Coordination of a supply chain with new products

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Abstract

In this paper, we consider the coordination issue on a supply chain when the firm on this chain tries to produce new products. By considering the risk of new products, three contracts, constant wholesale price contract, revenue sharing contract and linear quantity discount policy, are investigated.

Key words: supply chain coordination, new products, demand uncertainty

Introduction

The issue of supply chain coordination has been studied for many years and lots of well known contracts, such as revenue sharing, wholesale price, quantity discount, insurance, etc., have been used pervasively on coordinating a supply chain. The concept of “coordination” has also been well defined by many researchers such as Malone and Crowston(1994), Simatupang and Sridharan (2002) and Cachon (2003), but coordinating a supply chain with new products (NP) has received limited attention. The coordination of a supply chain with NP is worth to research for it typically represents a phenomenon of high risk of demand uncertainty. The purpose of this paper is to depict such a risk by mathematic model and to investigate the issue of supply chain coordination in a market with NP.

This paper considers a two-echelon supply chain selling a new product with an upstream manufacturer and a downstream retailer. Two kinds of product can be produced by the chain, the first one is the old products (OP) which has been sold for years and the second one is the NP, and before the selling season the decision maker of the chain needs to make a decision about which product to produce. In order to investigate the impacts of the NP on the supply chain coordination, we consider the scenario of OP-producing as a benchmark in which there is no demand uncertainty and three well known schemes, including revenue sharing contract (RSC), constant wholesale price contract (CWPC) and the linear quantity discount policy (LQDC), are utilized to coordinate the chain. In the NP-producing scenario, we take the risk
of demand uncertainty into consideration to investigate whether the above three schemes can coordinate the supply chain and to summarize the influences of the NP on the supply chain coordination. Some interesting results are found: (i) though the CWPC and the RSC cannot coordinate the supply chain under the OP-producing scenario, it does under the NP-producing scenario in some cases; (ii) the CWPC and the RSC can be substituted by the LQDC to coordinate the supply chain when they fails in coordinating the chain.

**Literature Review**

Literature related to this paper focuses mainly on supply chain coordination and demand uncertainty. Supply chain coordination is an important criterion for measuring the performance of supply chains (Anupindi and Bassok, 1999) and supply chain mechanism helps coordinate individual supply chain agents so that they will behave in a way which optimizes the whole supply chain system (Agrawal and Seshadri, 2000). It is well known that as the double marginalization (Spengler, 1950) and bullwhip effect (Lee et al., 1997) exists among the supply chain, the coordination cannot be achieved voluntarily. To achieve supply chain coordination, various schemes are proposed to coordinate the supply chain. A scheme is said to coordinate the supply chain if the set of supply chain optimal actions is Nash equilibrium, i.e., no firm has a profitable unilateral deviation from the set of supply chain optimal actions (Cachon, 2003). In fact, many well known contracts have been tried to coordinate the supply chain, such as revenue sharing, quantity discount, buy-back, wholesale price, etc. Among them, the constant wholesale price contract (CWPC), revenue sharing contract (RSC) and linear quantity discount policy (LQDC) are particularly popular and commonly implemented in supply chain coordination. The CWPC is the simplest one while is generally considered a non-coordinating contract (Cachon, 2003). For the LQDC, it can be used to coordinate a supply chain with one manufacturer and one retailer supply chain and which is beneficial to a seller (Lal and Staelin, 1984) and which has been wildly used by many researchers. Rosenblatt and Lee (1985) address the problem of determining the economic order quantities for the retailer, given a quantity discount schedule set by the supplier. Chen et al. (2001) provided a quantity discounts schedule to coordinate the supply chain with multiple independent retailers. Chen and Xiao (2009) using a linear quantity discount schedule to coordinate the supply chain after demand disruption. The RSC is regarded, regularly, as a kind of benchmark contract to compare with other contracts. Such as Gerchak and Wang (2004) who investigate the revenue sharing and wholesale price contract between an assembler/retailer and its suppliers to coordinate a decentralized supply chain with an uncertain demand, Pan et al. (2010) considers the impact of channel power structures on manufacturer’s profit by using revenue sharing and wholesale price, respectively, on a supply chain with two manufacturers and one retailer and Lin et al. (2010) propose an insurance contract in their paper and compare it with the revenue sharing contract, focusing particularly on their differences.

Coordinating a supply chain with demand uncertainty has also been well studied, such as Qi et al. (2004) which is the first paper that considers demand disruption in supply chain coordination. Based on this study, Xiao et al. (2007) consider the similar issue with Qi’s study but incorporate the retailer competition on a one-manufacturer-two-retailer system. Then other researchers consider this idea from different sides. Xu et al. (2006) consider the cost
disruption on a supply chain and find that the changing of production cost can also lead to demand variations. Wang et al. (2012) investigate a fashion supply chain and find the changing of fashion trends can also bring demand uncertainty to the supply chain.

To summarize, this paper complements the literature by studying the risk of NP on a supply chain and investigates its impacts to the supply chain coordination contracts, i.e., CWPC, RSC and LQDC. Our key contribution of this paper is to model the risk of NP on a supply chain and under this setting we investigate the coordination performance of the above three well known contracts.

**Benchmark: Supply Coordination under the OP-producing Scenario**

In this paper, we consider a two-echelon supply chain selling a product with an upstream manufacturer and a downstream retailer. Two products can be produced by the chain, the first one is the OP which has been sold for years and the second one is a new try for producing the NP, and before the selling season the firms on the chain need to make a decision about which product to choose. In the following, we will investigate, respectively, the issue of supply chain coordination under scenarios of OP-producing and NP-producing. The scenario of OP-producing will be regarded as a benchmark by the decision maker to decide whether to produce the NP.

In OP-producing scenario, we assume that the consumer’s utility of buying an OP is \( U(p,x) = vx - p \) where \( x \) is the quality of an OP, \( v \geq 0 \) is the consumer’s marginal valuation per unit quality and \( p \) is the retail price. Such a utility function emphasizes the risk of cannibalization when self-selecting customers with a high willingness to pay for quality are attracted to cheaper products of lower quality (Heese and Swaminathan, 2006). At the beginning of the selling season, the upstream manufacturer first decides the quality decision \( x \) and charges \( w \) for any unit order. Then the downstream retailer makes his retail price decision and places an order from the manufacturer due to the information that the manufacturer provides. After receiving the retailer’s order, the manufacturer produces strictly in accordance with the order and bears a unit production cost \( cx^2 \) which is convex, indicating increasing marginal costs of the quality investment, and assumed to be quadratic (Banker et al.1998). Furthermore, the retailer needs to forecast the market demand when making his order decision, while any forecasting bias will bring him a loss. To simplify the discussion, we assume that there is no such a loss of forecasting bias when marketing the OP which has been sold for years (this assumption is reasonable in practice for some large fashion firms such as H&M and Zara which have a large number of sales data that can be used to forecast their market demand and they have accumulated a wealth experiences in selling such a fashion product).

In the following the “OP” denotes the profit; Superscript “*” denotes optimality; subscripts of “sc”, “m” and “r” denote supply chain, manufacturer and retailer, respectively. Subscripts “o” and “n” denote the scenarios of OP-producing and NP-producing, respectively. In our paper, the product sales function is defined \( S(U) = \alpha U(p,x) \) where \( \alpha \geq 0 \) is the sales responsiveness to the consumer’s utility. Thus, we can drive the supply chain’s profit when the OP is produced that

\[
\Pi_{sc-o} = (p_{sc-o} - cx^2_{sc-o})U(p_{sc-o},x_{sc-o}).
\]
For solving the first order conditions of Eq. (1) that \( \frac{\partial \Pi_{sc-o}}{\partial p} = 0 \) and \( \frac{\partial \Pi_{sc-o}}{\partial x} = 0 \), we have the following lemma.

**Lemma 1.** The optimal pricing and quality decisions of the supply chain under OP-producing scenario are

\[
p_\star^{\text{sc-o}} = \frac{3v^2}{8c} \quad \text{and} \quad x_\star^{\text{sc-o}} = \frac{v}{2c},
\]

From Eq. (2), we can also calculate the supply chain’s optimal production \( S_\star^{\text{sc-o}} = \alpha(vx_\star^{\text{sc-o}} - p_\star^{\text{sc-o}}) = \alpha v^2 / 8c \) and profit \( \Pi_\star^{\text{sc-o}} = \alpha y^2 (p_\star^{\text{sc-o}} - cx_\star^{\text{sc-o}}) = \alpha v^4 / 64c^2 \). Intuitively, a higher consumer’s marginal valuation \( v \) will result in a higher production, which will further improve the chain’s profit.

Suppose a supply chain may be coordinated by different schedules. In our paper we only focus on the CWPC, RSC and LQDC which are most popular contracts in the literature of supply chain coordination. Under the RSC, the manufacturer charges \( w \) to the retailer and shares a portion of the retailer’s revenue that \( \phi < \phi < 1 \). The CWPC is a special case of the RSC when there is no revenue sharing between the retailer and the manufacturer, i.e., when \( \phi = 1 \). Under the LQDC, the manufacturer charges \( w^0 - \Theta S \) to the retailer where \( w^0 \) is the vertical maximum variable wholesale price and \( \Theta \) is the discount slope of the per-unit wholesale price schedule and \( S \) is the order quantity of the retailer (Ingene and Parry, 1995).

After investigating the above three contracts, we find that

**Proposition 1.** In a supply chain under the OP-producing scenario, the CWPC and the RSC fails to coordinate the supply chain, while the LQDC dose with \( w_\star^{\text{LQDC}} = v^2 / 2c \) and \( \Theta_\star^{\text{LQDC}} = 1 / \alpha \).

**Supply Coordination under the NP-producing Scenario**

When the decision maker tries to produce the NP, as the retailer has not enough information to forecast the demand from the market, the supply chain may bear the loss of forecasting bias of market demand (as the market is a new market for the firms, there has not so much first-hand sales data can be referenced, let alone the sales experiences of the NP). Two cases will be discussed in this scenario: in the first case, we assume the supply chain is centralized and optimal system decisions of pricing, quality and production are calculated; in the second case, a decentralized supply chain will be investigated and the CWPC, RSC and LQDC will be investigated to coordinate the chain.

**Centralized Decision Making**

In this case, as the firms on the supply chain are first to market their new product in a market, forecasting bias is most likely to occur. Let \( \bar{v} = v + \Delta \) be the consumer’s marginal valuation per quality of a NP where the \( \Delta \) represents the consumer’s extra marginal valuation, which is forecasted by the retailer, to the new features of the NP. Obviously, the case with \( \Delta > 0 (\Delta < 0) \) means the consumer shows a higher (lower) valuation to a NP than that of an OP. In real
business world, some people may dislike NP for which sacrifices some of the OP’s specialties (e.g. stability, usual practice, etc.) that he favors. Oppositely, some other people may prefer the NP for such people are more concerned with a new experience or they are fashion-mad. We assume \( \hat{v} \geq 0 \) for a rational consumer’s valuation to a product cannot be negative. Based on the above assumptions, the sales function in this scenario is given by \( S_{\alpha}(U) = \alpha \hat{U}(p_{\alpha}, x_{\alpha}) \) where \( \hat{U}(p_{\alpha}, x_{\alpha}) = \hat{v}_n - p_{\alpha} \). Let \( c \) denotes the unit underage cost and \( c_o \) is the unit overage cost. We can drive the supply chain’s profit under this scenario that

\[
\Pi_{\alpha \rightarrow \alpha} = (p_{\alpha \rightarrow \alpha} - cx_{\alpha \rightarrow \alpha})S_{\alpha \rightarrow \alpha}(\hat{U}) - c_o(S_{\alpha \rightarrow \alpha}^+ - S_{\alpha \rightarrow \alpha}^-) - c_o(S_{\alpha \rightarrow \alpha}^+ - S_{\alpha \rightarrow \alpha}^-),
\]

where \( (\cdot)^+ = \max(\cdot, 0) \). The first term in Eq. (3) is the total supply chain profit without forecasting bias and the second (third) term is the total underage (holding) cost incurred by the consumer’s increasing (decreasing) valuation to the new features in the NP.

From Eq. (3), the supply chain’s decisions under the OP-producing scenario are realized as follows.

**Proposition 2.** When the supply chain tries to enter the new market, we have the following conclusions.

(I). When the consumer reveals a low valuation to the NP, i.e., \(-v < \Delta < \sqrt{v^2 - 4cc_o - v}\), we have

\[
\begin{align*}
 p_{\alpha \rightarrow \alpha}^* &= p_{\alpha \rightarrow \alpha}^* + \frac{3\Delta (2v + \Delta) - 4cc_o}{8c} \\
x^*_{\alpha \rightarrow \alpha} &= x^*_{\alpha \rightarrow \alpha} + \frac{\Delta}{2c} \\
 S_{\alpha \rightarrow \alpha}^* &= S_{\alpha \rightarrow \alpha}^* + \frac{\alpha(2v + \Delta + 4cc_o)}{8c}
\end{align*}
\]

and

\[
\Pi_{\alpha \rightarrow \alpha} = \frac{\alpha v^2}{64c^2} (v^2 + 2\Delta^2 + 4\Delta).
\]

(II). When the consumer’s extra valuation to the NP is \( \sqrt{v^2 - 4cc_o - v} \leq \Delta \leq \sqrt{v^2 + 4cc_o - v} \), we have

\[
\begin{align*}
 p_{\alpha \rightarrow \alpha}^* &= p_{\alpha \rightarrow \alpha}^* + \frac{\Delta^2 + 2v\Delta}{2c} \\
x^*_{\alpha \rightarrow \alpha} &= x^*_{\alpha \rightarrow \alpha} + \frac{\Delta}{2c} \\
 S_{\alpha \rightarrow \alpha}^* &= S_{\alpha \rightarrow \alpha}^* + \frac{\alpha v^2}{64c^2} (v^2 + 2\Delta^2 + 4\Delta)
\end{align*}
\]

(III). When the consumer reveals a high valuation to the NP, i.e., \( \Delta > \sqrt{v^2 + 4cc_o - v} \), we have

\[
\begin{align*}
 p_{\alpha \rightarrow \alpha}^* &= p_{\alpha \rightarrow \alpha}^* + \frac{3\Delta (2v + \Delta) + 4cc_o}{8c} \\
x^*_{\alpha \rightarrow \alpha} &= x^*_{\alpha \rightarrow \alpha} + \frac{\Delta}{2c} \\
 S_{\alpha \rightarrow \alpha}^* &= S_{\alpha \rightarrow \alpha}^* + \frac{\alpha(2v + \Delta - 4cc_o)}{8c}
\end{align*}
\]

and

\[
\Pi_{\alpha \rightarrow \alpha} = \frac{\alpha v^2}{64c^2} (v^2 + 2\Delta^2 - 8cc_o (((v + \Delta)^2 - v^2) - 2cc_o)).
\]

After comparing the profits, respectively, in the Cases of I, II and III, we summarize the following conclusion.

**Proposition 3.** When the supply chain is under the OP-producing scenario, we have

\[
\Pi_{\alpha \rightarrow \alpha} < \Pi_{\alpha \rightarrow \alpha} < \Pi_{\alpha \rightarrow \alpha}.
\]

From the above results in Proposition 2 and Proposition 3, we can summarize the following management insights:

(i) Compare with the benchmark, scenario of OP-producing, the supply chain needs to take the risk of demand uncertainty which is caused by the variations of the consumer’s valuation to the NP and a higher (lower) valuation the consumer reveals to the NP, the higher (lower) profit the supply chain earns. The supply chain only achieves a higher profit in NP-producing scenario than that of OP-producing only
when the consumer reveals a high enough valuation per quality, when \( \Delta > \sqrt{v^2 + 4cc_w - v} \), to the NP.

(ii) All the decisions, pricing, quality and production, should be revised when the consumer’s valuation to the product quality changes largely compare to that in the benchmark. Though there is no need to change the production decision by the decision maker when the consumer’s valuation changes slightly, the pricing decision and quality decision should also be revised.

(iii) As \( \frac{\partial \pi^w_{m-g}}{\partial \|q\|} > 0 \) and \( \frac{\partial \pi^w_{m-g}}{\partial \|q\|} > 0 \) where \( i = I, II \) or \( III \), the larger the change of the consumer’s valuation to the product will result in a larger revision of the pricing decision and quality decision.

### Decentralized Decision Making

In this subsection, we will investigate the supply chain in a decentralized way. In order to achieve the optimal profit as high as that in the centralized supply chain, the manufacturer needs to set some mechanisms to constraint the retailer’s behavior. Three contracts, CWPC, RSC and LQDC, will be utilized by the manufacturer to coordinate the decentralized supply chain. In the following, we will not investigate the CWPC specifically for it is a special case of the RSC when the fraction of the revenue he keeps satisfies that \( \phi = 1 \).

As we mention before that under the RSC, the manufacturer charges \( w \) to the retailer and shares a portion of the retailer’s revenue with a fraction \( (1 - \phi) \). Thus, we have the functions of the retailer and manufacturer, respectively, under the RSC that

\[
\begin{align*}
\Pi_{m-n, \text{RSC}} &= \phi(S_n P_{m-n, \text{RSC}} - L_n) - S_n w_{m-n, \text{RSC}}, \\
\Pi_{m-n, \text{RSC}} &= (w_{m-n, \text{RSC}} - c A^2) S_n + (1 - \phi)(S_n P_{m-n, \text{RSC}} - L_n),
\end{align*}
\]

where \( S_n = \alpha((v + \Delta) x_{m-g, \text{RSC}} - P_{m-g, \text{RSC}}) \) and \( L_n = c \left(S_o - S_n\right)^+ + c \left(S_n - S_i\right)^+ \). After investigating the RSC and CWPC, respectively, in Case I with \( -v < \Delta < \sqrt{v^2 + 4cc_w - v} \), Case II with \( \sqrt{v^2 - 4cc_w - v} \leq \Delta \leq \sqrt{v^2 + 4cc_w - v} \) and Case III with \( \Delta > \sqrt{v^2 + 4cc_w - v} \), we have the proposition below that

**Proposition 4a.** Under the scenario of NP-producing, the supply chain cannot be coordinated by the RSC or CWPC in Case I or Case III. Furthermore, the RSC reveals a better profit performance for the supply chain than that under CWPC.

**Proposition 4b.** The RSC can be used to coordinate the supply chain under the NP-producing scenario in Case II when

\[
w^*_m = \frac{\phi(v^2 - 2\Delta^2)}{4c} \quad \text{and} \quad \phi = \frac{-6\Delta^2 + 4v\Delta}{(v + 2\Delta)^2},
\]

with \( \Delta \in (\max\{\sqrt{\frac{-4}{10}} v; \sqrt{\frac{-4}{3}} v; -\frac{2v}{3} v\}, 0) \) and so does the CWPC when \( w = \frac{(v^2 - 2\Delta^2)}{4c} \).

From the Propositions 4a and 4b, compare with the results in benchmark we can summarize something interesting that though the CWPC and the RSC fails to coordinate the supply chain in the OP-producing scenario, it works in the NP-producing scenario under certain conditions of Case II that when the consumer’s valuation to the NP changes slightly compare to the OP.
Now, we can also write the profit functions of the retailer and manufacturer, respectively, under LQDC that
\[
\begin{align*}
\Pi_{r, n, lqdc} &= (p_{r, n, lqdc} - (w_{r, n, lqdc}^0 - \theta S_n))S_n - L_n \\
\Pi_{m, n, lqdc} &= ((w_{m, n, lqdc}^0 - \theta S_n) - cx_{m, n, lqdc})S_n.
\end{align*}
\]

(6)

Similar to that under the RSC, we can also summarize the following conclusion under LQDC that

**Proposition 5.** In Case I (Case III) of the NP-producing scenario, the supply chain can be coordinated by the LQDC when
\[
w_{m, n, lqdc}^0 = \left(\frac{v + \Delta j^2 + 4cc_n}{4c}\right) \quad \text{and} \quad \theta_{m, n, lqdc} = 1/\alpha ,
\]
while in case II, the LQDC fails to coordinate the supply chain.

The above Proposition 5 tell us though the LQDC reveals a good performance on supply chain coordination that it not only coordinates the supply chain under the OP-producing scenario (the CWPC and RSC fails in this scenario), but also in the Case I and Case III of the OP-producing scenario, it still fails to coordinate the supply chain sometimes. As a consequence, it becomes very necessary to revise the supply chain strategies due to the change of the market.

**Numerical examples**

In this section, some numerical examples will be proposed to validate the theoretical results of this paper. We assume that the values of the basic parameters in our model are: \(\alpha = 4\), \(v = 2\), \(c = 1\), \(c_s = 0.4\) and \(c_n = 0.6\).

First, we consider the scenario of OP-producing in which no forecasting bias of demand occurs. We investigate the relationship of the consumer’s margin valuation per unit quality \(v\) to the supply chain’s optimal decisions of pricing, quality and production.
From the above Figure 1 and Figure 2 we can intuitively find that, a higher $v$ will result a higher retail price, a higher quality, a higher production and a higher profit. We can also see that the pricing decision reveals a higher growth rate than that of the quality decision, which reveals that pricing decision is more sensitive to the consumer’s valuation than quality decision.

In the following, we will describe the influences of the forecasting bias on the supply chain’s optimal strategies, pricing, quality and production, in three cases, Case I with $-3 < \Delta < -0.2797$, Case II with $-0.2797 \leq \Delta \leq 0.3764$ and Case III with $0.3764 < \Delta < 3$, which are shown in Figure 3. In Figure 4, we show the relationship of the forecasting bias to the supply chain’s optimal profit in three cases mentioned before and compare the supply chain’s profit under the OP-producing scenario and the NP-producing scenario, respectively.

The Figure 3 tell us that the forecasting bias of consumer’s margin valuation largely affect the supply chain’s optimal decisions. Intuitively, a higher forecasting will result in a higher revision for the supply chain’s decisions. In practice, the above results suggest that (i) when the consumer reveals a higher enough demand for the NP, the firms should increase
their production to meet the increasing demand and at the same times increase retail price and product quality to achieve a higher profit; (ii) if the consumer’s demand varies slightly, there is no need for the firms to change their production plan, while the pricing decision and the quality decision should be revised based on the forecasting bias; (iii) when the consumer reveals a lower enough demand for the NP, in order to avoid huge losses the firms should largely decrease their production, retail price and product quality.

![Optimal profit under the GFP-producing scenario](image1)

From Figure 4 we can see that compare with the OP there will be some risk for the NP producers. Obviously, the NP producers can achieve a higher profit than that of the OP producers only when the consumer reveals a high enough valuation to the NP, or they will bear huge losses. The Figure 4 strongly supports our model results in Proposition 3.

**Conclusion**

This paper investigates how the NP-producing can affect the decisions, pricing, quality and production, and the coordination of a supply chain. We show that compare with the OP-producing scenario the firm’s NP-producing will bring some risks of demand uncertainty to the supply chain and which largely affect the chain’s decisions. To be specific, compare to the benchmark, almost all the supply chain’s decisions need to be revised under the scenario of NP-producing. For the supply chain coordination, though the CWPC and the RSC cannot coordinate the supply chain under the OP-producing scenario, it does under the NP-producing scenario when the consumer’s valuation to the NP slightly changes compare with that under the OP-producing scenario; when the RSC is used, it fails to coordinate the supply chain when the consumer’s reveals largely variation to the NP’s valuation though it dose when the consumer’s valuation to the NP varies slightly. We also find that the LQDC shows a better performance than the CWPC and RSC on supply chain coordination, while it still fails on this some times.
Appendix

The readers who are interested in the proofs of all the Lemmas and Propositions in this paper can contact Dr. Ke Wang at wke620@mail.ustc.edu.cn.

References

Xu, M., Qi, X., Yu, G., Zhang, H. 2006. Coordinating dyadic supply chains when production costs are disrupted. IIE transactions 38(9): 765-775.