacturer $m1$. Substituting Eqs. (11)-(14) into Eqs. (11) and (12) respectively, we get the current value of all channel members’ profits (i.e., $J^C_s$, $J^C_{mi_1}$, $J^C_{mi_2}$).

**3.3 Scenario III: The supplier cooperates with a manufacturer as a joint venture.**

In this scenario, the supplier cooperates with one of manufacturers as a joint venture, we assume this manufacturer is $m1$, and there exists a new corporate entity that provides the components to the two manufacturers and determines the components quality level $x_s(t)$ instead of the original supplier. This cooperative program is generally the case in many industries. Then the Eq. (1) is changed into

$$dG_n(t) / dt = x_s(t) - \delta G_n(t), ~ G_n(0) = G_n^0 \geq 0,$$

the changing of the stock of goodwill of two manufacturers in Eq. (2) is changed into

$$dG_{mi}(t) / dt = \lambda_{mi}x_s(t) + \lambda_{mi}x_{mi}(t) + \beta G_{mi}(t) - \delta G_{mi}(t), ~ G_{mi}(0) = G_{mi}^0 \geq 0, ~ i \in \{1, 2\}.$$

The profit function of the new firm is given by

$$\pi^J_n(t) = \rho_{s1}S_1(t) + \rho_{s2}S_2(t) - x^2_s(t).$$

Here, the marginal profits of the new firm are identical to that of the original supplier, in addition, the new firm usually has an independent managerial authority and aims to maximize his own objective function. When the supplier and the manufacturer $m1$ cooperate as a joint venture, they often have a predetermined contract that specifies how to divide the subsidiary’s final profits. Initially, we assume the sharing ratio for the manufacturer $m1$ is $\psi(0 \leq \psi \leq 1)$. Then the profit function of the supplier is given by:

$$J^C_s = \frac{1}{2(1 - \phi)} \left( (\rho_{s1} - \theta\rho_{s2})\lambda_{s1} + (\rho_{s2} - \theta\rho_{s1})\lambda_{s2} \right) + \frac{\beta(1 - \chi)(\rho_{s1} + \rho_{s2})}{2(1 - \phi)(r + \delta)} + \frac{(\rho_{s1} - \chi\rho_{s2})\lambda_{s1} + (\rho_{s2} - \chi\rho_{s1})\lambda_{s2}}{2(1 - \phi)(r + \delta)}.$$
\[ \pi'_m(t) = (1 - \psi) \left( \rho_{s1} S_1(t) + \rho_{s2} S_2(t) - x^2(t) \right), \]  
\[ \text{and the profit function of the manufacturer } m1 \text{ is} \]
\[ \pi'_{m1}(t) = \rho_{m1} S_1(t) - x^2_{m1}(t) + \psi \left( \rho_{s1} S_1(t) + \rho_{s2} S_2(t) - x^2(t) \right), \]  
\[ \text{and the profit function of the manufacturer } m2 \text{ is} \]
\[ \pi'_{m2}(t) = \rho_{m2} S_2(t) - x^2_{m2}(t). \]  

Using the necessary conditions for equilibrium, we obtain the following results:  

**Proposition 3.** The supplier cooperates with a manufacturer as a joint venture, the equilibrium quality level for the new firm along time \( t \) is constant, i.e.,
\[ x'_m(t) = \frac{1}{2} \left( (\rho_{s1} - \theta \rho_{s2}) \lambda_{s1} + (\rho_{s2} - \theta \rho_{s2}) \lambda_{s2} \right) + \frac{\beta(1-\chi)(\rho_{s1} + \rho_{s2})}{2(r + \delta)^2} \]
\[ + \frac{(\rho_{s1} - \chi \rho_{s2}) \lambda_{s1} + (\rho_{s2} - \chi \rho_{s2}) \lambda_{s2}}{2(r + \delta)}, \]  

the equilibrium quality level for the manufacturer \( m1 \) along time \( t \) is constant, i.e.,
\[ x'_m = \frac{1}{2} \left( \lambda_{m1} \rho_{m1} + \frac{\lambda_{m1} \rho_{m1}}{r + \delta} \right) + \frac{1}{2} \psi \left( \lambda_{m1} (\rho_{s1} - \theta \rho_{s2}) + \frac{\lambda_{m2} \rho_{s2}}{r + \delta} \right), \]  

the equilibrium quality level for the manufacturer \( m2 \) along time \( t \) is constant, i.e.,
\[ x'_m = \frac{1}{2} \left( \lambda_{m2} \rho_{m2} + \frac{\lambda_{m2} \rho_{m2}}{r + \delta} \right). \]  

Together with the Eq. (9), we find the equilibrium quality level for the upstream firm (e.g., supplier or new firm) is not changed in Scenario I and III, in other words, the equilibrium quality level for the upstream firm does not depend on fact that the supplier cooperates with a manufacturer as a joint venture. Combining the Eq. (23) with the Eqs. (10) and (14), we note that the manufacturer \( m2 \) maintains the same quality level for his own component, no matter whether the supplier cooperates with the manufacturer \( m1 \) or not. In addition, the equilibrium quality level of the manufacturer \( m2 \) is not affected by the competition intensity in these three different scenarios. But for the manufacturer \( m1 \), by comparison with Eq. (10), we can get \( x'_m \geq x'_N \), which indicates that the equilibrium quality level for the manufacturer \( m1 \) with a joint venture is higher than that under a non-cooperative program, by an increment \( 0.5\psi(\lambda_{m1} (\rho_{s1} - \theta \rho_{s2}) + \frac{\lambda_{m2} (\rho_{s1} - \chi \rho_{s2})}{(r + \delta)}) \). An examination of this increment implies that as \( \psi \rightarrow 1 \), the value of the increment increases, and it exhibits its maximum value when \( \psi = 1 \). It appears that as the manufacturer \( m1 \) share of the new firm’s profit increases \( (\psi \rightarrow 1) \), the manufacturer \( m1 \) is likely to suggest a higher quality level for his own component. In the first two scenarios, the equilibrium quality level of the manufacturer \( m1 \) is not affected by the competition intensity, while if the supplier cooperates with the manufacturer \( m1 \) as a joint venture, an increase in competition intensity will decrease the manufacturer \( m1 \)’s equilibrium quality level. In addition, if the new firm obtain a large margin profit from selling the component to the manufacturer \( m2 \), the manufacturer \( m1 \) would do less on quality improvement, while if the new firm get a large margin profit from selling the component to the manufacturer \( m1 \), the manufacturer \( m1 \) would spend more on his quality improvement. Substituting Eqs. (21)-(23) into Eqs. (18)-(20) respectively, we get the current value of all channel members’ profits (i.e., \( J'_s, J'_m, J'_N \)).

4. Numerical Analysis
In this section, we use numerical analysis to further illustrate the impacts of the subsidy rate and sharing ratio on the profits for all channel members. In our numerical analysis, we use the following values to establish ranges for model parameters:

\[ \alpha = 200, \quad k_1 = 0.6, \quad k_2 = 0.4, \quad \lambda_{11} = 4, \quad \lambda_{12} = 5, \quad \lambda_{m1} = 5, \quad \lambda_{m2} = 4, \quad \rho_{s1} = 3, \quad \rho_{s2} = 4, \quad \rho_{m1} = 6, \quad \rho_{m2} = 5, \quad \delta = 0.2, \quad \beta = 0.2, \quad \theta = 0.3, \quad \chi = 0.2, \quad r = 0.3, \quad G_0 = 40, \quad G_{01} = 60, \quad G_{02} = 70, \quad \text{and} \quad G_n = 50. \]

To obtain qualitative insight regarding how the current value of each channel member’s profit varies as the subsidy rate \( \phi \) and sharing ratio \( \psi \) vary in three different scenarios, we keep the other parameters fixed and draw the relationships in the following Figures.

According to the Fig. 1, for the supplier, we can find the following results: (i) All else being equal, as the subsidy rate \( \phi \) increases, the profit for the supplier will increase when there exists a cooperative program, while the increase of the sharing ratio \( \psi \) will lead to the profit of the supplier decreases if the supplier cooperates with the manufacturer \( m1 \) as a joint venture. (ii) Compared with the benchmark scenario, the profit of the supplier always has a profit improvement if he can obtain the subsidy from the manufacturer \( m1 \). But the supplier’s benefit would be suffered if he cooperates with a manufacturer as a joint venture, thus, the supplier may not be willing to adopt this cooperative mechanism. Only when the supplier has not enough R&D ability to improve his component quality level to satisfy the demand of downstream firms, the supplier has to cooperate with the manufacturer as a joint venture. From the Fig.1, we also obtain some following results for the manufacturer \( m1 \): (i) Under the cooperative program, as the subsidy rate \( \phi \) increases, the profit of the manufacturer \( m1 \) will increase at first, and then decrease continuously after it reaches its maximum. (ii) Compared with the benchmark scenario, the manufacturer \( m1 \) would obtain more profit if the subsidy rate \( \phi \) is not large, once the value of the subsidy rate greater than a threshold, the manufacturer \( m1 \)’s benefit will be suffered. Additionally, the manufacturer \( m1 \) does not obtain a large benefit from this cooperative program. But according to the Fig. 3, the rival will obtain a large benefit from this cooperative program; this phenomenon can be explained by the rival’s “Free Rider” effect. Thus, this cooperative program is not very effective in the horizontal competitive market. (iii) If the supplier cooperates with the manufacturer \( m1 \) as a joint venture, the increase of the sharing ratio \( \psi \) will lead to the profit of the manufacturer \( m1 \) always increases. When the sharing ratio \( \psi \) equals to one, the profit of manufacturer \( m1 \) will reach the maximum. This is a extreme case, which means the supplier is acquired by the manufacturer \( m1 \). (iv) Compared with the
benchmark situation, once the sharing ratio $\psi$ greater than zero, the profit for the manufacturer $m1$ always has a profit improvement.

Using Fig.2, we can obtain the following facts: (i) Compared with the benchmark scenario, if the manufacturer $m1$ provides a subsidy to the supplier, the profit for the manufacturer $m2$ always has a profit improvement. The cooperation between the supplier and the manufacturer $m1$ will bring an extra benefit to the manufacturer $m2$, which can be explained by the “Free Rider” effect to some extent. (ii) With the increase in the subsidy rate $\phi$, the profit for the manufacturer $m2$ always increases in Scenario II. (iii) While as the sharing ratio $\psi$ increases, the profit of the manufacturer $m2$ will drop in Scenario III. (iv) Compared with benchmark scenario, if the supplier cooperates with manufacturer $m1$ as a joint venture, the profit of the manufacturer $m2$ will drop. Fig. 2 also shows that: (i) Compared with the benchmark scenario, the profits of the two firms (supplier and manufacturer $m1$) always have a profit improvement if the supplier cooperates with the manufacturer $m1$ as a joint venture. Together with the Fig. 1, if the manufacturer $m1$ provides a transfer payment to compensate the supplier’s loss, both the supplier and manufacturer can get an extra benefit from this cooperation. (ii) As the sharing ratio $\psi$ increases, the profits of these two firms will increase. (iii) Under the second scenario, the profits for these two firms will increase at first, and then decrease continuously after they reach the maximum. Together with the Fig. 1, we can find that if the profits for these two firms reach the maximum, the manufacturer $m1$’s benefit would suffer, thus the manufacturer may not be willing to provide a high subsidy rate $\phi$. However, if the supplier provides a transfer payment to compensate the manufacturer $m1$’s loss, both the supplier and manufacturer can get an extra benefit from the cooperation. (iv) Compared with the benchmark scenario, if the subsidy rate $\phi$ becomes very high, the profits for the two firms will drop.

5. Conclusion and directions for future research

The supply chain system considered in our paper consists of one supplier and two competing manufacturers. Utilizing differential game theory, the equilibrium quality decisions for all channel members are calculated and compared in three different scenarios. Some interesting results of this paper include the following: (i) The equilibrium quality level of manufacturer $m2$ is not affected by these factors (e.g., competition intensity, subsidy rate or sharing ratio). (ii) Due to the “Free Rider” effect, the manufacturer $m2$ may obtain an extra benefit if its rival provides a subsidy to the supplier. (iii) The traditional cooperative mechanism is not very effective in the horizontal competitive market. (iv) Compared with the benchmark
scenario, all channel members can obtain an extra benefit if a transfer payment exists.

Our study has some limitations that present directions for future research. It should be noted that our models assume that the price is held constant. It may be more interesting if we introduce the factors of pricing and advertising into the model.

Reference