Research papers

A general framework of supply chain contract models

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Abstract

A supply chain is two or more parties linked by a flow of goods, information, and funds. When one or more parties of the supply chain try to optimize their own profits, system performance may be hurt. Supply chain contract is a coordination mechanism that provides incentives to all of its members so that the decentralized supply chain behaves nearly or exactly the same as the integrated one. We have seen a vast literature on supply chain contracts recently. However, little work has been done on the relationships of those supply chain contract models. In this paper, we provide a general framework that synthesizes existing results for a variety of supply chain contract forms.

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Introduction

Consider the following situation faced by the toy industry (Johnson, 1999):

> Two key features that define many of the challenges in the toy industry for both large and small firms are the seasonal demand and short product life. Toy sales and volumes grow exponentially the last few days before Christmas. November and December alone represent nearly 45% of toy sales. Shipments from manufacturers to retailers follow the same lop-sided activity. Fourth quarter shipments have steadily grown over the past ten years with 1997 shipments representing 36% of the year's total ... This strong seasonal demand is only one component of the toy makers' challenge. While thousands of toys are brought to market every year, only a small fraction of them succeed. Even fewer have what it takes to last longer than one or two years. Classics, such as Mattel's Barbie and Hot Wheels are examples of products that have stood the test of time. As John Handy, vice president of product design at Mattel Inc., stated: "We're just one good idea away from going out of business."

In such a volatile market featured by uncertain demand and a short selling season, the retailer has a great chance to face the risk of either excess stock or lost sales. For example, department store markdowns have grown from 8 per cent of store sales in 1971 to 33 per cent in 1995 (Fisher *et al.*, 2000). The apparel, electronics, and semiconductor industries are facing the same problem as the toy industry. As time-based competition intensifies, product lifecycles become shorter and shorter so that more and more products acquire the attributes of fashion or seasonal goods (Petruzzi and Dada, 1999). In order to avoid significant product markdowns, the retailer tends to order less from the manufacturer to maximize his own expected profit, which is well-known as "double marginalization" (Spengler, 1950), i.e. the total expected profit of the decentralized supply chain is lower than the integrated supply chain. Developing strategies to decrease the risk faced by the retailer is becoming more and more critical in a supply chain, especially in the global marketplace where firm-to-firm competition is being replaced by supply-chain-to-supply-chain

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competition (Lee *et al.*, 2000). Among the solutions, supply chain contracts, which have drawn much attention from the researchers recently, are used to provide some incentives to adjust the relationship of supply chain partners to coordinate the supply chain, i.e. the total profit of the decentralized supply chain is equal to that achieved under a centralized system.

The format of supply chain contracts varies in and across industries. Returns policies allow the retailer to return a certain percentage of his unsold goods to the manufacturer for a partial rebate credit. They are common in the distribution of perishable commodities, such as books, magazines, newspapers, recorded music, computer hardware and software, greetings cards, and pharmaceuticals (Pasternack, 1985; Padmanabhan and Png, 1995). Quantity flexibility (QF) contracts define terms under which the quantity a retailer ultimately orders from the manufacturer may deviate from a previous planning estimate (Tsay *et al.*, 1999). QF contracts are very common in the electronic industry and used by Sun Microsystems, Nippon Otis, Solectron, IBM, HP, and Compaq, etc. (Tsay, 1999). Backup agreements have been used by Anne Klein, Finity, DKNY, Liz Claiborne, and Catco in the apparel industry (Eppen and Iyer, 1997). It states that, if a retailer commits to a number of units for the season, the manufacturer will hold back a fraction of the commitment and the retailer can order up to this backup quantity at the original purchase price after observing early demand. Barnes-Shuster *et al.* (1999) study an option contract which specifies that, in addition to a firm order at a regular price, the retailer can also purchase options at an option price at the beginning of the selling season. After observing early demand, the retailer can choose to exercise those options at an exercise price. Finally, price protection has been commonly used between manufacturers and retailers in the personal computer industry (Lee *et al.*, 2000). It states that the manufacturer pays the retailer a credit applying to the retailer's unsold goods when the wholesale price drops during the lifecycle (Taylor, 2001).

We have seen a vast literature on supply chain contracts recently. However, little work has been done on the relationships of those supply chain contract models. In this paper, we provide a general framework that synthesizes existing results for a variety of supply chain contract forms. Based on our two-period supply chain contract model, we also derive the optimal solution that could achieve channel coordination and identify some important managerial insights.

This paper is organized as follows. Section 2 provides a brief literature review of a variety of supply chain contract forms including returns policies, QF contracts, backup agreements, options, and price protections. In Section 3, we provide a general two-period model that synthesizes existing results for supply chain contracts and identify the optimal solution that could achieve supply chain coordination. In Section 4, we show how these existing supply chain contract models are only special forms of our general model. Finally, in Section 5, we discuss some important managerial insights and draw our conclusions.

Literature review

Supply chain contracts have been studied extensively in economics, operations management, and marketing science literature (see Lariviere (1999) and Tsay *et al.* (1999) for recent surveys). While there are various types of supply chain contracts in the real world, we focus on a group of closely related supply chain contract provisions.

A returns policy specifies that the retailer can return a certain percentage, say ρ, of his order quantity Q to the manufacturer at the end of the season for a partial rebate credit b. Pasternack (1985) is the first to study a single-period returns policy with stochastic demand for perishable goods. He shows that both fulfill full returns with full rebate credit and no returns are system suboptimal. The supply chain could be coordinated by an intermediate returns policy, e.g. partial returns with fulfill full rebate credit. Kandel (1996) extends Pasternack (1985) to a price-sensitive stochastic demand model and concludes that the supply chain cannot be coordinated by returns policies without retail price maintenance (i.e. allowing the manufacturer to dictate the retail price). Emmons and Gilbert (1998) study a multiplicative model of demand uncertainty for catalog goods and demonstrate that uncertainty tends to increase the retail price.

They also show that, under certain conditions, a manufacturer can increase his/her profit by offering a returns policy. Webster and Weng (2000) take the viewpoint of a manufacturer selling a short lifecycle product to a single retailer and describe risk-free returns policies through which, when compared with no returns, the retailer's expected profit is increased and the manufacturer's profit is at least as large as when no returns are allowed. Lee *et al.* (2000) analyze a two-period price protection policy in the personal computer industry. The basic idea of their single-buying-opportunity model is that the retailer orders Q products from the manufacturer at the beginning of the first period at a wholesale price w_1. At the beginning of the second period, the wholesale price of the same product drops to w_1 because of the introduction of new products. To share the risk of the retailer, the manufacturer will pay a rebate credit b to the retailer for all unsold inventory at the end of the first period. It is similar to Pasternack (1985), but looking at the dynamic optimal price protection policy when the product in the markets is faced with obsolescence during multiple periods.

Unlike returns policies which focus on flexibility in adjusting price, QF contracts focus on flexibility in adjusting ordering quantity. Lariviere (1999) and Tsay (1999) consider a single- and a multiple-period QF model separately. The basic idea of QF is that, when a retailer places an initial order q, the manufacturer agrees to provide up to $(1 + u)q$ units to the system. At the same time the retailer commits to order at least $(1 - d)q$ units. After observing the demand for a short period, the retailer can decide to order any quantity between $(1 - d)q$ and $(1 + u)q$ at the wholesale price w. Both Lariviere (1999) and Tsay (1999) show that QF can lead to a much greater profit of the decentralized supply chain than that achieved without QF. Eppen and Iyer (1997) focus on a two-period backup agreement between a catalog company and manufacturers. A backup agreement states that, if the catalog company commits to a number of units for the season, the manufacturer holds back a constant fraction ρ of the commitment Q and delivers the remaining units $(1 - \rho)Q$ at the beginning of the selling season. After observing early demand, the catalog company can order up to this backup quantity for the original purchase cost and receive quick delivery but will pay a penalty cost p for any of the backup units it does not buy. Barnes-Shuster *et al.* (1999) investigate the role of options in a supply chain. The retailer makes a firm order q at the beginning of the selling season at a wholesale price w. In addition, he purchases n options at an option price w_o. In the second period, the retailer may choose to exercise n $(n \leq m)$ options at an exercise price w_e. They illustrate how options provide flexibility to a retailer to respond to market changes in the second period quickly.

A general framework of supply chain contract models

We consider a supply chain composed of a single manufacturer and a single retailer selling short-lifecycle products with stochastic customer demand. The selling season is short and divided into two continuous periods. At the beginning of the first period, the retailer orders Q products from the manufacturer for both periods and cannot make any changes when the season begins. During the first period, if realized demand is higher than Q, all sales are lost and the retailer will incur a goodwill cost g_1. If realized demand is lower than Q, the retailer can return up to $\rho_1 Q$ to the manufacturer and get a per unit rebate credit b_1. Returned goods are salvaged at a value s_1. The rest of the leftover inventory y will be carried over to the second period and the retailer will incur a per unit end-of-period inventory holding cost h_1. At the beginning of the second period, because of the product obsolescence, the retailer has to mark down the product at a retail price r_2, which is lower than his retail price r_1 in the first period. Demand in the second period is still stochastic but correlated to the first period. If realized demand in the second period is higher than the available inventory y, all sales are lost and the retailer will incur a goodwill cost g_2. If realized demand is lower than y, the retailer will incur an end-of-period inventory holding cost h_2 and salvage the products at a value s_2. No returns are allowed in the second period. The following subsections formally define our two-period model.

Notation

We define the following quantities:

- c manufacturer's production cost in the first period;
- w manufacturer's wholesale price in the first period;
- r_i retail price in period $i = 1, 2$;
- b_1 manufacturer's rebate credit for returned goods in the first period;
- Q retailer's total order quantity at the beginning of the first period;
- y amount left after the end of the first period at the retailer;
- ρ_1 percentage of Q that can be returned to the manufacturer at the end of the first period;
- g_i retailer's goodwill cost in period $i = 1, 2$;
- h_i retailer's end-of-period inventory holding cost in period $i = 1, 2$;
- s_i salvage value in period $i = 1, 2$;
- X_i non-negative random variable for customer demand in period 1;
- $f_1(x_1)$ probability density function (PDF) for realized demand x_1 in period 1;
- $F_1(x_1)$ cumulative distribution function (CDF) for realized demand x_1 in period 1;
- $f_2(x_2|x_1)$ conditional PDF for demand x_2 in period 2, given x_1;
- $F_2(x_2|x_1)$ conditional CDF for demand x_2 in period 2, given x_1

Assumptions

We will use the following assumptions throughout the remainder of the paper:

- Both the manufacturer and the retailer are risk-neutral so that maximizing expected utilities would be equivalent to maximizing expected profits.
- We assume both manufacturer and retailer have full controls over the wholesale price and retail prices in both periods. These prices are exogenous.
- $r_1 > r_2 > w > c > b_1$. We assume the retail price in the second period is lower than the first period because of the product obsolescence. Retail prices are higher than the wholesale price so that the retailer can make a profit from selling the product. Similarly, we assume the wholesale price is higher than the production cost. The rebate credit is lower than the production cost.
- $g_2 < g_1$, $r_2 > s_2$, and $r_1 > s_1$. This assumption states that the goodwill cost in the second period is less than the first period and the retail price is higher than the salvage value in each period.
- There is no information asymmetry so that information on price, costs, and demand is common knowledge.

The timing

The timing of the events is as follows:

(1) The manufacturer moves first as the Stackelberg leader offering the retailer a take-it-or-leave-it contract which specifies a wholesale price w, a rebate credit b_1, and the returns percentage ρ_1 for the first period.
(2) In response, the retailer orders Q from the manufacturer before the beginning of the first period.
(3) Production takes place at the manufacturer and finished products are sent to the retailer at the beginning of the first period.
(4) Demand in the first period is realized. Some of leftover inventories are returned to the manufacturer and salvaged. Others that cannot be returned are carried over to the second period.
(5) Demand in the second period is realized. Leftover inventories are salvaged at the retailer.

The integrated supply chain

In the integrated supply chain, the manufacturer acts as his own retailer (i.e. company store). This model will enable us to determine the optimal policy for the system as a whole. In this setting, the integrated firm produces Q products at a per unit production cost c and sells them to the public directly at a retail price r_1 and r_2 in the first and second period respectively. The firm's objective is to choose an optimal production quantity that maximizes his expected profit.

To analyze the model, we work backward starting with period 2. At the end of period 1, if the leftover stock is y, the integrated firm's expected profit $\Pi_2^I(y)$ in the second period is given by:

$$\Pi_2^I(y) = \int_0^y [x_2 r_2 - (y - x_2)(h_2 - s_2)] f_2(x_2|x_1)dx_2. \tag{1}$$

Moving back to the first period, the expected profit of the integrated firm is given by:

$$\Pi_2^I(Q) = -cQ + \int_0^Q [x_1 r_1 + \Pi_2^I(Q - x_1) - (Q - x_1)h_1]f_1(x_1)dx_1 + \int_Q^\infty [Qr_1 + \Pi_2^I(0) - (x_1 - Q)g_1]f_1(x_1)dx_1. \tag{2}$$

Property 1

The integrated supply chain's expected profit function is concave in the decision variable Q and hence there is a unique optimal solution $Q^\star$ that maximizes the integrated supply chain's expected profit.

Proof. We take the first derivative of $\Pi_1^I(Q)$ with respect to Q and set this amount equal to 0. This gives:

$$d\Pi_1^I(Q)/dQ = r_1 + g_1 - c - (r_1 - r_2 + g_1 - g_2 + h_1)F_1(Q) - (r_2 + g_2 + h_2 - s_2)\int_0^Q F_2(Q - x_1) f_1(x_1)dx_1 = 0. \tag{3}$$

We take the second derivative of $\Pi_1^I(Q)$ with respect to Q. This gives:

$$d^2\Pi_1^I(Q)/dQ^2 = - (r_1 - r_2 + g_1 - g_2 + h_1)f_1(Q) - (r_2 + g_2 + h_2 - s_2) \int_0^Q f_2(Q - x_1)f_1(x_1)dx_1 < 0.$$

So $Q^\star$ that satisfies Condition (3) will be the optimal production quantity that maximizes the integrated supply chain's expected profit.

Independent retailer without returns

If both manufacturer and retailer are independent, they will try to maximize their own expected profits without considering maximizing the total supply chain's expected profit. In this setting, the independent manufacturer charges the retailer a wholesale price w which is higher than c. In turn, the retailer sells the products to the public at the retail price r_1 and r_2 in the first and second period respectively. The independent retailer's objective is to choose an optimal order quantity to maximize his expected profit.

Similarly, we work backward starting with period 2. At the end of period 1, if the leftover stock is y, the retailer's expected profit $\Pi_2^r(y)$ in the second period is given by:

$$\Pi_2^r(y) = \int_0^y [r_2 x_2 - (y - x_2)(h_2 - s_2)] f_2(x_2|x_1)dx_2 + \int_y^\infty [yr_2 - (x_2 - y)g_2]f_2(x_2|x_1)dx_2. \tag{4}$$

Moving back to the first period, the expected profit of the retailer is given by:

$$\Pi_1^r(Q_r) = -cQ_r + \int_0^{Qr} [x_1 r_1 + \Pi_2^I(Q_r - x_1) - (Q_r - x_1)h_1] f_1(x_1)dx_1 + \int_{Qr}^\infty [Q_r r_1 + \Pi_2^I(0) - (x_1 - Q_r)g_1]f_1(x_1)dx_1. \tag{5}$$

Property 2

The independent retailer's expected profit function is concave in the decision variable Q_r and hence there is a unique optimal solution Q_r^* that maximizes the retailer's expected profit.

Proof. Similar to Property 1.

From Property 2, we can derive that the retailer's optimal order quantity Q_r^* satisfies:

$$d\Pi_1^r(Q_r)/dQ_r = r_1 + g_1 - w - (r_1 - r_2 + g_1 - g_2 + h_1)F_1(Q_r) - (r_2 + g_2 + h_2 - s_2) \int_0^{Qr} F_2(Q_r - x_1)f_1(x_1)dx_1 = 0. \tag{6}$$

Property 3.

The independent retailer's optimal order quantity is less than the integrated supply chain's optimal production quantity, i.e. $Q_r^* < Q^*$.

Proof. To prove Property 3, we plug Q_r^* into $d\Pi_1^I(Q)/dQ$, which gives:

$$d\Pi_1^I(Q_r^*)/dQ = r_1 + g_1 - c - (r_2 - r_1 + g_2 - g_1 - h_1)F_1(Q_r^*) - (r_2 + g_2 + h_2 - s_2) \int_0^{Q_r^*} F_2(Q_r^* - x_1)f_1(x_1)dx_1 = r_1 + g_1 - w - (r_2 - r_1 + g_2 - g_1 - h_1)F_1(Q_r^*) - (r_2 + g_2 + h_2 - s_2) \int_0^{Q_r^*} F_2(Q_r^* - x_1) f_1(x_1)dx_1 + (w - c) = w - c > 0.$$

So $d\Pi_1^I(Q^*)/dQ = 0 < d\Pi_1^I(Q_r^*)/dQ$. Notice that $d\Pi_1^I(Q)/dQ$ is strictly decreasing in Q; we get $Q_r^* < Q^*$.

Property 3 shows that, without supply chain coordination, the independent retailer will always order less than the total supply chain's optimal quantity. The decentralized supply chain's expected profit will be lower than an integrated supply chain. This phenomenon is well-known as "double marginalization" (Spengler, 1950). In the next subsection, we will provide a supply chain contract model where the manufacturer provides a returns policy to encourage the retailer to order more so that the supply chain is coordinated.

Independent retailer with returns

To encourage the retailer to order more, the manufacturer offers a returns policy that specifies that the retailer can return a percentage of his initial orders, say ρ_1, to get a per unit rebate credit b_1 from the manufacturer at the end of the first period. In this way, the manufacturer shares the risk faced by the retailer.

To analyze the model, again, we start from period 2. At the end of period 1, if the leftover stock is y, the retailer's expected profit $\tilde{\Pi}_2^r(y)$ in the second period is given by:

$$\tilde{\Pi}_2^r(y) = \int_0^y [r_2x_2 - (y - x_2)h_2]f_2(x_2|x_1)dx_2 + \int_y^\infty [yr_2 - (x_2 - y)g_2]f_2(x_2|x_1)dx_2. \tag{7}$$

Moving back to the first period, the expected profit to the retailer when he orders $\tilde{Q}_r$ is given by:

$$\begin{aligned}\tilde{\Pi}_1^R(\tilde{Q}_r) = &-w\tilde{Q}_r \\ &+ \int_0^{(1-\rho_1)\tilde{Q}_r} [x_1r_1 + \rho_1\tilde{Q}_rb_1 \\ &- ((1-\rho_1)\tilde{Q}_r - x_1)h_1 \\ &+ \tilde{\Pi}_2^R((1-\rho_1)\tilde{Q}_r - x_1)]f_1(x_1)dx_1 \\ &+ \int_{(1-\rho_1)\tilde{Q}_r}^{\tilde{Q}_r} [r_1x_1 \\ &+ (\tilde{Q}_r - x_1)b_1 + \tilde{\Pi}_2^r(0)]f_1(x_1)dx_1 + \int_{\tilde{Q}_r}^\infty \\ &[\tilde{Q}_rr_1 - (x_1 - \tilde{Q}_r)g_1 + \tilde{\Pi}_2^R(0)]f_1(x_1)dx_1.\end{aligned} \tag{8}$$

Before going to Property 4, we define the following condition that will ensure an interior optimal solution for this model.

Condition 1

The manufacturer's returns policy (b_1, ρ_1) satisfies:

$$\begin{aligned}&(1-\rho_1)^2(r_2 + g_2 - b_1 - h_1)f_1 \\ &((1-\rho_1)\tilde{Q}_r) - (r_1 + g_1 - b_1)f_1(\tilde{Q}_r) \\ &- (1-\rho_1)^2(r_2 + g_2 + h_2)\int_0^{(1-\rho_1)\tilde{Q}_r} \\ &f_2((1-\rho_1)\tilde{Q}_r - x_1)f_1(x_1)dx_1 < 0.\end{aligned} \tag{9}$$

Property 4

Under Condition 1, the expected profit function of the independent retailer with a returns policy (b_1, ρ_1) is concave in the decision variable $\tilde{Q}_r$ and hence there is a unique optimal solution $\tilde{Q}_r^*$ that maximizes his expected profit.

Proof. We take the first derivative of $\tilde{\Pi}_1^r(\tilde{Q}_r)$ with respect to $\tilde{Q}_r$ and set this amount equal to 0. This gives:

$$\begin{aligned}&d\tilde{\Pi}_1^r(\tilde{Q}_r)/d\tilde{Q}_r = r_1 + g_1 - w + (1-\rho_1) \\ &(r_2 + g_2 - b_1 - h_1)F_1((1-\rho_1)\tilde{Q}_r) \\ &- (r_1 + g_1 - b_1)F_1(\tilde{Q}_r) \\ &- (r_2 + g_2 + h_2) \\ &(1-\rho_1)\int_0^{(1-\rho_1)\tilde{Q}_r} F_2((1-\rho_1)\tilde{Q}_r - x_1) \\ &f_1(x_1)dx_1 = 0.\end{aligned} \tag{10}$$

After taking the second derivative of $\tilde{\Pi}_1^r(\tilde{Q}_r)$ with respect to $\tilde{Q}_r$, this gives:

$$\begin{aligned}&d^2\tilde{\Pi}_1^r(\tilde{Q}_r)/d\tilde{Q}_r^2 - (1-\rho_1)^2 \\ &(r_2 + g_2 - b_1 - h_1)f_1((1-\rho_1)\tilde{Q}_r) \\ &- (r_1 + g_1 - b_1)f_1(\tilde{Q}_r) \\ &- (1-\rho_1)^2(r_2 + g_2 + h_2)\int_0^{(1-\rho_1)\tilde{Q}_r} \\ &f_2((1-\rho_1)\tilde{Q}_r - x_1)f_1(x_1)dx_1.\end{aligned}$$

According to Condition 1, $d^2\tilde{\Pi}_1^r(\tilde{Q}_r)/d\tilde{Q}_r^2 < 0$. This leads to the Property.

Given the integrated supply chain's optimal production quantity Q^* and the independent retailer's optimal order quantity $\tilde{Q}_r^*$, the manufacturer's objective is to provide the retailer with a returns policy (b_1, ρ_1) that satisfies $\tilde{Q}_r^* = Q^*$ so that the supply chain is coordinated. The following Property formally defines the optimal returns policy.

Property 5

Under Condition 1, a returns policy (b_1^*, ρ_1^*) that satisfies the following equation could coordinate the supply chain, i.e. $\tilde{Q}_r^* = Q^*$:

$$w - c - (r_2 - 2r_1 - 2g_1 + g_2 - b_1^* - h_1) F_1(Q) - (r_2 + g_2 + h_2) \int_0^Q F_2(Q - x_1) f_1(x_1) dx_1 - (1 - \rho_1^*)(r_2 + g_2 - b_1^* - h_1) F_1((1 - \rho_1^*)Q) + (r_2 + g_2 + h_2)(1 - \rho_1^*) \int_0^{(1-\rho_1^*)Q} F_2((1 - \rho_1^*)Q - x_1) f_1(x_1) dx_1. \quad (11)$$

Proof. If $Q^* = \tilde{Q}_r^*$, Equations (8) and (9) should coincide. This leads to Equation (11).

Relationship with models from the literature

In this section, we will show how returns policies, QF, backup agreements, options, and the single-order-opportunity price protection contract are only special forms of our general model. The correspondences between our general model and these supply chain contracts are summarized in Table I.

We begin our analysis with identifying some common features among these supply chain contract models and our general model. The supply chain studied in all these models is composed of a single retailer and a single manufacturer selling short-lifecycle products with stochastic demand. The wholesale price, retail price, production cost, inventory holding cost, goodwill cost, and salvage value are exogenous. The manufacturer acts as the supply chain leader and offers the retailer a take-it-or-leave-it contract. These contracts implicitly or explicitly allow the retailer to return certain percentage of his initial order quantity to the manufacturer. The main differences among these supply chain contracts are:

- returns policies are single-period models whereas others are two-period models;
- demands in returns policies and price protection contracts are independent whereas others are correlated; and
- in price protection and our model, we allow different retailer prices in periods whereas others assume constant retailer prices in periods.

We will show how our model is general enough to synthesize all these supply chain contract models.

Returns policies such as Pasternack (1985) are single-period newsvendor models. In our model, if we allow backorders at the beginning of the second period and assume retailer prices in both periods are constant, i.e. $r_1 = r_2$, then our model reduces to the returns policy.

The two-period single-order-opportunity price protection contract such as Lee *et al.* (2000) assumes demands in both periods are independent and the return percentage is 100 per cent, whereas, in our model, demand in both periods is correlated and we allow any percentage of returns. If we the correlation coefficient of the demand in both periods be zero and the returns percentage ρ_1 = 100 per cent, then our model reduces to a price protection contract.

The two-period backup agreement assumes demands in both periods are correlated and retail prices in both periods are constant. It states that, if the retailer orders Q from the manufacturer at the beginning of the first period, he/she can choose to order less than the backup quantity ρQ at the beginning of the second period after observing early demand, but will pay a penalty cost p for any of the backup units he/she does not buy. It is equivalent that the retailer orders Q from the manufacturer at the beginning of the first period and returns up to ρQ to the manufacturer at a rebate credit $w - p$. In our model, if we let $r_1 = r_2$, $b_1 = w - p$, and $\rho_1 = \rho$, then it reduces to the backup agreement.

Option contract is a two-period model like ours. It assumes demands in both periods are correlated and retail prices in both periods are constant. It states that the retailer orders a firm order q at the regular wholesale price and options m at an option price from the manufacturer. In the second period, the retailer may choose to exercise $n (n \leq m)$ options at an exercise price w_e. Then it is equivalent that the retailer's orders total $Q = q + m$ from the manufacturer at the beginning of the first period and could return up to $\rho = m/(q + m)$ of Q to the manufacturer with a rebate credit w_e. In our model, if we let $r_1 = r_2$, $b_1 = w_e$, and $\rho_1 = m/(q + m)$, then our model reduces to the option contract.

A two-period QF model assumes demands in the two periods are correlated and retail prices in both periods are constant. If the retailer orders q from the manufacturer at the beginning of the first period, he can choose to buy any amount between $(1 - d)q$ and $(1 + u)q$

Table I Relationship between the general model and other supply chain contracts

Model	Order quantity	Returns percentage	Rebate credit	Retail price in period 1	Retail price in period 2	Demands in both periods
General model	Q	ρ_1	b_1	r_1	r_2	Correlated
Returns Policy	Q	ρ_1	b_1	r_1	$r_2 = r_1$	Independent
QF	$Q = (1 + u)q$	$\rho_1 = (u + d)/(1 + u)$	$b_1 = w$	r_1	$r_2 = r_1$	Correlated
Backup agreement	Q	ρ_1	$b_1 = w - p$	r_1	$r_2 = r_1$	Correlated
Options	$Q = q + m$	$\rho_1 = m/(q + m)$	$b_1 = w_e$	r_1	$r_2 = r_1$	Correlated
Price protection	Q	ρ_1	b_1	r_1	r_2	Independent

later. It is equivalent that the retailer commits to buy $Q = q(1 + u)$ at the beginning of the first period, and could return up to $(u + d)q$ items to the manufacturer with a rebate credit w. In our model, if we let $r_1 = r_2$, $b_1 = w$, and $\rho_1 = (u + d)/(1 + u)$, then our model reduces to the QF contract.

Discussion and conclusion

We have investigated different supply chain contract models in the literature. The limitation of the single-period returns policy is that, even if the retailer has observed the market signal at the very beginning of the selling season and wants to make some adjustments of his/her initial order quantity, he/she cannot do that under the single-period returns policy. Price protection extends the single-period returns policy to a multi-period setting, but it neglects that demands in multiple periods may be correlated. In addition, manufacturers sometimes may not have incentives to offer a generous full returns policy to the retailer. The QF, backup agreement and option models focus on the flexibility of adjusting the order quantity. They all assume retail price does not change in the selling season. This is a very restrictive assumption in the real world, especially in retailing industries where price discounts are very common. Our model overcomes the limitations of those supply chain contracts and extends them to a more general and realistic setting. It is very flexible for managers to make decisions under different scenarios.

In our model, we assume the retail price in each period is fixed and exogenous. If demand is price-sensitive and stochastic, then a time-invariant fixed price may not be in the retailer's interest, especially in a volatile market where the retailer often faces temporary promotions or significant markdowns. Consequently, a dynamic pricing policy which allows the retail price to change from time to time may behave much better than a static retail price (see Gallego and van Ryzin (1994); Bitran and Mondschein (1997); Zhao and Zheng (2000) for recent discussions on dynamic pricing). In addition, we have overlooked competition, either among multiple retailers, or among multiple manufacturers. That is another possible future research area.

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