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BUNDLING STRATEGY IN COMPLEMENTARY PRODUCT SUPPLY CHAIN

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Abstract. *While most bundling decisions studied in the literature are geared to centralized system and focused on the independent products, we examine bundling strategy of complementary products with positive bundling effect in a decentralized supply chain channel. In this paper, we establish the complex pricing games among the channel members, and generate some interesting insights of the profitability of complementary product bundling. Bundle profits of all members and channel will increase in the bundling effect, and there exists a threshold of bundling effect for channel's Pareto improvement. We also analyze the effect of channel power structure on the profitability of bundling strategy, and find that the attraction of complementary product bundling will be stronger in a supply chain consisting of members with more equal channel power. Several numerical experiments are constructed to illustrate the properties of thresholds and the effect of complementary coefficient on suppliers' bundle profit. The results show that all thresholds decrease in the products' cost proportion and the suppliers' thresholds are also related to complementary coefficient.*

Keywords: Supply chain management, Complementary product, Bundling effect, Decentralized channel

1. **Introduction.** The bundling strategies are very common in our life, for example, Nippon paint and its refreshing service, travel solutions, automobile and automotive electronic equipment, and management solutions. In common sense, the manufacturers or retailers can earn more by the bundling products; however, the bundling strategies are not always beneficial in the real cases. Some mobile phone manufacturers who have attempted personal digital assistant functions in the phone configuration failed to get more profit. In this paper, we investigate the decentralized supply chain channel with complementary products, and provide a bundling strategy to obtain the equilibrium of complex pricing game among the channel members.

Currently, the bundling strategies mostly are investigated in marketing area, and the scenario with one decision-maker case is considered. Oldenrog and Skiera [1] investigated the benefit of bundling strategy with the assumption that the reservation price distribution for the bundle is obtained as the convolution of components' reservation price distributions. Fang and Norman [2] derived the conditions for the profitability of pure bundling in the case of independent symmetric log-concave reservation price distributions. McCardle et al. [3] and Eckalbar [4] studied the bundling decisions involving two items with the uniformly distributed reservation prices, and they found that the profit of bundling depends on the demand and cost of the individual products, and the relationship between the items. These research presents some interesting managerial insights about the benefits of bundling strategy, in which the production cost of component product is exogenous and not impacted by the choice of selling strategy.

However, along with the transfer of competition from companies to supply chains, the decentralized channel is becoming more common in reality, and the bundling strategies are attractive to the researchers from the perspective of decentralized supply chain in operations management. In this scenario, the production cost is generally endogenous and impacted by the bundling strategy. Bhargava [5] analyzed the product bundling issues in a supply chain with a downstream retailer and two upstream manufacturers, and they found that the retailer always prefers to separate sales rather than bundling when she sells several products from different manufacturers. Chakravarty et al. [6] examined the bundling decisions in a two-stage supply chain, and focused on comparative analysis of advantages and disadvantages of different bundled forms; they found that if all parties coordinate a supply chain, it has more to gain from bundling relative to an integrated firm, and when the suppliers coordinate the bundling, gain is higher than when the retailer bundles the products. Girju et al. [7] found that selling pure components by both manufacturer and retailer is the equilibrium except in a narrow region of the parameter space.

In this paper, we study bundling strategy in a decentralized channel; however, there are two differences with the researches mentioned above. Firstly, we consider the bundling strategy of two complementary products whose reservations are related and take account of positive bundling effect of complementary products, following the assumption as Venkatesh and Kamakura [8] that the consumer's reservation price for bundle product would be higher than the sum of stand-alone reservation price of complements. Secondly, the members have asymmetric channel power where two complementary suppliers are channel leaders followed by retailer, and the main product supplier is stronger than another complementary supplier, which can be observed in many industries including high-tech electronics, automotive industries, and media.

The rest of this paper is organized as follows. Section 2 provides the problem description and analyses. We will detail the pricing games between the channel members, and study the profitability of complementary product bundling. Then, we analyze the impact of channel power on the profitability of product bundling in Section 3. In Section 4, we will do some parameter analyses through numerical experiments. Section 5 closes the paper with a short conclusion.

2. **Problem Description and Bundling Strategy in the Decentralized Channel.**

We consider two selling strategies of retailer: pure bundling and unbundling. In the pure bundling strategy, only the bundles of two complements 1 and 2 are offered with the retailing price p_b. In the unbundling strategy, the products are offered separately with retailing prices p_1, p_2. In each strategy, two upstream suppliers set the wholesale prices w_1, w_2 firstly, and then the retailer sets his retailing prices. We also assume that the supplier 1 who provides main product 1 acts as a leader followed by supplier 2 who provides complementary product 2.

The value of basic product 1 is represented by the customer's reservation price, which is a random variable whose distribution is uniform: $r_1 \sim U[0, a]$, $a > 0$. It is a common practice in the bundling literature to assume uniformly distributed reservation prices. We assume that the reservation price of complementary product 2 is $r_2 = (b/a)r_1$, $0 < b \leq a$. The similar assumption has been used in other researches such as those of McCardle et al. [3], Sheikhzadeh and Elahi [9] and Derdenger and Kumar [10]. Here we use b/a to denote the complementary coefficient of two products. In addition, it is reasonable to assume that: $c_1 < a$, $c_2 < b$, while c_1 and c_2 are the unit production costs of two products. The bundling effect of two complementary products is denoted as θ, and then we define bundle product's reservation price as $r_b = (1 + \theta)(r_1 + r_2)$. Evidently, θ is specific to a product pair, and it would be positive.

In a homogeneous market with size M, the customer will buy the product if the retailing price is not higher than his reservation price. Hence, we can get the market demands of product 1 and product 2 in the unbundling setting: $D_1 = M\left(1 - \frac{p_1}{a}\right)$, $D_2 = M\left(1 - \frac{p_2}{b}\right)$; and the demand of bundle products in the bundling setting: $D_b = M\left(1 - \frac{p_b}{(1+\theta)(a+b)}\right)$.

In the integrated supply chain, we can get the optimal prices under two different strategies: $p_1^{cu} = \frac{a+c_1}{2}$, $p_2^{cu} = \frac{b+c_2}{2}$; $p_b^{cb} = \frac{(a+b)(1+\theta)+c_1+c_2}{2}$. We use superscripts '$c$', '$u$' and '$b$' to denote centralized system, unbundling setting and bundling setting. Then we can get that: $\prod^{cb} \geq \prod^{cu}$, when $\theta \geq \theta^{cb*}$, $\theta^{cb*} = \frac{\left[\sqrt{\frac{(a-c_1)^2}{a}+\frac{(b-c_2)^2}{b}}+\sqrt{\frac{(a+c_1)^2}{a}+\frac{(b+c_2)^2}{b}}\right]^2}{4(a+b)} - 1$. Especially when $\frac{c_1}{a} = \frac{c_2}{b} = \lambda$, $\theta^{cb*} = 0$. It shows that the integrated system will get more profit in bundling setting than that in unbundling setting, when the bundling effect is higher than a threshold. The threshold is zero and the bundling strategy is always beneficial, when the two complementary products have the same cost proportion.

In the decentralized channel, we assume that $p_1 = w_1 + m_1$, $p_2 = w_2 + m_2$, where m_i $(i = 1, 2)$ is unit profit of product for retailer in unbundling setting, and $p_b = w_1 + w_2 + m_b$, where m_b means unit profit of bundle product for retailer in bundling setting. The standard backward deduction method will be used to solve the pricing games between members in the unbundling and pure bundling settings.

In the unbundling setting, given the wholesale prices w_1, w_2, the retailer makes the unique optimal reaction to maximize his profit $\prod_r^u = m_1\left(1 - \frac{p_1}{a}\right) + m_2\left(1 - \frac{p_2}{b}\right)$. We calculate $\frac{\partial \prod_r^u}{\partial m_1^u} = 0$ and $\frac{\partial \prod_r^u}{\partial m_2^u} = 0$, and get the equations:

$$m_1^u = \frac{a - w_1}{2}, \quad m_2^u = \frac{b - w_2}{2} \tag{1}$$

It could be proved that $\frac{\partial \prod_r^{u2}}{\partial m_1^{u2}} < 0$, $\frac{\partial \prod_r^{u2}}{\partial m_2^{u2}} < 0$, $\frac{\partial \prod_r^{u2}}{\partial m_1^u \partial m_2^u} > 0$, $\frac{\partial \prod_r^{u2}}{\partial m_2^u \partial m_1^u} > 0$, and the Hessian matrix $H = \begin{pmatrix} \frac{\partial \prod_r^{u2}}{\partial m_1^{u2}} & \frac{\partial \prod_r^{u2}}{\partial m_1^u \partial m_2^u} \\ \frac{\partial \prod_r^{u2}}{\partial m_2^u \partial m_1^u} & \frac{\partial \prod_r^{u2}}{\partial m_2^{u2}} \end{pmatrix} > 0$ which shows that the profit function is joint-concave and satisfies the second-order condition for a maximum and Equation (1) is the unique optimal solution for retailer.

With the retailer's reaction (1), the supplier 2's profit function could be written as $\prod_{s2}^u = (w_2 - c_2)\left(1 - \frac{w_2+m_2^u}{b}\right)$. Then we calculate $\frac{\partial \prod_{s2}^u}{\partial w_2^u} = 0$, and get the equation as:

$$w_2^u = \frac{b + c_2}{2} \tag{2}$$

It can be proved that $\frac{\partial \prod_{s2}^u}{\partial w_2^u} > 0$ when $w_2^u < \frac{b+c_2}{2}$ and $\frac{\partial \prod_{s2}^u}{\partial w_2^u} < 0$ when $w_2^u > \frac{b+c_2}{2}$. So the profit function is quasi-concave, and Equation (2) is the unique optimal solution for supplier 2.

Taking Equations (1) and (2) into supplier 1's profit function, the supplier 1 will the optimal wholesale price as $w_1^u = \frac{a+c_1}{2}$. So we get the equilibrium optimal solution of pricing game in the unbundling setting as $w_1^u = \frac{a+c_1}{2}$, $w_2^u = \frac{b+c_2}{2}$, $p_1^u = \frac{3a+c_1}{4}$, $p_2^u = \frac{3b+c_2}{4}$ and the profits: $\prod_{s1}^u = \frac{(a-c_1)^2}{8a}$, $\prod_{s2}^u = \frac{(b-c_2)^2}{8b}$, $\prod_r^u = \frac{(a-c_1)^2}{16a} + \frac{(b-c_2)^2}{16b}$, $\prod_s^u = \frac{3(a-c_1)^2}{16a} + \frac{3(b-c_2)^2}{16b}$.

Similarly, we solve the pricing game in pure bundling setting and get the firms' optimal solution: $w_1^b = \frac{(a+b)(1+\theta)+c_1-c_2}{2}$, $w_2^b = \frac{(a+b)(1+\theta)+3c_2-c_1}{4}$, $p_b^b = \frac{7(a+b)(1+\theta)+c_1+c_2}{8}$; and profits: $\prod_r^b = \frac{[(a+b)(1+\theta)-c_1-c_2]^2}{64(a+b)(1+\theta)}$, $\prod_{s1}^b = \frac{[(a+b)(1+\theta)-c_1-c_2]^2}{16(a+b)(1+\theta)}$, $\prod_{s2}^b = \frac{[(a+b)(1+\theta)-c_1-c_2]^2}{32(a+b)(1+\theta)}$, $\prod_s^b = \frac{7[(a+b)(1+\theta)-c_1-c_2]^2}{64(a+b)(1+\theta)}$.

Comparing the optimal prices and profits in the unbundling and pure bundling settings, we can get the following proposition without the process of proof.

Proposition 2.1. *If* $\frac{c_1}{a} = \frac{c_2}{b} = \lambda$ *and* $\theta > 0$*, then:*

(1) $\frac{\partial \prod_r^b}{\partial \theta} > 0$, $\frac{\partial \prod_{s1}^b}{\partial \theta} > 0$, $\frac{\partial \prod_{s2}^b}{\partial \theta} > 0$, $\frac{\partial \prod_s^b}{\partial \theta} > 0$;

(2) $\prod_i^b > \prod_i^u$ $(i = r, s_1, s_2, s)$ *when* $\theta > \theta_i^{b*}$ $(i = r, s_1, s_2, s)$*, where* $\theta_r^{b*} = 2(1-\lambda)^2 + (1-\lambda)\sqrt{2\lambda + 4(1-\lambda)^2} - (1-\lambda)$, $\theta_{s1}^{b*} = \frac{a(1-\lambda)^2 + (1-\lambda)\sqrt{2a(a+b)\lambda + a^2(1-\lambda)^2} - (a+b)(1-\lambda)}{a+b}$, $\theta_{s2}^{b*} = \max\left[0, \frac{2b(1-\lambda)^2 + (1-\lambda)\sqrt{4b(a+b)\lambda + 2b^2(1-\lambda)^2} - (a+b)(1-\lambda)}{a+b}\right]$, $\theta_s^{b*} = \frac{6(1-\lambda)^2 + 2(1-\lambda)\sqrt{21\lambda + 9(1-\lambda)^2} - 7(1-\lambda)}{7}$;

(3) The decentralized supply chain will be Pareto improved, when $\theta > \theta^{b*}$, $\theta^{b*} = \max\left\{\theta_i^{b*}(i = r, s_1, s_2, s)\right\} = \theta_r^{b*}$.

Part (1) of Proposition 2.1 shows that the bundle profits of members and supply chain will increase in the bundling effect. So there is unique threshold of bundling effect for every member and supply chain, as presented in part (2). The bundle profit of retailer is strictly more than unbundled profit, when the bundling effect is higher than his threshold. And we can prove that the retailer's threshold is the highest one of all. So we also call this highest one the supply chain Pareto improvement threshold, because the bundle profits of all members will be higher than unbundle profits as showed in part (3) of the above proposition.

The result shows the fact that bundling strategy of complementary products is not always benefit for firms, because the strategy will limit consumers' purchases and reduce the market demand. However, at the same time, channel members will benefit from the complementary bundling effect. The members would get more in bundling setting, only when the bundling effect is high enough. And then the bundling strategy is attractive for the supply chain in some cases. In another way, consistently with Bhargava and Hemant [5] and Girju et al. [7], we also prove that the conflict between members in the decentralized channel will weaken the attraction of bundling policy. Comparing with the centralized system, we get the inequality $\theta^{b*} > \theta^{cb*}$ which means that the bundling strategy is benefit for supply chain in smaller parameter range in a decentralized channel than that in centralized system.

3. The Impact of Channel Power.

In this section, we try to study the impacts of members' channel power on profitability of bundling strategy. In the first setting 1 where we use superscript 'b1' to denote it, two suppliers with the same channel power choose their wholesale prices simultaneously, and then downstream retailer sets his price for bundle product. The players' pricing game has a unique equilibrium that is given as:

$$w_1^{b1} = \frac{(a+b)(1+\theta) + 2c_1 - c_2}{3}, \quad w_2^{b1} = \frac{(a+b)(1+\theta) + 2c_2 - c_1}{3},$$

$$p^{b1} = \frac{5(a+b)(1+\theta) + c_2 + c_1}{6}.$$

Similarly, we could get the Pareto improvement threshold for supply chain as follows: $\theta^{b1*} = \frac{9(1-\lambda)^2 + 3(1-\lambda)\sqrt{16\lambda + 9(1-\lambda)^2} - 8(1-\lambda)}{8}$.

In the second setting 2 which is denoted by the superscript 'b2', the suppliers and retailer make their price decisions simultaneously. We can get the unique Nash equilibrium solution as:

$$w_1^{b2} = \frac{(a+b)(1+\theta) + 3c_1 - c_2}{4}, \quad w_2^{b2} = \frac{(a+b)(1+\theta) + 3c_2 - c_1}{4},$$

$$p^{b2} = \frac{3(a+b)(1+\theta) + c_2 + c_1}{4}.$$

The Pareto improvement threshold for supply chain is denoted as follows:

$$\theta^{b2*} = \max\left\{\frac{b(1-\lambda)^2 + (1-\lambda)\sqrt{2b(a+b)\lambda + b^2(1-\lambda)^2} - (a+b)(1-\lambda)}{a+b}, 0\right\}.$$

Comparing the solutions, we can get the following proposition about the impact of member's channel power on the performance of bundling strategy.

Proposition 3.1. *In three settings with different channel power structures, (1)* $p_b^{b2} < p_b^{b1} < p_b^b$*; (2)* $\prod_s^{b2} > \prod_s^{b1} > \prod_s^b$*; (3)* $\theta^{b2*} < \theta^{b1*} < \theta^{b*}$*.*

An interesting fact we observe in part (1) of Proposition 3.1 is that the retail price of bundle product will be the lowest in the supply chain where all members have the same channel power and make decisions simultaneously, and the bundle price in the setting with equal suppliers is lower than that in the basic setting. Then the bundle profit of supply chain will be higher in more equal channel power environment, as proved in part (2) of the proposition. Part (3) further highlights the impact of channel power on attraction of product bundling. As it shows, the threshold for Pareto improvement of supply chain will be smaller in more equal channels with congenial members. And then the bundling strategy is more attractive in more equal supply chain.

In addition, it is shown that the bundling strategy in the decentralized supply chain will be affected by the channel power structure. Bundle retailing price will be lower in more equal power structure, and the bundle profit will be higher. So the bundling strategy would be more attractive for customers and supply chain members, when the members have the equal power in the supply chain channel.

4. **Numerical Experiments.** Firstly, we can obtain some properties of thresholds in numerical experiments described in Figure 1 and Figure 2.

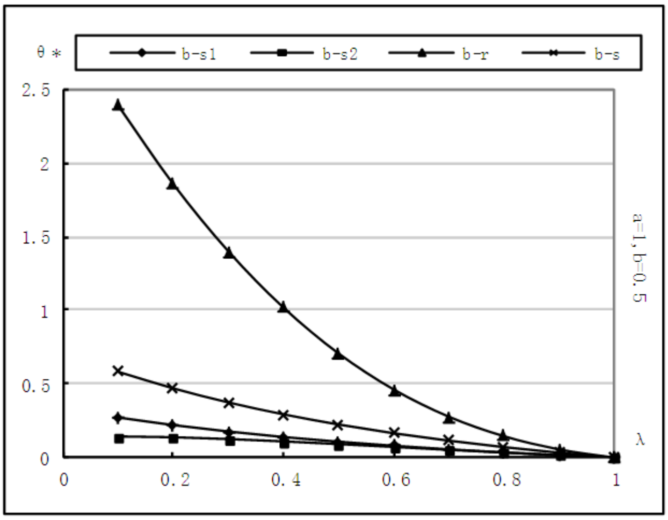

FIGURE 1. Thresholds and λ

From Figure 1, we can see that all thresholds decrease in cost proportion λ. Given the values of complementary products, the thresholds of members and supply chain will become lower with higher unit production cost. When cost proportion is close to 1 and the margin profit of product approaches to zero, the thresholds will approximate zero. It means that the bundling strategy of complementary products with smaller margin is more attractive for members and supply chain.

In addition, the thresholds of upstream suppliers are related to the complementary coefficient denoted by $k = b/a$, as described in Figure 2. The supplier 1's threshold will decrease in the value of k. When $k = 1$, his threshold will decrease to zero. However,

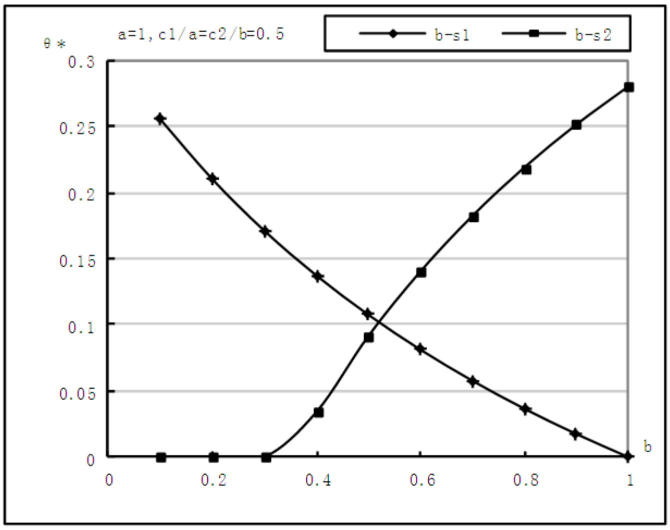

FIGURE 2. Thresholds of suppliers and k

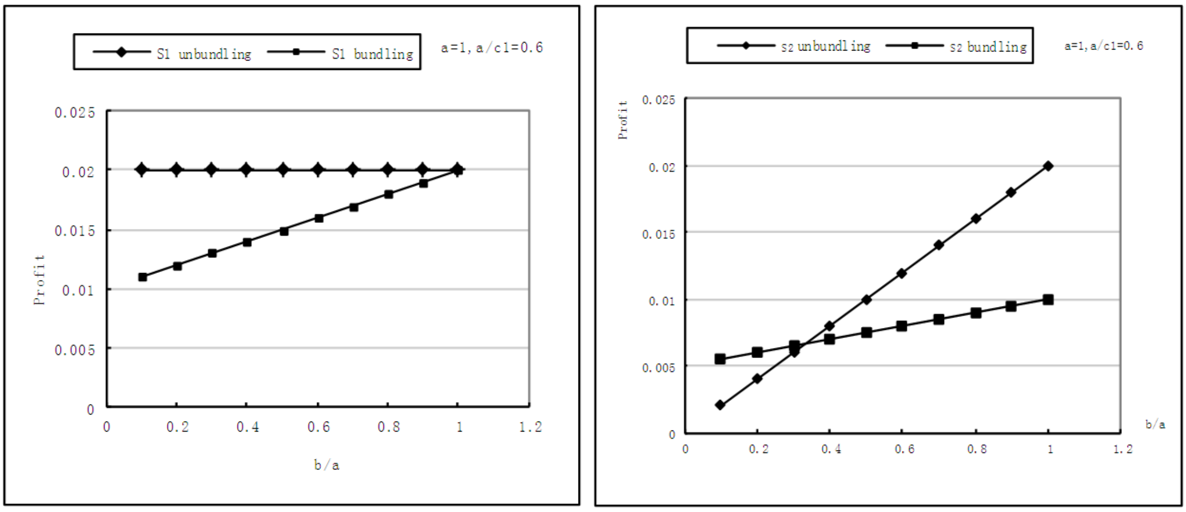

FIGURE 3. Complementary coefficient and bundle profit

conversely, the supplier 2's threshold increases in k. When k is small enough such as $0 < k < 0.333$, the threshold of supplier 2 will decrease to zero.

Secondly, we want to investigate the effect of complementary coefficient on the suppliers' bundle profit and get Figure 3.

In the case of fixed cost proportion λ and $\theta = 0$, Figure 3 shows that the bundle profit line of supplier 1 is always below unbundling profit line. So supplier 1 cannot benefit from bundling when $0 < k \leq 1$. However, supplier 2 could get more profit in bundling setting when the complementary coefficient is small enough and the value of his product is equivalently smaller than supplier 1's product, i.e., $0 < k < 0.333$.

Finally, we do further study on the attraction of bundling strategy in different power structure channels through numerical experiment descripted in Figure 4.

We denote the attraction of product bundling in centralized system as $\Delta \prod_c = \prod_{cb} - \prod_{cu}$ and the attraction in decentralized supply chain as $\Delta \prod_s = \prod_b - \prod_u$, and the reduction of attraction is denoted as $\Delta \prod_c - \Delta \prod_s$. From Figure 4, the reduction of attraction of bundling strategy is positive and it is more obvious in decentralized channel of complementary products with more significant bundling effect. In other words, the bundling effect will increase the reduction of bundling attraction for channel conflict. Meanwhile,

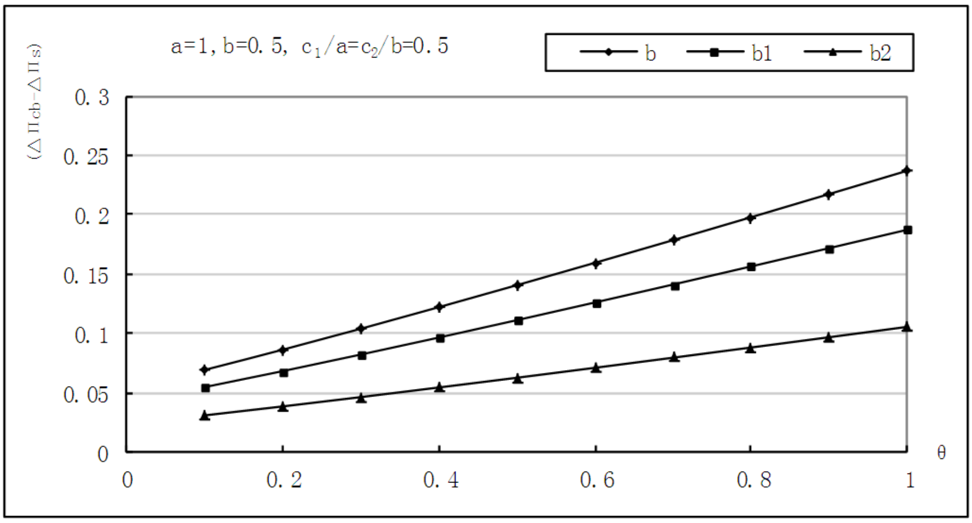

FIGURE 4. Reduction of attraction of bundling strategy

the reduction will decrease because of the channel power structure. In a more equal supply chain, the reduction will be smaller.

5. **Conclusion.** In this paper, we analyze the bundling strategy of complementary products in the decentralized supply chain. It is found that the bundle profits of members and channel increase in the bundling effect, and there exists a threshold of bundling effect for supply chain's Pareto improvement using bundling strategy. We also find that the channel conflict would weaken the attraction of product bundling, and the attraction of product bundling would be restored in decentralized supply chain where the members have more equal channel power.

Our research can be extended from different perspectives. First, in this research we only considered pure bundling strategy, and it should be possible to extend our research to mixed bundling in the supply chain. Second, it will be interesting to study the supply chain members' strategy choice of bundling.

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