Impact of product pricing and timing of investment decisions on supply chain co-opetition

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Abstract

In supply chain co-opetition, firms simultaneously compete and co-operate in order to maximize their profits. We consider the nature of co-opetition between two firms: The product supplier invests in the technology to improve quality, and the purchasing firm (buyer) invests in selling effort to develop the market for the product before uncertainty in demand is resolved. We consider three different decision making structures and discuss the optimal configuration from each firm’s perspective. In case 1, the supplier invests in product quality and sets the wholesale price for the product. The buyer then exerts selling effort to develop the market and following demand potential realization, sets the resale price. In case 2, the supplier invests in product quality followed by the buyer’s investment in selling effort. Then, after demand potential is observed, the supplier sets the wholesale price and the buyer sets the resale price. Finally, in case 3, both firms simultaneously invest in product quality and selling effort, respectively. Subsequently, observing the demand potential, the supplier sets the wholesale price and the buyer sets the resale price. We compare all configuration options from both the perspective of the supplier and the buyer, and show that the level of investment by the firms depends on the nature of competition between them and the level of uncertainty in demand. Our analysis reveals that although configuration 1 results in the highest profits for the integrated channel, there is no clear dominating preference on system configuration from the perspective of both parties. The incentives of the co-opetition partners and the investment levels are mainly governed by the cost structure and the level of uncertainty in demand. We examine and discuss the relation between system parameters and the incentives in designing the supply contract structure.

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1. Introduction

In supply chain co-opetition, firms may both compete and co-operate with each other in order to maximize their profits. Through co-operative relationships, the firms work to influence product demand by investing in
demand-enhancing efforts. These efforts may include, for example, investment in technology by one firm to improve product quality/design, as well as investment in selling effort by the other firm to develop the market for the product. The cost of these selling effort is incurred by the firm that exerts effort but the benefit, in form of improved demand potential, affects both firms. As such, due to the spillover effect, investment in innovation by either firm can benefit both supply chain partners. For instance, in the personal computer industry, demand for computers depends not only on the investment by Intel in newer generation of faster processors, but also on the innovations from the computer manufacturers (for e.g. Dell) in investing in infrastructure to provide customer support services. At the same time, the firms independently set prices in order to maximize their profits: the firm investing in product technology (supplier) may prefer to charge a higher wholesale price to the buying firm (buyer), whereas the firm exerting selling effort to develop the market (buyer) may prefer a higher resale price in the end-market. The timing of the price commitment decisions can influence the investment decisions as firms may not risk high investment in innovations due to the fear of opportunism by the other firm in setting a high price. We analyze the nature of both product pricing and timing of investment decisions for the two firms depending on the structure of the contract between them.

In this paper, we consider the problem of supply contract design for a one-time interaction between a supplier and a buyer. This assumption is widely used in the supply chain contracting literature and is applicable to many settings including those with seasonal or high-tech products. The main purpose and motivation of using such approach is to derive managerial insights for high level managers in supply chains. We study the problem at a macro level in order to investigate the incentives and equilibrium investment policies in a two echelon supply chain, and the contribution of the paper is to study the effect of timing of price commitment decisions on the investment decisions and on the profits for the two firms. While both the firms can benefit from each other’s investment in product quality and selling effort, respectively, the timing of the price commitment decisions influences the level of investment by the firms. As such, the nature of competition between firms affects the level of co-operation they provide to each other.

The supplier invests in the technology used to make the product; a larger investment in technology improves the quality of the product which results later in an increased demand potential for the product. However, the technology investment/quality-improvement costs are directly incurred by the supplying firm only. As such, the supplier may charge a high wholesale price in order to recuperate these costs. For instance, in the electricity markets, power generating firms can invest in different dimensions of power quality such as environmentally-friendly green power or premium power for sensitive computing, as opposed to lower quality interruptible power for flexible producers (Savitski, 2002). In the fast food retail business, final demand is not only affected by the retail price and the value added by the buyer, it also depends on the investments made by the franchisor in its brand name (Lal, 1990). In the automotive industry, Japanese firms made dramatic gains in market share in the 1980s as compared to the US firms by investing in quality-improvement efforts (Garvin, 1988).

Similarly, the buyer, e.g., a retailer, has the opportunity to influence final demand by choosing the appropriate selling/promotional efforts. Examples of such activities include breaking bulk, providing shelf spaces, promotional displays, advertising, and other demand enhancing activities. In the automotive industry, final demand depends not only on the quality/brand reputation of the product, but also on the dealer’s selling efforts including customer financing and after-sales service support, etc. The cost of these promotional efforts is directly incurred by the dealer only.

In general, demand enhancing investments such as the supplier’s technology choice and the buyer’s market building efforts involve long lead times and often need to be committed before final demand information for the end product is revealed. Therefore, in our setting, such investments are committed before demand uncertainty is resolved. On the other hand pricing decisions, i.e., the supplier’s wholesale pricing and the buyer’s resale pricing, can be postponed until after final demand potential is observed. While both firms can invest in demand enhancing innovations, there is a possibility that they may under-invest due to the fear that the other firm may take advantage of improved demand potential by charging a high price. As such, the investment and pricing decisions are inter-linked and the timing of price commitment would influence the level of investment in demand enhancing innovations. In order to analyze this, we model the structure of the decision making process between a supplier, \( S \), selling a product through an independent buyer, \( B \).

We consider three possible cases as outlined in Fig. 1: In case 1, the supplier invests in technology and offers the product with a certain quality and wholesale price to firm \( B \). There is no negotiation over the contract
terms – Firm B may accept the contract or reject it, in which case both sides could walk away. If firm B decides to accept the contract, he can influence the demand through his promotional/selling efforts. He determines the optimal selling effort before observing the final demand potential and postpones his resale pricing decisions until after uncertainty is resolved. Here, except for demand uncertainty, there is no source of risk for firm B since firm S commits to both wholesale price and quality-investment decisions a priori. In case 2, the supplier first invests in the technology and sets the product quality; subsequently, firm B invests in selling effort in order to develop the market. Here, both firms make their investment decisions sequentially without making any price commitments. Then, followed by the realization of the final demand potential, the supplier sets the wholesale price, and finally, firm B sets the optimal resale price. Here, firm B faces a higher risk since he makes his investment decision prior to the wholesale price commitment from firm S. In case 3, the supplier and buyer simultaneously invest to set the product quality and the selling effort, respectively. Again, the investment decisions are made prior to any price commitment, but now, both firms simultaneously make these decisions. Then, similar to case 2 above, demand uncertainty is resolved, the supplier sets the wholesale price, and finally the buyer determines the optimal resale price.

In the comparison of the three cases, we discuss the role of uncertainty, cost of building quality, and the cost of selling effort in determining the preference for a certain decision-making configuration. We show that there is no clear dominating preference on system configuration for both parties – The preferences of the co-opetition partners and the investment levels are mainly governed by the investment costs and the level of demand uncertainty. Our analysis indicates that if wholesale price is not committed by the supplier before the market is developed, the buyer will always under invest in his selling effort. This result is mainly due to the fear of supplier opportunism. Clearly, in such cases, the supplier can benefit from the buyer’s selling effort by charging a high wholesale price. It turns out that low investment in selling effort by the buyer eventually hurts the supplier’s profits, and the system as a whole. Consequently, we observe that the supplier prefers to be the leader and make her pricing and quality investment decisions first when demand uncertainty is low. On the other hand, if cost of selling effort is low, the buyer expects the supplier to free ride on his selling effort and hence prefers that the supplier commit to the wholesale price first. Based on this observation, we show that when investment costs are sufficiently low, both parties prefer configuration 1, which also yields the highest integrated channel profits.

However, we observe that the level of demand uncertainty and investment costs can lead to conflicting preferences for the co-opetition partners when investment costs are high. When demand variability is high, the increased value of information motivates the supplier to give up some of her first-mover advantage in return for postponement of her pricing decision. In this case, the supplier would prefer configuration 2. On the other hand, while intuition suggests that the buyer would always prefer to make his investment decision after the supplier has set the wholesale price, under certain conditions, it may be optimal for the buyer to simultaneously make investment decisions along with the supplier even though no wholesale price commitment has been made. We show that if cost of selling effort is high, the buyer would benefit from the supplier’s investment in quality in case 3 and profits would be higher in case 3 even without the wholesale price commitment from the supplier. Here the supplier invests more in product quality in case 3 as compared to case 1, and therefore, the profits for the buyer may be higher since his investment in selling effort will be lower compared to case 1.

The rest of the paper is organized as follows. In Section 2, we discuss the related concepts and examples, and discuss some related literature. In Section 3, we formulate the model and determine the optimal expressions for various decision making structures. In Section 4, we compare the different configurations and discuss each firm’s preference for a certain decision-making structure. Finally, we conclude the paper in Section 5.

2. Related concepts and examples

Co-opetition refers to the interdependence in which competition and co-operation occurs between two or more firms. It looks for win-win scenarios in which firms strive to increase the size of the total pie which they can divide up (Luo, 2004). The interdependence entails competing and collaborating elements, with rivalry as well as collaborative mechanisms, in course of maximizing individual profits (Brandenburger and Nalebuff, 1996). Co-operative elements can nourish joint payoff creation through exploiting complementary resources cooperatively. Meanwhile, competitive elements can breed conflicts that may emerge when either party
emphasizes its own gains from specific projects or transactions in which respective needs are not compatible. Competitive aims always exist because of the underlying incentive for any party to share a higher percentage of returns generated from co-operation. The simultaneity of co-operation and competition arises because firms have both private goals and common goals as they deal with other businesses such as suppliers or buyers.

Co-opetition is mainly attributed to increasing interdependence between firms (e.g., wholesaler versus retailer or buyer versus supplier) and heightened needs for collective actions, risk sharing, strategic flexibility, joint return enhancement, and prompt response to market demands. Co-opetition implies the existence of co-operation and competition between the same firms, not about co-operation with one firm and competing with another firm. The latter, also an important issue and prominent phenomenon in building cooperative alliances, has been addressed in several studies such as Lado et al. (1997), Dyer and Singh (1998) and Gnyawali and Madhavan (2001). Co-operation and competition between the same firms are attributed to increasing interdependence between global players and heightened needs for collective actions, risk sharing, strategic flexibility, and prompt response to market demands.

In the operations literature, researchers have focused on supply chain coordination by designing incentive mechanisms such that all members in the supply chain align their objectives with the system-wide objective, that is, to achieve channel coordination. A variety of mechanisms have been studied to improve supply chain efficiency including buy-back agreements (Pasternack, 1985), quantity commitment contracts (Anupindi and Bassok, 1999), and information sharing (Gavirneni et al., 1999). However, the operations literature has not studied co-opetitive investment interactions among firms in a supply chain. In a paper in the economics/industrial organization area, Klein et al. (1978) discuss how and when relation-specific investments can lead to opportunistic behavior among vertically related firms. However, their paper focuses on conditions when vertical integration is preferred to decentralization. Finally, in a paper in the marketing literature, Amaldoss et al. (2000) examine how resource commitments by alliance partners is influenced by three structural variables: the profit-sharing arrangement between the firms, the type of alliance as modeled by the rule for combining partners’ inputs, and the size of the market reward for winning the inter-alliance competition.

The objective of our study is to focus on different types of decision-making structures. As such, we study the various sequences used by the firms in making both investment and pricing decisions in the supply chain. We are able to show the preference of the supplier and the buyer for certain configurations, depending on the cost of building quality as well as the cost of selling effort. To the best of our knowledge, there is no similar study of the contract selection problem when both the buyer and the supplier can use price and non-price factors to cooperate and compete with each other in the supply chain.

There are many examples that fit well into one or more of the cases that we study in the paper. In this regard, we believe that the models studied in this paper and insights generated therefrom have not only theoretical importance but also practical appeal.

For example, in a scenario based on case 1, Lowe’s, the second-largest home improvement retailer in the world, buys toilet products from one of dozen vendors including Fluidmaster, based in San Juan Capistrano, CA, (Kern, 2002). Vendors such as Fluidmaster constantly invest to improve the product quality or to include novel features. In the vendor agreement, Fluidmaster sets its wholesale price for various product types, and Lowe specifies its expectations in various areas such as on-time shipment, quantity fill rate, bar coding, packaging requirements, and other policies with which all vendors must comply. There is no negotiation over these terms or requirements. With this pre-documented standardized agreement, Fluidmaster, like some other vendors, can either accept or reject the contract with Lowe. If these conditions are not acceptable, Fluidmaster may approach Home Depot which is also the company’s main buyer. Likewise, Lowe can accept or reject Fluidmaster’s offer since it has many other vendors available to ship toilet parts. If Lowe signs a vendor agreement, it will then decide the retail price as well as the selling efforts (more promotional efforts are made toward high price-point goods or brand products), (Canlen, 2002).

In an example based on case 2 scenario, Cepheid Corporation, based in Sunnyvale, CA, is a leading developer and manufacturer of miniaturized, fully integrated systems of rapid detection of DNA, the universal biological identifier. The Smart Cycler System (SCS), its flagship product, amplifies and analyzes DNA for life science research faster than other analyzers. In 2002, Cepheid signed a multi-year distribution agreement with Izasa SA based in Barcelona, Spain, to market the Cepheid SCS in Spain, Portugal, Italy, Austria, France, the Netherlands and the United Kingdom. To reap benefits from high profit margin in this product/market
segment, both firms decided to put more investments in respective areas: Cepheid invests in technology and development and sequentially, Izasa invests in marketing and sales in order to create a win-win payoff. According to the agreement, Izasa provides marketing, sales and service support for Cepheid’s SCS, and such marketing plans (including advertising investments and resale pricing) are sequentially linked to Cepheid’s preceding investments in innovation, customization, and product quality. For instance, for better-innovated and customized SCS’s manufactured by Cepheid, Izasa will invest more in marketing and promotion, in the use of CH-Werfen, a network of sales and marketing of health care products in Europe, (Anonymous, 2002). Izasa sets the resale price on the basis of its purchasing costs (i.e., Cepheid’s wholesale price), the actual investments in marketing and promotion, as well as market demand conditions it has influenced through advertising.

The next example exemplifies the third case scenario. Guidant Corporation, a world leader in the design and development of cardiovascular medical products has a distribution agreement with Henry Schein Inc., a national distributor of medical supplies, (Burton, 1998). Guidant (the supplier) and Henry Schein (distributor) simultaneously invested to develop cutting-edge products and marketing and promotion, respectively. Guidant invested enormously in the multi-link pixel coronary stent, which provides physicians with an immediate, minimally invasive way of treating blockages in small diameter vessels, while Henry Schein simultaneously launched a new promotional effort, through catalogs, trade shows, and advertisement, to enhance nationwide sales of coronary stent. Because the resale price was determined solely by Henry Schein (the original wholesale price was set by Guidant), the distributor was motivated to marketing so as to profit from higher margin.

In business practice, all three channel structures can exist as discussed above. However, the selection of an appropriate channel structure would depend on a number of factors including the presence of other competitors, demand uncertainty, information asymmetry, sequence of product pricing commitment/investment decisions, etc. In this paper, we focus on the role of sequence of product pricing commitment decisions on the investment decisions and on the overall profits for the firms.

3. Model formulation

We define the following notation. Let \( \theta \) be the quality level selected by the supplier and \( \omega \) be the wholesale price charged to the buyer. The buyer’s selling effort is \( e \), and the resale price set in the end-market is \( p \). Without loss of generality, we normalize the retail demand expression, \( D \) to be:

\[
D = a - p + \gamma e + \lambda \theta + \zeta,
\]

where \( a \) is the market size, \( \zeta \) is the error term on demand with mean 0 and standard deviation \( \sigma \), \( \gamma \) measures the influence of buyer’s selling effort on demand, and \( \lambda \) measures the impact of product quality on demand. Similar demand models have been used in the marketing literature by Desai and Srinivasan (1995) and Desai (1997). We do not assume any specific distribution for \( \zeta \) but note that the lower support is such that the demand is always non-negative. Since the resale pricing decision is made after realization of demand uncertainty, if the realized outcome is very low and demand is likely to be negative at the lowest possible resale price, there would be no transaction between the buyer and the supplier.

3.1. Case 1: Product quality and price commitment by supplier

In the first case (see Fig. 1A), the supplier acts as the leader and determines the investment in product quality/design and sets the wholesale price for the buyer prior to the realization of \( \zeta \). Subsequently, the buyer determines the optimal selling effort and after observing \( \zeta \), the resale price.

In the analysis of this model, we determine the optimal decisions in the two stages of the problem. First, we determine the optimal resale price for the buyer for a given contract \((\omega, \theta)\) offered by the supplier and \( e \) decided by the buyer before the realization of \( \zeta \). Then, we find the optimal selling effort that maximizes the expected buyer profit. Next, we determine the optimal contract offered by the supplier given the best response of the buyer. After the realization of \( \zeta \), the buyer’s objective function is

\[
\max_{(p)} \{ \Pi_{B}(p) = (p - \omega)[a - p + \gamma e + \lambda \theta + \zeta] - \eta e^2 / 2 \},
\]
where the cost of selling effort is assumed to be $\eta e^2/2$. Similar to the existing marketing literature, we use convex cost of investment to model the diminishing return of investment in influencing demand. It is easy to see that the buyer’s profit function is concave in $p$. Then, from the first order conditions, we have:

$$
\frac{\partial \Pi_B}{\partial p} = 0 \Rightarrow p = \frac{\alpha + \gamma e + \lambda \theta + \omega + \xi}{2}.
$$

Using the expression of $p$ from above, we can re-write the expected profit of the buyer as follows:

$$
E[\Pi_B] = \left[\frac{\alpha + \gamma e + \lambda \theta - \omega}{2}\right]^2 + \frac{\sigma^2}{4} - \frac{\eta e^2}{2}.
$$

(1)

Next, we find the optimal selling effort level that maximizes the buyer’s expected profit:

$$
\frac{\partial E[\Pi_B]}{\partial e} = 0 \Rightarrow e^* = \frac{\gamma}{2\eta - \gamma^2}(\alpha + \lambda \theta - \omega).
$$

(2)

In order to ensure concavity and that there are no pathological cases of negative selling effort, we require that $2\eta > \gamma^2$. Thus, using $e^*$ from (2) we get:

$$
p^* = \frac{(\alpha + \lambda \theta)\eta + (\eta - \gamma^2)\omega}{2(2\eta - \gamma^2)} + \frac{\xi}{2}.
$$

(3)

Define $K = \frac{\eta}{(2\eta - \gamma^2)}$. On substituting from above in (1) and simplifying terms, we get:

$$
E[\Pi_B(\omega, \theta)] = \frac{K}{2} (\alpha + \lambda \theta - \omega)^2 + \frac{\sigma^2}{4},
$$

and

$$
D(\omega, \theta) = \alpha - p + \gamma e + \lambda \theta + \xi = K(\alpha + \lambda \theta - \omega) + \frac{\xi}{2}.
$$

(4)

(5)

The supplier invests in quality improvement efforts that may include new high-precision equipment with high reliability, fast or flexible equipment, organizational training and restructuring, etc., which improve the demand potential of the product. Another example of supplier-initiated effort to improve the demand potential is the investment in brand name (see Lal, 1990). By inferring the buyer’s selling effort reaction function in response to the terms of the contract, the supplier can suitably choose the contract in order to maximize his profits.

The quality level selected by the supplier $\theta$, affects his total expected costs in two ways: First, investment in quality improvement programs increases fixed costs, $\zeta \theta^2/2$. The quality level also has an impact on the variable...
costs. We let the variable costs be \( c(1 + v\theta) \), where \( v \) may be less than or greater than zero. Allowing \( v \) to be negative allows us to model the case when the variable production costs actually decline due to improvement in quality (Banker et al., 1998). Then, we get:

\[
\operatorname{Max}_{(\omega, \theta)} \left[ E[\Pi_s] = E \left[ (\omega - c(1 + v\theta))D - \frac{\zeta\theta^2}{2} \right] \right] = E \left[ (\omega - c(1 + v\theta)) \left( K(\lambda + \lambda\theta - \omega) + \frac{\xi}{2} \right) - \frac{\zeta\theta^2}{2} \right].
\]  \( (6) \)

We can show that the supplier’s profit function is concave as the Hessian is negative semi-definite if \( (2\zeta - K(\lambda - cv)^2) > 0 \). We shall assume that the above condition is valid. Then, from the first order conditions and noting that \( E[\xi] = 0 \), we get:

\[
\frac{\partial E[\Pi_s]}{\partial \omega} = 0 \Rightarrow \omega = \frac{\lambda + \lambda\theta + c(1 + v\theta)}{2},
\]  \( (7) \)

and

\[
\frac{\partial E[\Pi_s]}{\partial \theta} = 0 \Rightarrow \theta = \frac{K(\lambda(\omega - c) - cv(\omega - \lambda) - \lambda c)}{(2\lambda Kcv + \zeta)}.
\]  \( (8) \)

Solving \( (7) \) and \( (8) \) for \( \omega \) and \( \theta \), we get:

\[
\omega_i = \frac{\zeta(\lambda + c) + Kc(\lambda - cv)(xv - \lambda)}{(2\zeta - K(\lambda - cv)^2)},
\]  \( (9) \)

and

\[
\theta_i = \frac{K(\lambda - cv)(x - c)}{(2\zeta - K(\lambda - cv)^2)}.
\]  \( (10) \)

Substituting into \( (6) \) and upon simplifying terms, we get:

\[
E[\Pi_{s1}^*] = \frac{\zeta K(\lambda - c)^2}{2(2\zeta - K(\lambda - cv)^2)}.
\]  \( (11) \)

From \( (2) \)–\( (5) \), we get:

\[
p_i = \omega_i + \frac{\zeta K(\lambda - c)}{(2\zeta - K(\lambda - cv)^2)} + \frac{\xi}{2},
\]  \( (12) \)

\[
e_i = \frac{\gamma\zeta K(\lambda - c)}{\eta(2\zeta - K(\lambda - cv)^2)},
\]  \( (13) \)

\[
D_i = \frac{\zeta K(\lambda - c)}{(2\zeta - K(\lambda - cv)^2)} + \frac{\xi}{2},
\]  \( (14) \)

and

\[
E[\Pi_{b1}^*] = \frac{K}{2} \left( \frac{\zeta(\lambda - c)}{(2\zeta - K(\lambda - cv)^2)} \right)^2 + \frac{\sigma^2}{4}.
\]  \( (15) \)

We note from above that \( \theta_i, p_i, e_i \) and \( E[\Pi_{s1}^*], E[\Pi_{b1}^*] \) are decreasing in \( c \), as expected. Further, observe that the optimal terms of the contract offered by the supplier depend on the buyer’s cost of selling effort, \( \eta \). We can show that \( (\theta_i, \omega_i) \) and \( (p_i, e_i) \) are all decreasing in \( \eta \), as expected. That is, if the buyer has a lower cost of selling effort, he is likely to provide more effort, and in anticipation of the same, the supplier provides a higher quality product. As such, both the wholesale price and the resale price are also higher. Also, note that \( \frac{\partial E[\Pi_{s1}^*]}{\partial \eta}, \frac{\partial E[\Pi_{b1}^*]}{\partial \eta} < 0 \), and \( \frac{\partial E[\Pi_{s1}^*]}{\partial c}, \frac{\partial E[\Pi_{b1}^*]}{\partial c} < 0 \), that is, the suppliers’ and buyer’s profits are decreasing in increasing cost of selling effort and in the cost of building quality. We observe from \( (11) \) and \( (15) \) that while expected supplier profits are independent of level of uncertainty in demand, expected buyer profits increase in \( \sigma \).

\footnote{We use the subscript ‘1’ to denote the optimal expressions for the contract problem in case 1.}
3.2. Case 2: Product quality commitment by supplier

In case 2 (see Fig. 1B), the supplier first determines the investment in product quality/design and the buyer then invests in selling effort to develop the market. Here, both players make their investment decisions prior to any wholesale price commitment by the supplier and realization of $\xi$. Pricing decisions are postponed until after $\xi$ is observed. Then, the supplier sets the wholesale price, and finally, the buyer determines the optimal resale price.

Unlike the three-stage analysis in case 1, here we have four stages to consider: We first solve the last stage problem to determine the optimal resale price as a function of the other three decisions. Next, we determine the solution to stage 3 where the supplier determines the optimal wholesale price given the decisions made in stages 1 and 2, and recognizing the optimal reaction function of the buyer in setting the resale price in stage 4. Then, we solve the stage 2 problem where the buyer determines the optimal selling effort, and finally, we solve the stage 1 problem where the supplier determines the optimal investment in product quality/design.

The buyer’s objective in stage 4 is to determine the optimal resale price, that is

$$\max_{(p)} \Pi_B(p) = (p - \omega)[x - p + \gamma e + \lambda \theta + \xi] - \eta e^2 / 2],$$

which yields

$$p^* = \frac{(x + \gamma e + \lambda \theta + \omega + \xi)}{2},$$

and

$$D^* = \frac{(x + \gamma e + \lambda \theta - \omega + \xi)}{2}.$$ (18)

The supplier’s objective in stage 3 is to determine the optimal wholesale price, that is

$$\max_{(\omega)} \Pi_S(\omega) = (\omega - c(1 + v\theta))[\frac{x + \gamma e + \lambda \theta - \omega + \xi}{2}] - \zeta \theta^2 / 2],$$

which yields

$$\omega^* = \frac{(x + \gamma e + \lambda \theta + c(1 + v\theta) + \xi)}{2}.$$ (20)

In stage 2, $\xi$ is not observed yet. The buyer’s objective in stage 2 is to determine the optimal selling effort, that is

$$\max_{(e)} \left[ E[\Pi_B(e)] \right] = \left[ \frac{x + \gamma e + \lambda \theta - c(1 + v\theta)}{4} \right]^2 + \frac{\sigma^2}{16} - \frac{\eta e^2}{2},$$

Fig. 1B. Case 2 – product quality commitment by supplier.
which yields \( e^* = \frac{\gamma}{8\eta - \gamma^3} (\alpha + \lambda \theta - c(1 + \nu \theta)) \). (22)

Finally, the supplier’s objective in stage 1 is to determine the optimal investment in product quality/design, that is

\[
\max_{(\theta)} \left[ E[\Pi_S(\theta)] \right] = \frac{8\eta^2}{(8\eta - \gamma^2)^2} \left[ \alpha + \lambda \theta - c(1 + \nu \theta) \right]^2 + \frac{\sigma^2}{8} - \frac{\zeta \theta^2}{2},
\]

which yields \( \theta^*_2 = \frac{K^2_2(\lambda - cv)(\alpha - c)}{\zeta - K^2_2(\lambda - cv)^2} \). (24)

where, \( K_2 = \frac{4n}{8\eta - \gamma^2} \). We note that since \( K > 2K^2_2 \), our assumption of \((2\zeta - K(\lambda - cv)^2) > 0 \) (in case 1) also ensures concavity in this case. Substituting backwards into (22), (20) and (17), we get:

\[
e^*_e = \frac{\gamma \zeta K_2(\alpha - c)}{4\eta(\zeta - K^2_2(\lambda - cv)^2)},
\]

\[
\omega^*_2 = \frac{K_2(\alpha - c)}{\zeta - K^2_2(\lambda - cv)^2} + \frac{c}{2} \left( \frac{\zeta - K^2_2(\lambda - cv)(\lambda - cv)}{(\zeta - K^2_2(\lambda - cv)^2)} + \frac{\zeta}{2} \right),
\]

\[
p^*_2 = \omega^*_2 + \frac{K_2(\alpha - c)}{2(\zeta - K^2_2(\lambda - cv)^2)} + \frac{\zeta}{4},
\]

\[
D^*_2 = \frac{\zeta K_2(\alpha - c)}{2(\zeta - K^2_2(\lambda - cv)^2)} + \frac{\zeta}{4},
\]

and

\[
E[\Pi^*_S] = \frac{\zeta K^2_2(\alpha - c)^2}{2(\zeta - K^2_2(\lambda - cv)^2)} + \frac{\sigma^2}{8},
\]

\[
E[\Pi^*_B] = \frac{K_2}{8} \left[ \frac{\zeta (\alpha - c)}{(\zeta - K^2_2(\lambda - cv)^2)} \right]^2 + \frac{\sigma^2}{16}.
\]

Again, similar to the result in case 1, we can show that \( \frac{\partial E[\Pi^*_S]}{\partial \zeta} < 0 \), \( \frac{\partial E[\Pi^*_B]}{\partial \zeta} < 0 \), and \( \frac{\partial E[\Pi^*_S]}{\partial c} < 0 \), \( \frac{\partial E[\Pi^*_B]}{\partial c} < 0 \), that is, the suppliers’ and buyer’s profits are decreasing in increasing cost of selling effort and in the cost of building quality. In contrast to the previous case, the supplier’s expected profits depend on the level of demand uncertainty since she now postpones her pricing decision in this scenario. In fact, both players’ profits increase in \( \sigma \), though, the expected buyer profits are less sensitive to demand uncertainty compared to the previous case.

3.3. Case 3: Simultaneous product quality commitment by supplier and selling effort commitment by buyer

In case 3 (see Fig. 1C), the supplier and buyer simultaneously determine the investment in product design and selling effort, respectively. Then, \( \zeta \) is realized, the supplier sets the wholesale price, and finally, the buyer determines the optimal resale price.

Here we have three stages to consider: We first solve the last stage problem to determine the optimal resale price as a function of the other three decisions. Next, we determine the solution to stage 2 where the supplier determines the optimal wholesale price given the decisions made in stage 1 and the optimal reaction function of the buyer in stage 3. Finally, we solve the stage 1 problem where the supplier and the buyer move simultaneously and determine the optimal investment in product quality/design and selling effort, respectively. The buyer’s objective in stage 3 is to determine the optimal resale price, that is

\[
\max_{(p)} \left[ \Pi_B(p) = (p - \omega)[\alpha - p + \gamma e + \lambda \theta + \zeta] - \eta e^2/2 \right],
\]

which yields \( p^* = \frac{(\alpha + \gamma e + \lambda \theta + \omega + \zeta)}{2} \). (32)
Suppliers objective in stage 2 is to determine the optimal wholesale price, that is

\[ \max (x) = P_S(x) = \left(\frac{x}{C_0} - c(1 + v\theta) + \frac{\eta e}{2}\right)^2. \]

which yields

\[ x^* = \left(\frac{a + ce}{2}\right). \]

The stage 1 problem is to simultaneously determine the optimal investment in product quality/design and the selling effort. For the buyer, the objective is

\[ \max (e) = E\left[P_B(e)ight] = \left[\frac{a + ce + \lambda\theta - c(1 + v\theta)}{4}\right]^2 + \frac{\sigma^2}{16}. \]

and, for the supplier, the objective is

\[ \max (\theta) = E\left[P_S(\theta)\right] = \left[\frac{a + ce + \lambda\theta - c(1 + v\theta)}{8}\right]^2 + \frac{\sigma^2}{8}. \]

In order to ensure concavity and that there are no pathological cases of negative selling effort or product quality, we require that \((\zeta - K_3(\lambda - cv)^2) > 0\), where \(K_3 = \frac{2\eta}{4\eta - \gamma}\). Solving (35) and (36) simultaneously for \(\theta\) and \(e\), we get:

\[ \theta^*_3 = \frac{K_3(\lambda - cv)(a - c)}{\zeta - K_3(\lambda - cv)^2}, \]

and

\[ e^*_3 = \frac{\gamma K_2(\lambda - cv)}{4\eta(\zeta - K_3(\lambda - cv)^2)}. \]

**Theorem 3.1.** Assume that \((\zeta - K_3(\lambda - cv)^2) > 0\). Then, there is a unique Nash equilibrium to the simultaneous game between the buyer and the supplier in case 3.

**Proof.** All Proofs are in the Appendix.

Substituting (37) and (38) backwards into (34) and (32), we get:

\[ \omega^*_3 = c + \frac{K_2(\lambda - cv)\xi}{\zeta - K_3(\lambda - cv)^2} + \frac{\xi}{2}. \]
$p^*_3 = \omega^*_3 + \frac{\zeta K_2(\alpha - c)}{2(\zeta - K_4(\lambda - cv)^2)} + \frac{\xi}{4},$ \hspace{1cm} (40)

$D^*_3 = \frac{\zeta K_2(\alpha - c)}{2(\zeta - K_4(\lambda - cv)^2)} + \frac{\xi}{4},$ \hspace{1cm} (41)

and $E[I'_{33}] = \left(\frac{\zeta K^2_2 - K^2_3(\lambda - cv)^2}{2(\zeta - K_4(\lambda - cv)^2)}\right) + \frac{\sigma^2}{8},$ \hspace{1cm} (42)

$E[I'_{33}] = \frac{K_2}{8} \left[\frac{\zeta(x - c)}{(\zeta - K_4(\lambda - cv)^2)}\right]^2 + \frac{\sigma^2}{16}.$ \hspace{1cm} (43)

Similar to the result in cases 1 and 2, we can show that $\frac{\partial E[I'_{33}]}{\partial \eta} < 0$, that is, the suppliers’ and buyer’s profits are decreasing in increasing cost of selling effort. However the effect of cost of quality is different. While we note that $\frac{\partial E[I'_{33}]}{\partial \alpha} < 0$, we have $\frac{\partial E[I'_{33}]}{\partial \alpha} > 0$, that is, while the buyer’s profits are decreasing in increasing cost of quality, the supplier’s profits are increasing in the cost of quality. Essentially as cost of quality increases, the supplier reduces her investment in quality and instead is able to free ride on the buyer’s investment in selling effort. Hence, counter to our expectation, the supplier actually benefits if the cost of quality is high. However, for the system as a whole, $\frac{\partial E[I'_{33}]}{\partial \alpha} + \frac{\partial E[I'_{33}]}{\partial \eta} < 0$, that is, profits for the system are decreasing with increasing cost of quality, as expected. We note that a similar effect is not observed for an increase in cost of selling effort. Here, the buyer is not able to free ride on the supplier’s investment in quality since the supplier has the ability to negate this by charging a higher wholesale price later. Hence, the profits for both firms are decreasing as the cost of selling effort increases, as expected. The impact of demand uncertainty on players’ expected profits are similar to case 2.

4. Channel configuration comparisons

In the previous section, we derived the expressions for the optimal parameters for the three cases. In this section, we compare the configurations and discuss the potential of conflicting choices between the buyer and the supplier.

4.1. Two-way comparisons

We first compare configuration pairs from the perspective of the supplier, the buyer, and the integrated channel. The results are summarized in Table 1 and discussed below. Later, we discuss the results of the three-way comparison.

<table>
<thead>
<tr>
<th>Results of two-way comparisons</th>
<th>Cases 1 and 2</th>
<th>Cases 2 and 3</th>
<th>Cases 1 and 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quality investment</td>
<td>$\theta^<em>_1 &gt; \theta^</em>_2$</td>
<td>$\theta^<em>_1 &lt; \theta^</em>_3$</td>
<td>$\theta^<em>_1 &gt; \theta^</em>_3$ if $\gamma^2 &lt; 3\gamma^2/2$; $\theta^<em>_1 &lt; \theta^</em>_3$ if $2\eta &gt; 3\gamma^2/2$.</td>
</tr>
<tr>
<td>Selling effort investment</td>
<td>$e^<em>_1 &gt; e^</em>_2$</td>
<td>$e^<em>_3 &lt; e^</em>_3$</td>
<td>$e^<em>_1 &gt; e^</em>_3$</td>
</tr>
<tr>
<td>Supplier profits</td>
<td>$E[I'<em>{31}] &gt; E[I'</em>{32}]$ for low demand variability</td>
<td>$E[I'<em>{32}] &lt; E[I'</em>{33}]$</td>
<td>$E[I'<em>{31}] &gt; E[I'</em>{32}]$ for low demand variability</td>
</tr>
<tr>
<td></td>
<td>$E[I'<em>{31}] &lt; E[I'</em>{32}]$ for high demand variability</td>
<td></td>
<td>$E[I'<em>{31}] &lt; E[I'</em>{32}]$ for high demand variability</td>
</tr>
<tr>
<td>Buyer profits</td>
<td>$E[I'<em>{33}] &gt; E[I'</em>{32}]$</td>
<td>$E[I'<em>{33}] &gt; E[I'</em>{33}]$</td>
<td>$E[I'<em>{33}] &gt; E[I'</em>{33}]$</td>
</tr>
<tr>
<td>Channel profits</td>
<td>$E[I'<em>{31}] + E[I'</em>{33}] &gt; E[I'<em>{32}] + E[I'</em>{32}]$</td>
<td>$E[I'<em>{32}] + E[I'</em>{32}] &gt; E[I'<em>{33}] + E[I'</em>{33}]$</td>
<td>$E[I'<em>{33}] + E[I'</em>{33}] &gt; E[I'<em>{33}] + E[I'</em>{33}]$</td>
</tr>
</tbody>
</table>
4.1.1. Comparison of case 1 and case 2 configurations

In case 1, the supplier announces both the quality investment and the wholesale price before the buyer commits to anything and all supplier decisions are to be made before the realization of demand uncertainty. The trade-off for the supplier is to enjoy the first-mover advantage associated with the leadership position or to postpone decisions until after demand uncertainty is resolved.

Lemma 1. (a) When product quality/design investment and wholesale price commitment is initially made by the supplier, the supplier invests more in product quality, and the buyer invests more in selling effort, that is, $0_1^* > 0_2^*$ and $e_1^* > e_2^*$.

(b) The buyer prefers that the supplier commit to both product quality/design and wholesale price decisions before all buyer commitments, that is, $E[\Pi_{B1}] > E[\Pi_{B2}]$. The integrated channel as a whole is also better off in case 1. However, the supplier is better off by postponing the wholesale price decision and thus, prefers case 2 over case 1 if and only if $\sigma$ is beyond a certain threshold.

It can be observed from (3) and (12) that the buyer’s resale price is higher in the first case unless $\zeta$ turns out to be negative and sufficiently small. In general the buyer will tend to charge more in case 1 as it makes higher investment in selling effort. However, the resale price in case 1 is more sensitive to the realization of $\zeta$, as it is the only means that is used to adjust to variations in demand as opposed to case 2 where wholesale price is also postponed until the uncertainty is resolved. As such, if the realized value of $\zeta$ is too small the buyer will be compelled to offer larger price cuts in case 1 and hence may end up charging a lower resale price. We also note that the wholesale price charged by the supplier in case 1 is not necessarily higher than the price charged in case 2 even though $0_1^*$ is greater than $0_2^*$. In fact, for a given $\zeta$, there exists a threshold of $\zeta$ (the cost of building quality), such that, $w_1 < w_2$ if $\zeta$ exceeds this critical threshold. In general for low cost of quality, $w_1 > w_2$. The intuition for this observation is as follows: As $\zeta$ increases, even though $0_1^* > 0_2^*$, the supplier’s investment in quality decreases and the difference in quality investment between the two cases is smaller. As such, the comparative role of product quality in influencing demand is diminished.

In case 2, the buyer makes the investment in selling effort after the supplier has invested in product quality/design, but before the wholesale price is set. As such, the buyer has the risk of over investing in developing the market and facing a high wholesale price from the supplier. Therefore, the buyer would invest less in developing the market, that is, $e_2 < e_1$. In anticipation of the lower investment in selling effort by the buyer, the supplier also invests less in product design/quality, that is, $0_2 < 0_1$. The combination of a lower investment in product design/quality along with the lower effort in developing the market leads to lower demand potential for the product, and lower profits for the integrated channel. When demand uncertainty is relatively low, the supplier enjoys the benefits of being the leader in case 1 and makes higher profits. However, as demand uncertainty increases, early commitment leads to higher opportunity costs. In such case, the value of additional information ($\zeta$) outstrips the advantages of being the first mover and hence, the supplier will have incentive to postpone her wholesale price decision until after the buyer commits to the selling effort and realization of demand information. This is especially true if the supplier faces high investment costs for quality.

We illustrate how the supplier preferences change with quality cost and demand uncertainty using the following example. Let $\alpha = 70$; $\gamma = 0.6$; $\lambda = 2$; $c = 7$; $v = 0.1$; and $\eta = 1$. As depicted in Fig. 2, the supplier is always better off in case 1 when demand uncertainty is low, however, she prefers case 2 when both uncertainty level and cost of quality are high.

If demand uncertainty is low, the supplier and buyer have higher profits in case 1 as compared to case 2. However, in markets with volatile demand, the supplier and the buyer would have conflicting preference in the business setting. In a supplier dominant market, the supplier would postpone the wholesale price decision until after full information regarding demand is received and thus, require the buyer to make her commitment on selling effort, a priori.

4.1.2. Comparison of case 2 and case 3 configurations

The main difference between cases 2 and 3 is in the leadership position in the channel. In case 3, the leadership advantage of the supplier is compromised in that both parties move simultaneously and decide on their commitments on quality and selling effort.
Lemma 2. (a) When product quality/design investment is made by the supplier prior to the buyer’s selling effort commitment, the supplier invests more in product quality, and the buyer invests more in selling effort, that is, \( h_1/C_3 > h_2/C_3 \) and \( e_1/C_3 > e_2/C_3 \). Moreover, both parties charge higher prices in case 3.

(b) The supplier is better off under case 2 whereas the buyer strictly prefers case 3. That is, \( E[P_{S2}/C_{3S}] > E[P_{S3}/C_{3S}] \) and \( E[P_{B2}/C_{3B}] < E[P_{B3}/C_{3B}] \). On the balance, the expected integrated channel profit is higher in case 2, i.e., \( E[P_{S2}/C_{3S}] + E[P_{B2}/C_{3B}] > E[P_{S3}/C_{3S}] + E[P_{B3}/C_{3B}] \).

As indicated in the lemma above, both parties make higher investments and therefore charge higher prices in case 3. In case 2, the supplier anticipates that once she commits to the quality, the buyer will have incentive to invest in low selling effort and free ride on the supplier’s quality investment. This in return creates incentive for the supplier not to choose a high quality level. On the other hand, such concern is not prevalent when both parties move simultaneously and choose their investment levels in case 3. In this case, none of the parties would find it risky to increase their investments. Nevertheless, increased quality and selling effort does not necessarily mean that both parties would be better off under case 3 as explained by the following result.

Clearly, the buyer has a better share in the channel leadership in case 3 since both parties simultaneously decides on their investment as opposed to case 2 where the buyer reacts to the supplier’s choice of quality. Hence, case 3 implies increased negotiation power for the buyer which is reflected in her higher expected profits. On the flip side, the supplier looses her first mover advantage in case 3 and thus, some of her expected profits as compared to case 2.

4.1.3. Comparison of case 1 and case 3 configurations

In case 3, the buyer invests in selling effort prior to the wholesale price commitment from the supplier (similar to case 2). However, both players make their investment decisions simultaneously. In the comparison of the two configurations, we determine the role of cost of selling effort (\( \eta \)) and the cost of quality (\( \zeta \)) on the supply chain decisions and profits.

Lemma 3. (a) The supplier invests more in product quality in case 1 as compared to case 3 when the buyer’s cost of selling effort is low; else, the investment in quality is higher in case 3. Mathematically, we have \( 0_1^* > 0_3^* \) if \( \gamma^2 < 2\eta < 3\gamma^2/2 \), and \( 0_1^* < 0_3^* \) if \( 2\eta > 3\gamma^2/2 \).

(b) The buyer’s investment in selling effort is always higher in case 1 as compared to case 3, that is, \( e_1^* > e_3^* \).

(c) The expected integrated channel profits are always higher in case 1, that is, \( E[P_{S1}/C_{3S}] + E[P_{B1}/C_{3B}] > E[P_{S3}/C_{3S}] + E[P_{B3}/C_{3B}] \). The supplier’s expected profits are higher in case 1 as compared to case 3, when demand uncertainty is low. For sufficiently high uncertainty, while the supplier is better off, the buyer is worse off in case 3 as compared to case 1.

Essentially, if cost of selling effort is low, the supplier expects that the buyer would use high selling effort and is able to free ride on the buyer’s investment by under investing in product quality. If, however, the cost of effort is high, the buyer is not expected to exert high selling effort, and hence, the supplier has to invest in product quality in order to stimulate demand. We also note that even though the supplier and buyer make their
investment decisions simultaneously in case 3, the buyer still faces the risk of a high wholesale price charged by the supplier, and as such, the buyer’s investment in using selling effort to develop the market is lower than in case 1.

In case 3, the supplier gives up the first mover advantage. Under sufficiently low demand uncertainty she would prefer to keep this advantage by committing to both the product quality and price before the buyer moves. However, when demand uncertainty is high, the supplier prefers to postpone her pricing decision and expects higher profits under case 3. In this case, the value of making decision after receiving the demand information overweights the early mover advantage. The buyer, in a market with high uncertainty, prefers to wait until the supplier makes her commitments before making any decision. In general the comparison between buyer profits in both cases depends on the cost of quality and cost of selling effort as explained through a numerical analysis in the following subsection.

4.2. The three-way comparison

The results from Section 4.1 establish that none of the three cases strictly dominates the others for all parameter combinations from the perspectives of the supplier and the buyer. It is concluded that the optimal quality, selling effort, and profits are quite sensitive to cost of quality, cost of selling effort, and the level of uncertainty in all cases. Our first observation is that the buyer’s optimal choice of selling effort is the highest in case 1 and lowest in case 2. Specifically, \( e_1^* > e_3^* > e_2^* \). On the other hand, it is observed that optimal quality is the lowest also in case 2. The comparison between \( \theta_1^* \) and \( \theta_3^* \) depends on cost parameters as explained in Lemma 3. To analyze the impact of cost of quality and cost of selling effort on the optimal quality and selling effort levels, consider the following numerical example. Let \( a = 70; \gamma = 0.6; \lambda = 2; c = 7; v = 0.1 \).

First we let \( \zeta = 5 \) and study the impact of \( \eta \). Fig. 3 outlines the impact of cost of selling effort on both optimal quality and selling efforts. As mentioned above the relation among selling effort levels does not change in \( \eta \), however, the gap between case 1 \( e \) values and others closes as \( \eta \) increases. From the definitions of \( K \) and \( K_3 \), note that there exist two ranges of \( \eta \): (i) low range defined as \( \gamma^2 < 2\eta < 3\gamma^2/2 \), where \( K > 2K_3 \); (ii) high range defined as \( 2\eta > 3\gamma^2/2 \), where \( K < 2K_3 \). In our example, we let \( \eta \) be equal to 0.25 and 1 for the low and high cost cases respectively. Consider first the case of low cost of selling effort. While we have analytically shown that \( \theta_1^* > \theta_3^* \) and \( e_1^* > e_3^* \) (Lemma 3), numerically we note that \( E[w_3^1] > w_1^1 \) and \( E[p_1^1] > E[p_3^1] \). When cost of selling effort is low, the supplier expects the buyer to use more selling effort. However, the buyer then faces a high risk of the supplier taking advantage of his investment in selling effort by charging a high wholesale price. As noted above, the supplier charges a higher wholesale price even though the product quality is lower in case 3. Anticipating that, the buyer would not invest as much in selling effort unless the supplier has made her pricing commitment, and hence, \( e_1^* > e_3^* \). Consequently, the supplier also under invests in quality in case 3 as compared to case 1 when cost of selling effort is low. Due to lower investment by both firms in case 3 as compared to case 1, the demand and integrated channel profits are lower in case 3 as compared to case 1.

![Fig. 3. Effect of cost of selling effort on investment decisions.](image-url)
Now consider the case when the cost of selling effort is high. Here, from Lemma 3, we note that $\theta_3^* > \theta_1^*$ and $e_3^* > e_1^*$. This is due to the fact that the buyer still faces the risk of over investing in selling effort and getting served with a high wholesale price from the supplier. As such, the buyer gets a higher quality product in case 3, but does not invest in selling effort as much as in case 1. As underlined earlier, quality in case 2 remains to be the lowest for all values of $\eta$. However, observe in Fig. 3 that gap between $\theta_1^*$ and $\theta_2^*$ closes in cost of selling effort. This is due to the fact that as cost of selling effort becomes higher, the type of the configuration will not affect the effort choice significantly and thus the reaction of the supplier in her quality investment.

We use the same parameters in the numerical example to illustrate the impact of cost of quality. In our analysis we first assume that $\sigma = 0$ and investigate the effect of uncertainty later. The results are given in Figs. 4 and 5 are summarized below. First, consider the case when cost of selling effort is high. Then we know from Lemmas 1–3 that $\theta_3^* > \theta_1^* > \theta_2^*$. Since cost of selling effort is high, the supplier does not expect to free ride on the buyer using high selling effort and hence she invests in quality to stimulate demand. As such, the buyer benefits by getting a higher quality product even though his own investment in selling effort is low. Hence, the buyer’s profits may be higher in case 3 as compared to case 1 when the cost of quality is low. As cost of quality increases, the supplier’s investment in quality gets lower and the gap between $\theta_3^*$ and $\theta_1^*$ narrows further. As such the buyer does not benefit much from the supplier’s investment in quality in case 3 as compared to case 1. In this case, the buyer may prefer that the supplier make the wholesale price commitment first, and hence, we note that $E[\Pi_B^3] > E[\Pi_B^1]$ when cost of quality is high.

Next consider the case when cost of selling effort is low. Here, we note that $\theta_1^* > \theta_3^* > \theta_2^*$. In addition, since cost of selling effort is low, the supplier expects the buyer to use more selling effort and thus, the risk of supplier opportunism increases. In this case, the buyer would then prefer that the supplier make the wholesale price commitment first, and we observe that $E[\Pi_B^1]$ is always greater than $E[\Pi_B^3]$ when cost of selling effort is low. We note that the gap between supplier profits in case 1 and others increase as the cost of selling effort decreases.

The analysis in Section 3 indicates that demand uncertainty does not affect the optimal choice of quality and selling effort since both parties adjust risk with corrective pricing after uncertainty is resolved. Hence, the foregoing results and discussion regarding optimal quality and selling effort would be unchanged for all
values of $\sigma$. However, the expected profits and thus, the player preferences will be affected by the level of uncertainty. As explained earlier, case 1 becomes more profitable for the buyer as $\sigma$ increases. Therefore, observe from Fig. 5 that when the cost of selling effort is low, the buyer is always better off in case 1. Also observe in Fig. 2 that under case 1, supplier profits are significantly higher for low cost of quality compared to other cases even with increased level of uncertainty. Consequently, we can conclude that case 1 would be the preferable configuration for both parties when both cost of quality and cost of selling effort are sufficiently low. In such case there will be no conflict between the supplier and the buyer about the choice of the system configuration. In fact, since case 1 is the best configuration for the integrated channel, the player incentives benefit the overall system profits.

However, for higher investment costs, both parties could have conflicting preferences. It is established in Lemmas 1–3 that case 2 and case 3 are always outperformed for the supplier and the buyer, respectively. Hence, the supplier compares case 1 with case 2, and the buyer, case 1 and case 3. A cross-comparison of both supplier and buyer expected profits under varying $\sigma$ are given in Fig. 6. The figure uses the example given above with $\zeta = 5$ and $\eta = 1$. We note that level of uncertainty indeed governs player incentives and may lead to conflicting preferences. The impact on player incentives can be explained using the three regions depicted in Fig. 6. First region (Region I) shows the supplier-buyer profits when the level of uncertainty is low. Note that in this region while the supplier prefers case 1, the buyer is better off with case 3. In Region II, where the uncertainty is a bit higher, case 1 becomes the choice of both parties. When uncertainty is very high, as represented by Region III, the supplier and the buyer prefer case 2 and case 1 respectively. Hence, we observe that except for the case where the uncertainty is “mild”, the supplier and the buyer face conflicting preferences when cost of quality and cost of selling effort are high.

In general, the conflict in choice of configuration would be resolved based on negotiation powers of the supply chain partners. Alternatively, a coordinating approach can be initiated by one of the partners depending on the level of uncertainty. For example when uncertainty is low, the supplier can make a side payment (of at least $E[\Pi^1_S] - E[\Pi^1_B]$) to the buyer to convince her to accept configuration 1. Since configuration 1 has the highest expected profits for the integrated channel (i.e., $E[\Pi^1_S] > E[\Pi^2_S] > E[\Pi^3_S] = E[\Pi^3_B]$), the supplier can pay this amount to the buyer and still be better off. Under high uncertainty, the buyer can adopt a similar strategy and make side payment to the supplier to convince her for an alliance under configuration 1.
4.3. Centralized system solution

In the analysis so far, we considered the case where each firm maximized their individual profits only. In this section, we determine the optimal investment and pricing decisions for the integrated channel. The centralized solution can be used as a reference in evaluating the potential benefits that a certain configuration can bring to the channel partners. Clearly, in the centralized case there are only three decision variables: $h$, $e$, and $p$. The decisions are made in two stages. First, before the demand uncertainty is resolved, investment decisions $h$ and $e$ must be given. Second, the selling price, $p$ is decided following the realization of the final demand potential. As usual, we start with the second stage objective function:

$$\text{Max}_{(p)} \left[ \Pi_c(p) = (p - c(1 + v\theta))(\alpha - p + \gamma e + \lambda \theta + \xi) - \frac{\eta e^2}{2} - \frac{\xi \theta^2}{2} \right],$$

which at optimality yields

$$p^*_c = \frac{\alpha + \gamma e + \lambda \theta + c(1 + v\theta) + \xi}{2}.$$  \hfill (44)

Now, second stage expected channel profit is

$$E[\Pi_c(\theta, e)] = \frac{(\alpha + \gamma e + \lambda \theta - c(1 + v\theta) + \xi)^2}{4} - \frac{\eta e^2}{2} - \frac{\xi \theta^2}{2}.$$  \hfill (46)

To ensure concavity, we need $(\zeta - K(\lambda - cv)^2) > 0$, which also ensures that there are no pathological cases of negative quality or selling effort. Then, from first order optimality conditions we get:

$$\theta^*_c = \frac{K(\alpha - c)(\lambda - cv)}{\zeta - K(\lambda - cv)^2},$$  \hfill (47)

$$e^*_c = \frac{\zeta \gamma K(\alpha - c)}{\eta(\zeta - K(\lambda - cv)^2)}.$$  \hfill (48)

Finally, the optimal expected channel profit is

$$E[\Pi^*_c] = \frac{K\zeta(\alpha - c)^2}{2(\zeta - K(\lambda - cv)^2)} + \frac{\sigma^2}{4}.$$  \hfill (49)
A comparison of (49) to case 1 profits reveals that the gap between the expected system optimal profit and the expected integrated channel profit under case 1 stays constant in demand uncertainty. On the other hand, the gap between the expected integrated channel profits in the decentralized and the centralized solutions grows in \( \sigma \) for both cases 2 and 3. This indicates that the value of configuration 1 and thus, its potential benefits to both parties is higher under higher demand uncertainty. Fig. 7 illustrates the effect of demand uncertainty on the difference in the integrated channel profits for the various configurations.

5. Conclusions

In supply chain co-opetition, firms both compete and co-operate with each other in order to maximize their profits. In this paper, we study the nature of co-operation between firms in making investments to improve demand potential, as well as the competition between firms in making their pricing decisions. The incentives of the co-opetition partners and the investment levels are mainly governed by the cost structure and the level of uncertainty in the market. Our results can be summarized as follows:

- When the cost of quality and cost of selling effort are sufficiently low, both parties prefer configuration 1 where the supplier commits to both the product quality investment and the wholesale price up-front.
- Under high cost of quality and cost of selling effort, the supplier still prefers configuration 1 if the uncertainty level is low. Otherwise, she is better off with configuration 2 where she postpones the wholesale price decision until after uncertainty is resolved. Under no circumstances would the supplier prefer configuration 3 where she shares her first mover advantage with the buyer.
- Under high cost of selling effort the buyer may prefer configuration 3 if the uncertainty level is sufficiently low. With high uncertainty, the buyer is better off with configuration 1 where he postpones his decisions until the supplier makes all his commitments. Under no circumstances would the buyer prefer configuration 2.
- In all cases, integrated channel profits are the highest under configuration 1.
- Configuration 2 will lead to the lowest product quality and effort commitments. Although, the highest selling efforts are employed in configuration 1, the comparison of quality in case 1 and case 3 depends on the cost of selling effort. The quality will be higher in configuration 1 if the cost of selling effort is sufficiently low. Otherwise configuration 3 yields higher quality levels.

Our analysis indicates that if the supplier does not commit to the wholesale price before the market is developed, the buyer will always under invest in his selling effort. This result is mainly due to the fear of supplier opportunism. Clearly, in such cases, the supplier can get a free ride on the buyer’s selling effort by charging a high wholesale price. It turns out that low investment in selling effort by the buyer eventually hurts the supplier’s profits, and the system as a whole. Consequently, we observe that the supplier prefers to be the leader.
and make her pricing and quality investment decisions first when demand uncertainty is low. On the other hand, if cost of selling effort is low, the buyer expects the supplier to free ride on his selling effort and hence prefers that the supplier commit to the wholesale price first. Based on this observation, we show that when investment costs are sufficiently low, both parties prefer configuration 1. Thus, we conclude that with high investment costs, the level of demand uncertainty can lead to conflicting preferences for the supply chain partners.

We note that the supply contract design problem in the paper is based on the notion of “co-opetition” between the buyer and the supplier. As such, the supplier will not unilaterally choose a certain structure if the buyer is worse off under that structure. We discuss the issue of side-payments to reinforce the co-opetitive behavior between the two firms. In the absence of co-opetition, the supplier would choose the contract that generates the highest expected profit for him. Using the co-opetition approach, case 1 in the paper generates the highest expected profit for the supply chain as a whole and suitable distribution of profits can ensure that both firms prefer that arrangement.

The contribution of this paper is to study the effect of timing of price commitment decisions on the investment decisions and on the profits for the two firms. While both the firms can benefit from each other’s investment in product quality and selling effort, respectively, the timing of the price commitment decisions influences the level of investment by the firms. As such, the nature of competition between firms affects the level of cooperation they provide to each other. In future research, we plan to include the effect of information asymmetry in cost of quality and/or cost of selling effort in determining the optimal form of co-opetition between the firms. Multi-period setting consideration is another interesting extension for future research.

Appendix

Proof of Theorem 3.1. Since the objective functions of both players are continuous and concave, the existence of equilibrium is established from the Theorem (Section 1.2) in Fudenberg and Tirole (1991). The uniqueness of equilibrium can be established through index theory approach. Index theory approach implies that if the multiplication of the slopes of the best response functions does not exceed one, then, if exists, the pure strategy equilibrium must be unique (see Cachon and Netessine, 1998 for details). Let \( \Pi^*_B \) and \( \Pi^*_S \) represent the profit functions given in (35) and (36) for the buyer and the supplier respectively. From implicit function theorem, slope of the best response function for the buyer, \( f_B \), is

\[
\frac{\partial f_B}{\partial \eta} = \frac{\partial^2 \Pi^*_B}{\partial \hat{\theta} \partial \hat{e}} / \frac{\partial^2 \Pi^*_B}{\partial \hat{e}^2} = \frac{\gamma (\lambda - cv)}{8 \eta - \gamma^2}
\]

and slope of the response function for the supplier, \( f_S \), is

\[
\frac{\partial f_S}{\partial e} = \frac{\partial^2 \Pi^*_S}{\partial \hat{\theta} \partial \hat{e}} / \frac{\partial^2 \Pi^*_S}{\partial \theta^2} = \frac{\gamma (\lambda - cv)}{4 \xi - (\lambda - cv)^2}.
\]

Consequently, the multiplication of the slopes is

\[
\frac{\partial f_B}{\partial \theta} \frac{\partial f_S}{\partial e} = \frac{\gamma^2 (\lambda - cv)^2}{(8 \eta - \gamma^2)(4 \xi - (\lambda - cv)^2)}.
\]

To prove that the equilibrium is unique, it is sufficient to show that the foregoing function is below one. Clearly, this is true if

\[
(8 \eta - \gamma^2)(4 \xi - (\lambda - cv)^2) > \gamma^2 (\lambda - cv)^2.
\]

2 “Contract pre-emption” by the supplier would be protested by the buyer as both parties are likely to first agree on the format of the contract before determining the terms.
It is straightforward to see that the above inequality can be reduced to
\[ \zeta - K_3(\lambda - cv)^2 > 0. \]
Since this condition is assumed for concavity, the equilibrium is unique. \( \square \)

**Proof of Lemma 1.** For part (a) of the lemma, note that \( \theta_1^* > \theta_2^* \), if
\[
\frac{K(\lambda - cv)(x - c)}{2\zeta - K(\lambda - cv)^2} > \frac{K_2(\lambda - cv)(x - c)}{2\zeta - K_2^2(\lambda - cv)^2},
\]
which, on simplification is true if \( K > 2K_2^2 \). From the definitions of \( K \) and \( K_2 \), we can show that \( K > 2K_2^2 \), and hence, the quality offered by the supplier when the uncertainty level is low enough. The expected integrated system profits are higher in case 1 than in case 2. Similarly, we can show that \( e_3^* > e_2^* \).

For part (b), note that \( E[\Pi_{11}] > E[\Pi_{21}] \), if
\[
K \left( \frac{\zeta(x - c)}{(2\zeta - K(\lambda - cv)^2)} \right)^2 > K_2 \left[ \frac{\zeta(x - c)}{(\zeta - K_2^2(\lambda - cv)^2)} \right]^2.
\]
which, on simplification is true if \( K > 2K_2^2 \). As noted above, \( K > 2K_2^2 \), and hence, the buyer expects higher profits in case 1 as compared to the profits in case 2. Similarly, \( E[\Pi_{12}] > E[\Pi_{22}] \), if
\[
\frac{\zeta K(x - c)^2}{2(2\zeta - K(\lambda - cv)^2)} > \frac{\zeta K_2^2(x - c)^2}{2(\zeta - K_2^2(\lambda - cv)^2)} + \frac{\sigma^2}{8}.
\]
Clearly, the inequality cannot hold for sufficiently high values of \( \sigma \) implying that that case 1 is preferable to the supplier when the uncertainty level is low enough. The expected integrated system profits are higher in case 1 due to the fact that \( E[\Pi_{11}] + E[\Pi_{21}] > E[\Pi_{12}] + E[\Pi_{22}] \) from (11), (15), (21), and (23). \( \square \)

**Proof of Lemma 2.** The proof of part (a) is due to the fact that \( 2K_2^2 < K_3 \) and follows from comparison of (24)--(26), (27), (38)--(40), respectively. For part (b), note from (30) and (43) that \( E[\Pi_{13}] > E[\Pi_{23}] \) since \( K_3 > K_2^2 \). Also, \( E[\Pi_{13}] < E[\Pi_{23}] \), if
\[
(\zeta K_3^2 - K_3^2(\lambda - cv)^2) \frac{\zeta(x - c)^2}{2(\zeta - K_3^2(\lambda - cv)^2)^2} < \frac{\zeta K_3^2(x - c)^2}{2(\zeta - K_3^2(\lambda - cv)^2)^2}.
\]
The foregoing inequality can be reduced to \( (K_3 - K_3^2)^2 > 0 \), which clearly holds for \( K_3 \) and \( K_2 \). Observe that the last part of the lemma is true if \( E[\Pi_{13}] - E[\Pi_{23}] < E[\Pi_{13}] - E[\Pi_{23}] \). This inequality can be reduced to
\[
(4K_3 - 4K_2^2 - K_3)(\zeta - K_3^2(\lambda - cv)^2) > K_2(\zeta - K_3(\lambda - cv)^2),
\]
which holds since \( K_3 > K_2^2 \). \( \square \)

**Proof of Lemma 3.** For part (a) of the proof, note that \( \theta_1^* > \theta_3^* \) if
\[
\frac{K(\lambda - cv)(x - c)}{2\zeta - K(\lambda - cv)^2} > \frac{K_3(\lambda - cv)(x - c)}{\zeta - K_3(\lambda - cv)^2},
\]
which on simplification is true if \( K > 2K_3 \). From the definitions of \( K \) and \( K_3 \), we can show that \( K > 2K_3 \) if \( \gamma^2 < 2\eta < 3\gamma^2/2 \). and hence, the quality offered by the supplier in case 1 is higher than the quality offered in case 3, provided that the buyer’s cost of selling effort (\( \eta \)) is below a certain threshold. For higher values of \( \eta \), we have \( \theta_1^* < \theta_3^* \).

For part (b), the proof follows from comparing \( e_1^* \) defined in (13) with \( e_3^* \) defined in (38).

For part (c) the first part of the proof directly follows from Lemmas 2 and 3. To prove the second part, we first assume that \( \xi = 0 \). Second, we note that the supplier’s profits are decreasing in \( \zeta \) in case 1 and increasing
in \( \zeta \) in case 3, that is, \( \frac{\partial E[I_{S1}^*]}{\partial \zeta} < 0 \) and \( \frac{\partial E[I_{S3}^*]}{\partial \zeta} > 0 \). Since it is tedious to compare the general expressions for \( E[I_{S1}^*] \) and \( E[I_{S3}^*] \), we initially evaluate the limiting behavior as \( \zeta \to \infty \).

From (11), we have
\[
E[I_{S1}^*|_{\zeta=\infty}] = \frac{K(\alpha - c)^2}{4}.
\]

Similarly, from (42), we have
\[
E[I_{S3}^*|_{\zeta=\infty}] = \frac{K^2(\alpha - c)^2}{2}.
\]

Then, \( E[I_{S1}^*|_{\zeta=\infty}] > E[I_{S3}^*|_{\zeta=\infty}] \) since \( K > 2K_2^2 \). Further, since \( E[I_{S1}^*] \) is decreasing in \( \zeta \) and \( E[I_{S3}^*] \) is increasing in \( \zeta \), we have \( I_{S1}^* > I_{S3}^* \) for all \( \zeta \) when \( \zeta = 0 \). Observe from (11) and (42) that \( E[I_{S1}^*] - E[I_{S3}^*] \) decreases in \( \sigma \) implying that there exists a threshold value for \( \sigma \), above which expected profits in case 3 exceed case 1. Since the expected profits in the integrated channel are higher in case 1, the buyer profits must be lower when the supplier profits are higher in case 3 compared to case 1. \( \square \)

References


