SUPPLY CHAIN STRUCTURES
Coordination, Information and Optimization

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Chapter 3

INTRAFIRM INCENTIVES AND SUPPLY CHAIN PERFORMANCE

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1. Introduction

Companies in many industries have begun to realize that conflicts of interest among the various parties in a supply chain can engender operationally inefficient behavior. Consequently, many researchers have become interested in identifying and evaluating methods of coordinating supply chains in which multiple decision makers pursue individual agendas (cf. [32]). The typical approach in the OM literature is to partition a traditional inventory model into a number of subproblems, each representing the decisions and objectives of a distinct organization. Most commonly, the supply chain is assumed to contain just two firms, e.g., a manufacturer and a retailer. The analysis then proceeds to pinpoint the root causes of inefficiency, and recommend mechanisms for appropriately adjusting individual incentives.

A shortcoming of the existing literature, however, is that it assumes a monolithic preference structure within each organization. In fact, evidence shows that operational-level decisions are often made by subordinates who may be motivated by the performance measurement structure to pursue objectives different from those of the firm. We believe that this has profound implications for the performance of each firm, and should be considered when structuring any contracts between firms in a supply chain. With this motivation, in this chapter we study how incongruence of goals within one firm impacts the behaviors of all parties involved in the supply contract, and the consequences for the welfare of end customers.

We consider a manufacturer-retailer supply chain serving a price-sensitive stochastic market demand. As in the extant supply chain literature, we assume that the manufacturer intends to maximize its individual profit. Our point of departure is to further partition the retail firm into two entities - an owner and a manager. The owner, as a long-term and deep-pocketed stakeholder, favors the maximization of expected retail profit. On the other hand, his store manager, charged with making operational decisions (inventory ordering and pricing to the market), is more interested in whether the profit outcome achieves some owner-specified threshold level[1], as this determines the manager's job security and prospects for advancement[2]. Such threshold-based performance measurement has been observed in a number of settings, as documented in the accounting literature ([6], [10], [11], [34])[3]. According to [19], "In many managerial situations, a budgeted profit is established, and the disutility resulting from not achieving this targeted profit level is much larger than the rewards for overachieving. A manager may then be interested primarily in maximizing the probability of meeting the budget, regardless of whether the target level is exceeded or barely attained." [8] refers to this objective as the "aspiration" criterion.

Several researchers suggest that this is a more realistic model of behavior in many settings, especially where risk preferences come into play. A number have examined its consequences in a single-node, single decision-maker, inventory context ([12], [14], [19], [20], [22], [23], [25], [28], [29]). It also appears in the financial literature on asset allocation (cf. [9]) and the decision theory literature ([3]).

In light of the potential for goal incongruence and therefore inefficiency, one might raise a number of questions of the described internal structure of the retail firm. First, why delegate? [1] argues that "since managers, by virtue of specialization, presumably develop better insights into the technology, process and external environment of the organization, it is natural for an owner to relinquish operational control of the organization to a manager." Moreover, the owner may simply be busy doing other things. We do not explicitly treat such motivations in our model, but assume this decision structure as a starting point. We therefore prohibit the owner from exerting direct control over the retail price and stocking level since this would defeat the purpose of delegation. This is analogous to the common modeling assumption that creates distinct manufacturers and retailers within supply chains, and grants each undisputed control over certain decisions, but without explicitly addressing why the parties exist independently in the first place.

Next, why does the owner use this type of incentive structure? Indeed, there may well exist alternatives that are theoretically more efficient (some possibilities are discussed in the concluding section). The empirical popularity of the above scheme and its variants may simply be due to ease of operationalization. For better or worse, real incentive systems tend to reward good *outcomes* (for instance, a large *actual* profit), rather than good *decisions* (such as ones that maximize *expected* profit). Our objective is certainly not to defend or advocate the described practices, but to explore the ramifications of their usage for supply chain behavior and performance. The specific, single-threshold form we study is the simplest such scheme and enjoys significant academic precedent, although it certainly has limitations. For instance, [9] correctly highlights the inability of this metric to distinguish among outcomes that fail to reach the threshold, while defending it as the most tractable of a useful class. In summary, our representation of the incentive structure should be considered a simple approximation that captures the flavor of an empirically well-documented phenomenon.

We extend the existing literature on supply contracts in a number of ways. First, by expanding upon the behavioral dynamics within the retailer organization, we provide a more realistic model of decision making within organizations in supply chains - both in terms of the *number of parties* making decisions as well as the *types of objective functions* that guide their individual behavior. Second, we discuss the effect of intrafirm goal incongruence not only on the firm itself, but also on those with which it does business. For instance, we demonstrate that the terms of the contract with the upstream supplier may depend upon who within the retail organization handles the negotiation. Finally, in order to quantify the consequences for the welfare of end customers, we develop a modification of the traditional measure of consumer surplus that is often used in the economics literature. We believe that we are unique in the supply chain literature in performing such analysis.

The remainder of the chapter is organized as follows. §2 details our key assumptions. §3 considers the control system outlined above, formulating and analyzing the behaviors of all three decision-makers (manufacturer, retail owner, and retail manager). Two benchmarks are then examined, one in which all retail decisions are made by the owner (§4) and the completely coordinated supply chain (§5). The various control regimes are compared in §6, followed by concluding remarks in §7. All proofs are deferred to an Appendix for clarity of exposition.

2. Model Assumptions

We consider a single-period model of a supply chain in which a manufacturer provides product wholesale to a retailer, who in turn serves a price-sensitive stochastic demand. In the base model, denoted as control system M, the retail organization consists of the owner and a manager (see Figure 3.1). The manager makes all operational decisions for the retail firm, namely the market price p and the quantity Q to order from the manufacturer. For reasons described previously, the manager attempts to maximize the probability that retail profit will be at least T, a threshold set by the retail owner. The manufacturer, who builds exactly to the retailer's order, chooses a wholesale/transfer price c that maximizes his own profit in light of the order that will be induced. Customer demand D then occurs.

2.1. Cost Structure

We modify the standard newsvendor model to represent this two-firm setting, hence the cost structure follows the newsvendor assumptions, augmented with a linear price for the transfer of product between the two firms:

m: manufacturer's unit production cost

c: unit wholesale/transfer price
p: retailer's unit selling price
s: unit salvage value

We assume that $0 < m \leq c \leq p$ and $s < m$. Goodwill loss is excluded to simplify the analysis and presentation.

2.2. Demand Model

D, the total demand per period, is a random variable with density and distribution of ϕ and Φ, respectively, and mean $\hat{\mu}$. We assume a multiplicative form of demand, with deterministic and stochastic components specified by $D = N \cdot g(p)$, where

N = the number of customer arrivals during the period, a random variable with density f, distribution F, and mean μ, and

$g(p)$ = demand per customer, a deterministic function of price that is defined on $[0, p_{max}]$ for some $p_{max} < \infty$, and satisfies the following structural assumptions:
(i) $g(p) \geq 0$, (ii) $g'(p) < 0$, (iii) $g(p_{max}) = 0$, (iv) $g''(p) \leq 0$.

Under these assumptions, the distribution of D may be written as $\Phi(d) = F(d/g(p))$. Also, by differentiation, $\phi(d) = f(d/g(p))/g(p)$ except when $p = p_{max}$, in which case $\phi(d)$ has unit mass precisely at $d = 0$. Also, $\hat{\mu} = \mu \cdot g(p)$.

This multiplicative form is a common way to model price-sensitive and stochastic demand (cf. [4], [7], [13]). Conditions (i) and (ii) are standard. (iii) implies that the market price cannot be increased indefinitely without eventually eliminating all demand. (iv) suggests that customers become more price-sensitive at higher prices. To focus attention on supply chain incentives, we make the fairly standard assumption of common beliefs about market demand (cf. [32]).

2.3. Benchmark Alternatives

Context for evaluating system M will be provided by comparison to two natural benchmarks described below:

Control System R: Here pricing and inventory management decisions are made directly by the retail owner, who wishes to maximize his expected profit. The manufacturer negotiates a wholesale price with the goal of maximizing his own expected profits.

Control System C: This is the first-best case of central control, in which all appropriate price-quantity tradeoffs are made from a global perspective.

For each regime, we will formulate the appropriate decision problem for each player, derive the rational behaviors, and characterize the equilibrium outcome (retail price, retail order quantity, target profit, wholesale price). We will then illuminate to the extent possible the structure of each system's equilibrium through comparative statics and cross-comparisons. M, R, and C will be used as subscripts on notation where appropriate.

3. Analysis of Control System M

3.1. The Retail Manager's Problem

Retail profit is the following random variable:

$$Z_M(p,Q) = p \cdot min(D,Q) - cQ + s \cdot max(Q-D,0).$$

Taking c (wholesale price) and T (profit target set by the owner) as given, the retail manager chooses p (retail selling price) and Q (quantity ordered from the manufacturer) to maximize the probability that this profit exceeds T. We denote this objective as $\theta(p,Q) = \Pr\{Z_M(p,Q) \geq T\}$. The p and Q that accomplish this are obtained in Theorem 3.1.

Theorem 3.1 *The retail manager's decisions in system M have the following properties:*

(i) For any fixed p, the order size that maximizes $\theta(p,Q)$ is

$$Q_M^*(T,p) = \frac{T}{p-c}, \text{ so that } \theta(p, Q_M^*(T,p)) = 1 - F\left(\frac{T}{(p-c)\,g(p)}\right) \tag{3.1}$$

(ii) For any profit target T, the optimal selling price is $p_M^*(T) = \overline{p}$, where $\overline{p} = argmax_{0 \leq p \leq p_{max}} (p-c)\,g(p)$, and may be obtained as the unique solution to $(\overline{p}-c)\,g'(\overline{p}) + g(\overline{p}) = 0$.

(iii) Hence, for a given T, the retail manager's decisions will be

$$\{p_M^*(T), Q_M^*(T, p_M^*(T))\} = \left\{\overline{p}, \frac{T}{\overline{p}-c}\right\}, \quad \text{and,} \tag{3.2}$$

(iv) the corresponding optimal probability of achieving the profit target is

$$\theta(p_M^*(T), Q_M^*(T, p_M^*(T))) = 1 - F\left(\frac{T}{(\overline{p}-c)\,g(\overline{p})}\right). \tag{3.3}$$

Interestingly, the probability of obtaining a profit of *at least* T is maximized by ordering a quantity such that T is the *largest possible attainable profit*[4]. So, the method of motivation rules out any pleasant surprises, since there is zero probability that this threshold will be exceeded. This formalizes the notion of "satisficing" behavior, and has implications for how the manager's actions might affect the organizational performance in the long run. Note also that both Q_M^* and p_M^* are independent of the demand distribution. That is, even though the manager's outcome (the resulting value of $\theta(p, Q_M^*(T,p))$) is related to the probability distribution of demand, his operational decisions are not. In fact, this invariance property provides the intuition for the form of p_M^*. Since the same p_M^* must result under any demand distribution, it is sufficient to consider the special case of deterministic demand, as in traditional Cost-Volume-Profit analysis (e.g., [34]). Because production can be matched perfectly to demand, avoiding both shortage and excess, $(p-c)\,g(p)$ is the retailer's profit-per-customer in this case. N is independent of p, so the manager's optimal price will be the one that maximizes this quantity, which is exactly how $\overline{p}$ is defined in part (ii) of Theorem 3.1.

3.2. The Retail Owner's Problem

The owner's only control variable is the profit target T. Whether or not an immediate financial reward is involved, for reasons outlined in §1 the manager may believe that his job security, prospects for promotion, and generally favorable standing in the eyes of the owner will suffer if this threshold is not met. Hence, the manager will behave so as to maximize the probability that the profit will be at least T. Anticipating this, the owner will set T in hopes of maximizing expected retail profit, which we denote as $\pi_M(T) = E\left[Z_M\left(p_M^*(T), Q_M^*(T, p_M^*(T))\right)\right]$.

Theorem 3.2 *In system M, the retail owner will set a profit target of*

$$T^* = (\overline{p}-c)\cdot\Phi^{-1}\left(\frac{\overline{p}-c}{\overline{p}-s}\right) = (\overline{p}-c)\,g(\overline{p})\cdot F^{-1}\left(\frac{\overline{p}-c}{\overline{p}-s}\right) \qquad (3.4)$$

Hence the retail manager orders

$$Q_M^*\left(T^*, p_M^*(T^*)\right) = g(\overline{p})\cdot F^{-1}\left(\frac{\overline{p}-c}{\overline{p}-s}\right). \qquad (3.5)$$

The resulting expected retail profit is

$$\pi_M^* = \pi_M (T^*) = (\overline{p} - s) \int_0^{Q_M^*(T^*,\overline{p})} D\phi (D) \, dD$$

$$= (\overline{p} - s) \, g (\overline{p}) \int_0^{F^{-1}\left(\frac{\overline{p}-c}{\overline{p}-s}\right)} y f (y) \, dy \tag{3.6}$$

and the resulting probability of meeting the profit target is

$$\theta^* = \theta \left(p_M^* (T^*) , Q_M^* (T^*, p_M^* (T^*))\right) = 1 - F \left(\frac{T^*}{(\overline{p} - c) \, g (\overline{p})} \right) = \frac{c - s}{\overline{p} - s}. \tag{3.7}$$

So, the owner will set a profit target such that the manager will order exactly the quantity that will maximize expected retail profit *given a selling price of* $\overline{p}$. But since $\overline{p}$ is not the expected-profit-maximizing price, it is apparent that the delegation of operational decision-making creates inefficiency within the retail firm[5].

(3.7) has the following interesting interpretation. Recall that the owner sets T so that the optimal newsvendor quantity results. Since the manager's order is such that the profit target is attained when the retail demand is no less than the order quantity, the resulting likelihood of meeting the profit target is the same as that of stocking out.

3.3. The Manufacturer's Problem

The manufacturer seeks to maximize his own profit, which we denote as $\Lambda_M(c)$, by appropriately setting the wholesale price c. Since the manufacturer's choice of c will influence the retailer, we henceforth parametrize the decisions and outcomes for the retailer as functions of c [i.e., $T^* (c) , \overline{p} (c) , Q_M^* (c) , \pi_M^* (c)$, and $\theta^* (c)$]. So $\Lambda_M (c) = (c - m) \, Q_M^* (c)$, which is a deterministic function since the retail order quantity is determined prior to the realization of the stochastic market demand, and the manufacturer produces exactly to that order. In fact, $Q_M^* (c)$ is precisely the demand curve perceived by the manufacturer, and the choice of c simply boils down to the standard exercise of trading off profit margin against sales volume. Insight into this decision may be obtained by examining the effect of c on the retailer's decisions. These comparative statics results are presented in Theorem 3.3.

Theorem 3.3 *As c increases, the equilibrium for system M changes in the following ways:*

(i) the retail manager will increase the retail price, but by no more than half the increase in the wholesale price $\left(0 \leq \frac{d\overline{p}(c)}{dc} \leq \frac{1}{2}\right)$, *which implies that the unit contribution to net profit decreases* $\left(\frac{d(\overline{p}(c)-c)}{dc} \leq -\frac{1}{2}\right)$,

(ii) the retailer's order will decrease $\left(\frac{dQ_M^*(c)}{dc} \leq 0\right)$,

(iii) the retail owner will lower the manager's profit target $\left(\frac{dT^*(c)}{dc} \leq 0\right)$,

(iv) the retail manager's probability of meeting the profit target will increase $\left(\frac{d\theta^*(c)}{dc} \geq 0\right)$, *and*

(v) the retail owner's expected profit will decrease $\left(\frac{d\pi_M^*(c)}{dc} \leq 0\right)$.

Having studied the impact of c on the retailer, we turn our attention to the manufacturer's preferences towards c.

Theorem 3.4 *There is some* $c \in (m, p_{max})$ *for which the manufacturer's profits are maximized.*

While increasing c increases the manufacturer's profit per unit, eventually this is overwhelmed by the decrease in the quantity demanded by the retailer. So, there is some threshold below p_{max} at which the manufacturer would prefer not to increase the wholesale price. However, the optimal c, which we refer to as c_M^*, cannot be established analytically without assuming further structure on the form of the market demand distribution. The method for doing this is illustrated for a numerical example in Figure 3.2. The manufacturer's profit is $\Lambda_M^* = \Lambda_M(c_M^*)$, and then the expected total profit for the system will be denoted by $\Omega_M^* (= \pi_M^* + \Lambda_M^*)$.

3.4. Discussion of Control System M

Our study of this system reveals two key sources of inefficiency. The first is due to the delegation of authority within the retail entity. Because the retail manager and the owner have different criteria for success, the resulting price and quantity differ from those that the owner himself would select. Certainly, because the owner can influence the quantity decision through the specification of T, a quantity will result that maximizes expected profit for *whatever retail price is chosen.* However, the retail price chosen will, in general, not be optimal with respect to expected profit since this is not the retail manager's objective, and T has no leverage over the price decision. A second source of inefficiency comes from the interplay with the negotiation of the wholesale price. We show above that, all else being equal, there is a disparity between the owner's preferences for c and the manager's. Part (v) of Theorem 3.3 indicates that the retail owner prefers as low a wholesale price as possible (ideally $c = m$), and will oppose any increase the manufacturer might propose. However, surprisingly the retail manager actually prefers as high a c as possible, since increasing c increases the probability of attaining the profit target (part (iv) of Theorem 3.3). (This is because raising c causes the retail manager to lower the target.) So, different outcomes will result depending on who on the retail side negotiates the contract. If the owner negotiates c, all we know is that the wholesale price must be sufficiently low that his reservation profit is attained. If the retail manager negotiates, he will acquiesce to whatever the manufacturer proposes, no matter how much expected retail profit is sacrificed in the process.

4. Analysis of Control System R

In this first benchmark, the manufacturer sets a wholesale price and the retail owner determines the retail price and order quantity, each party wishing to maximize individual expected profits. The retail manager plays no role.

4.1. The Retail Owner's Problem

Here the retailer's expected profit is

$$\pi_R(p,Q) = \int_0^Q (pD - cQ + s(Q-D))\,\phi(D)\,dD + \int_Q^\infty (p-c)\,Q\phi(D)\,dD$$

$$= (p-s)\,\widehat{\mu} - (c-s)\,Q - (p-s)\,g(p)\int_{Q/g(p)}^\infty [1-F(y)]\,dy. \qquad (3.8)$$

The retailer chooses p and Q to jointly maximize this, as indicated in the following theorem.

Theorem 3.5 *The retailer's behavior in system R has the following properties:*

(i) for any given selling price, the order quantity is

$$Q_R^*(p) = \Phi^{-1}\left(\frac{p-c}{p-s}\right) = g(p)\cdot F^{-1}\left(\frac{p-c}{p-s}\right). \qquad (3.9)$$

(ii) the selling price, denoted as p_R^*, may be obtained as the solution to the following condition,

$$\frac{(p-c)\,g'(p)+g(p)}{(c-s)\,g'(p)}+1=\frac{\nu(p)}{X(p)},\quad \textit{where} \tag{3.10}$$

$$\nu(p)=F^{-1}\left(\frac{p-c}{p-s}\right)\ \textit{and}\ X(p)=\int_0^{\nu(p)}[1-F(y)]\,dy<\nu(p)$$

(iii) for any given c, p_R^* is greater than the price that results under system M, i.e. $c<p_M^*<p_R^*<p_{max}$.

(iv) the resulting retail profit is

$$\pi_R\left(p_R^*,Q_R^*(p_R^*)\right)=(p_R^*-s)\,g(p_R^*)\int_0^{F^{-1}\left(\frac{p_R^*-c}{p_R^*-s}\right)} yf(y)\,dy \tag{3.11}$$

This theorem indicates that for a given wholesale price, system M provides end customers with a lower purchase price and more product to buy than does system R. A framework for evaluating the net benefit to consumers is illustrated in §6.

4.2. The Manufacturer's Problem

The manufacturer prefers a c that will maximize his profits, denoted as $\Lambda_R(c)=(c-m)\,Q_R^*(p_R^*(c))$. As before, we parametrize all retailer decisions and outcomes to make explicit the influence of c [e.g., $p_R^*(c)\,,Q_R^*(p_R^*(c))\,,\pi_R^*(p_R^*(c))$].

Establishing analytically the properties of the manufacturer's preferred wholesale price, which we denote c_R^*, is difficult because $c_R^*=argmax_c\left[(c-m)\,g(p_R^*(c))\,F^{-1}\left((p_R^*(c)-c)/(p_R^*(c)-s)\right)\right]$, and characterizing $p_R^*(c)$ in closed form is itself problematic. (See [16] for elaboration on the confounding factors.) However, c_R^* can be determined numerically, and its properties will be studied in the context of a numerical example later. The manufacturer's equilibrium profit is $\Lambda_R^*=\Lambda_R(c_R^*)=(c_R^*-m)\,Q_R^*(p_R^*(c_R^*))$, and the retailer's is

$$\pi_R^*=\pi_R\left(p_R^*(c_R^*)\,,Q_R^*(p_R^*(c_R^*))\right).$$

We will denote the expected total supply chain profit as $\Omega_R^*=\Lambda_R^*+\pi_R^*$.

5. Analysis of Control System C

In this, the first-best case, the selling price and quantity are set to maximize expected total supply chain profit. This is essentially a standard newsvendor problem with the pricing decision included (cf. [27] for a review, and [26] for additional details).

For a given selling price p and order quantity Q, the supply chain expected profit is

$$\Lambda_C(p,Q) = \int_0^Q (pD - mQ + s(Q-D))\,\phi(D)\,dD +$$

$$\int_Q^\infty (p-m)\,Q\phi(D)\,dD$$

$$= (p-s)\,\widehat{\mu} - (m-s)\,Q - (p-s)\,g(p)\int_{Q/g(p)}^\infty [1-F(y)]\,dy. \qquad (3.12)$$

The following theorem establishes the behavior under this control system.

Theorem 3.6 *The optimal outcome in system C has the following properties:*

(i) for any given selling price, the order quantity is the following newsvendor solution:

$$Q_C^*(p) = \Phi^{-1}\left(\frac{p-m}{p-s}\right) = g(p)\cdot F^{-1}\left(\frac{p-m}{p-s}\right)$$

(ii) the selling price, denoted as p_C^*, may be obtained as the solution to the following condition,

$$\frac{(p-m)\,g'(p)+g(p)}{(m-s)\,g'(p)} + 1 = \frac{\nu(p)}{X(p)}, \quad \textit{where,} \qquad (3.13)$$

$$\nu(p) = F^{-1}\left(\frac{p-m}{p-s}\right) \quad \textit{and} \quad X(p) = \int_0^{\nu(p)} [1-F(y)]\,dy < \nu(p).$$

(iii) the resulting total supply chain profit is

$$\Omega_C^* = \Lambda_C(p_C^*, Q_C^*(p_C^*)) = (p_C^*-s)\,g(p_C^*)\int_0^{F^{-1}\left(\frac{p_C^*-m}{p_C^*-s}\right)} yf(y)\,dy \qquad (3.14)$$

For reasons outlined in the previous section, closed forms for p_C^* and $Q_C^*(p_C^*)$ are not available.

6. Comparing the Control Systems

In this section we compare the behavior of the decision makers across the three control systems. Since only limited analytical results are available for the general model, to enable explicit illustration of key properties we further specify the demand model as follows:

number of customers	N is exponentially distributed[6] with mean μ, so $F(y) = 1 - exp(-y/\mu)$
demand per customer	$g(p) = a - bp^2 \quad (a, b > 0)$[7]

The resulting expressions for the equilibria under each control system are presented in Tables 3.3-3.5 in the Appendix. These indicate that a and b affect the outcome for each system only through the ratio a/b. Further, while the equilibrium wholesale price c is a function of the manufacturer's m, for any given c the retailer's behavior and outcomes are independent of m. Consequently, we lose no generality by using $b = 1$ and $m =$\$1.00/unit in our numerical analysis, which reduces the number of free parameters to be considered. For the base case example, we set $a = 60$ and $s =$\$0.30/unit. The choice of μ is immaterial since it is merely scales the size of the market, and we set it to 15. In the discussion that follows we will be very careful to note the extent to which the conclusions depend on the specific assumptions used for this numerical analysis. The main purpose of this exercise is to demonstrate a methodology for making such comparisons, and call attention to the possibility of certain non-obvious outcomes.

Figures 3.2 and 3.3 illustrate the results that were established analytically in Theorems 3.3 and 3.4. Specifically, Figure 3.2 shows the profits for each firm, along with the retail manager's probability of achieving his profit target, all as functions of c. Notice that as c increases, the retail profit continuously decreases, whereas the manager's likelihood of meeting his profit target increases. This reiterates one of the sources of inefficiency under such a system, as described earlier. If the retail manager were to negotiate the contract, he would allow a high wholesale price even though it opposes the interests of the retail organization. On the other hand, the owner would prefer as small a wholesale price as possible. Figure 3.3 shows the impact of c on the various retail decisions (p, T, and Q), based on the behaviors derived in §3. Consistent with the analysis presented in Theorem 3.3, as the wholesale price increases, the retail owner is forced to reduce the profit target for the retail manager, who in turn makes fewer units available to the market, and at a higher price. Thus, as the manufacturer increases the wholesale price, the end customer's buying price increases, which reduces the demand in the price-sensitive market.

The next two figures examine system R. Figure 3.4 shows how the retailer's expected profit and the manufacturer's profit vary with c, as established in §4.1. Figure 3.5 shows the corresponding order and retail price chosen by the retailer. As the wholesale price increases, the retail owner raises the retail price, orders less and makes less profit. The manufacturer's pricing policy therefore trades off the increased revenue per unit against the lower number of units sold. c_R^*, and hence the resulting system equilibrium, may be obtained from Figure 3.4.

Finally, we illustrate the dynamics driving the equilibrium for system C. Figure 3.6 shows how the order quantity and the system profit vary with p. The downward-sloping curve of mean customer demand $(g(p))$ is displayed for comparison. When the retail price is low, increasing it in conjunction with the order size increases profits. Although mean demand always decreases with price increases, this is more than offset by the amount collected per sale. However, beyond a certain threshold, the reduction in customer demand dominates, leading to lower order quantities and profits. p_C^* is illustrated in the figure as the price at which the Ω_C reaches its peak.

We now turn our attention to comparing the three control systems. Table 3.1 summarizes the equilibrium behaviors and outcomes for all players in each case.

	Control System		
Equilibrium Outcome	M	R	C
Wholesale Price (c)	\$2.70	\$2.67	-
Retail Manager's Profit Target (T)	\$956.00	-	-
Retail Price (p)	\$5.46	\$5.93	\$5.14
Retailer's Order Quantity (Q)	346.20	322.44	973.37
Expected Demand ($\hat{\mu} = \mu g(p)$)	452.46	372.22	503.21
Probability of Meeting All Demand	0.53	0.58	0.85
Retailer's Expected Profit (π)	\$417.58	\$451.13	-
Manufacturer's Profit (Λ)	\$589.20	\$537.95	-
Total Supply Chain Expected Profit (Ω)	\$1006.78	\$989.07	\$1403.71
Manufacturer's Share of Total Exp. Profit	58.5%	54.4%	-

Table 3.1. Comparison of Behavior and Performance Across Control Systems.

As expected, total expected profit is highest under the centralized control of system C. The inefficiency of system R is due to double marginalization (cf. [30]). That is, the retailer's benefit from making a sale is less than that which accrues to the supply chain as a whole, since part of the profit margin goes to the manufacturer via the wholesale price. Hence, the retailer stocks too little and prices too high relative to the supply chain optimum. System M has the additional issue of intrafirm conflict. Interestingly, though, while the retailer is less profitable in system M than in system R (\$417.58 vs. \$451.13), the manufacturer is better off by more than an offsetting amount (\$589.20 vs. \$537.95), making total profit lowest in system R[8]. This raises the possibility that reducing the extent of coordination within a supply chain need not damage the system-wide performance. Additional numerical analysis (details omitted due to space considerations) over a broad range of combinations of a (range: 10 to 100) and s (range: 0 - $0.8m$) has demonstrated this result to be robust to the specific values assumed in the base case.

The discussion thus far has focused on each supply chain entity's financial outcome. However, although difficult to describe using traditional constructs, the implications for the end customer should not be overlooked. A simplistic view might be that the lower the retail price, the better off are the customers. This would be reasonable if all demand were to be served. However, the stochastic premise of the newsvendor setting highlights the possibility that some demand will go unfilled, to an extent that is determined jointly by the demand realization and the stocking level. Indeed, a lower price does not necessarily make customers better off if the service level is drastically lessened as well (which is plausible, since newsvendor analysis recommends stocking less when the unit profit margin is reduced). This is demonstrated by Table 3.1, which reports that the three control systems may be ranked one way with respect to price (R > M > C) and differently with respect to the fraction of demand filled (C > R > M).

Our method for reconciling this derives from the classical economic notion of consumer surplus (cf. [33]). This measures the benefit derived by customers given a particular price outcome, and is typically used to inform public policy concerns such as antitrust policy. However, we can also view consumer surplus as a proxy for customer goodwill, which relates to long-term profits. Hence, this becomes relevant to profit-minded supply chain managers as well. Since the reality for such managers usually includes stochastic demand, we must modify the construct to account for the number of customers actually satisfied at a given price-quantity combination, as described below.

Since all customers are assumed to be identical, we can define the total consumer surplus for a given price, quantity, and demand realization, denoted by $TCS(p, Q, N)$, as follows:

$$TCS(p, Q, N) = CS(p) \cdot min(N, Q/g(p)).$$

Here $CS(p)$ is the consumer surplus per customer $[= \int_p^{p_{max}} g(z)\,dz]$, and $min(N, Q/g(p))$ gives the number of customers fully satisfied. Then, the expected total consumer surplus can be computed as:

$$E_N[TCS(p, Q, N)] = CS(p) \cdot E_N[min(N, Q/g(p))].$$

Note that when demand is deterministic (in which case $Q = N \cdot g(p)$ is the appropriate quantity), the traditional consumer surplus construct is recovered. Alternatively, when the retail price is held fixed as in the basic newsvendor model, this metric is proportional to the fill rate. Table 3.2 summarizes the calculations comparing the three control systems. It suggests two observations. First, note that coordinating the supply chain in a way that maximizes total supply chain profit need not be detrimental to customers, as expected consumer surplus is highest for C. This extends a property observed in deterministic economic models, where eliminating double marginalization unambiguously improves consumer welfare since more customers are satisfied, and each is paying less ([31]). In our example the system with the lowest efficiency, R, turns out to provide the lowest consumer surplus. Since much of the economic discussion regarding the merits of vertical integration does not explicitly incorporate the intrafirm decision hierarchies and incentive systems, and the resulting consequences for consumer surplus, we believe that this observation suggests a possible topic for further investigation, both theoretical and empirical. Second, comparing the surplus per customer to the fraction of demand met from stock reinforces the idea that a higher service level need not be in the best interests of the customer base. Here, a greater proportion of interested customers' demand is met under R, but the surplus per consumer is lower than under M. The net effect is that M provides a higher total consumer surplus than R. So even though the retail organization suffers from internal inefficiencies under M (leading to lower expected profits for the retailer), under the assumptions of this study the supply chain is more efficient and the consumers are better off under this regime than under R. In this case the cost of supply chain inefficiency is borne by the retailer, not the manufacturer or the consumer.

	Control System		
Equilibrium Outcome	M	R	C
Retail Price (p^*)	\$5.46	\$5.93	\$5.14
Product Availability (Q^*)	346.20	322.44	973.37
Probability of Meeting All Demand ($\text{Prob}\{N \cdot g(p^*) \leq Q^*\}$)	0.53	0.58	0.85
Consumer Surplus Per Customer Served ($CS(p^*)$)	36.60	23.60	46.80
Expected Number of Customers Served ($E[min(N, Q^*/g(p^*))]$)	2.68	3.23	8.63
Expected Consumer Surplus ($E_N[TCS(p^*, Q^*)]$)	**97.80**	**76.40**	**403.20**

Table 3.2. Comparison of Consumer Welfare Across Control Systems.

7. Conclusion

In this chapter, we have developed a more detailed representation of decision making in supply chains than has appeared in the operations management literature. We have incorporated the very real premise that not all decision-making is guided by the maximization of expected profit (or minimization of expected cost). By examining the behavioral consequences of intrafirm incentives, we have been able to shed light on certain key inefficiencies. This, we believe, is a significant contribution to the emerging operations management literature on supply contracts.

Our analysis reveals that when goal incongruence exists within any organization, the outcome of any contract negotiation will be highly dependent upon who is involved in the negotiations. In our model, for example, while the retail owner would be expected to pressure the manufacturer for a lower wholesale price, the retail manager has no such agenda. A knowledge of such a possibility is obviously crucial to the owner of any business organization.

In contrast to extant supply chain literature, we have also examined the consequences for the end customer by extending the classical economic notion of consumer surplus to a stochastic environment. This composite measure is useful since standard metrics (selling price, stock level, or the fraction of customer demand filled) cannot individually characterize whether a particular control system makes customers better or worse off. Our analysis suggests that increasing the profitability of a supply chain need not be at the expense of the end customer. This notion has been developed in the economics literature, but primarily for deterministic settings.

Comparison across the three control systems revealed a counterintuitive observation. While the effect of double marginalization on supply chain efficiency is as expected, the effect of goal incongruence within an organization (the retail entity) is not. While, as would be expected, we obtained a higher expected retail profit in system R than in system M, this was not the case for the total system profit. We found that the internal conflict of goals within the retail organization can potentially counter the effect of double marginalization, since supply chain efficiency can be higher in system M than in system R. In other words, coordination of goals within an organization does not necessarily improve the efficiency of the supply chain. Whether this phenomenon results in more general settings will be, we believe, an important area of future research.

Clearly, the profit target criterion is only one alternative to expected profit. Our analysis could be further extended by considering behavioral responses to other intrafirm incentive scheme such as profit-sharing (reward as a percentage of profits), commission (reward as a percentage of sales), or multi-tiered compensation plans. The question of how to remedy the intrafirm goal incongruence remains open.

Finally, the manufacturer-retailer supply contract could take on more general structure. We have assumed only a linear wholesale price contract, and have not pursued the question of optimal contract design.

8. Appendix: Proofs of Theorems

PROOF OF THEOREM 3.1. To obtain the p and Q that maximize $\theta(p,Q)$, we first compute the Q that is optimal for a given p. This result has been developed in several papers, including [19], [25] and [29]. We provide a slightly different proof here.

Clearly, if $Q \leq T/(p-c)$, $\theta(p,Q) = 0$. Therefore, to reach the target profit at all we must consider only values of Q such that $Q \geq T/(p-c)$. Then, $Z_M(p,Q) = T$ when $pD - cQ + s(Q-D) = T$, or $D = (T + (c-s)Q)/(p-s)$. Thus

$$\theta(p,Q) = Pr\left(D \geq \frac{T + (c-s)Q}{p-s}\right).$$

This is maximized by setting Q to the smallest allowable value, i.e., $Q_M^*(T,p) = T/(p-c)$.

The optimal objective function value for a fixed p, $\theta(p, Q_M^*(T,p))$, is then

$$\theta\left(p, Q_M^*(T,p)\right) = Pr\left(D \geq \frac{T + (c-s)\, Q_M^*(T,p)}{p-s}\right) = Pr\left(D \geq \frac{T}{p-c}\right) \tag{3.15}$$

$$= 1 - \Phi\left(\frac{T}{p-c}\right) = 1 - F\left(\frac{T}{H(p)}\right) \tag{3.16}$$

where $H(p) = (p-c)\, g(p)$. This proves (i). Since $F()$ is monotone, the price that maximizes $H(p)$ does the same for $\theta\left(p, Q_M^*(T,p)\right)$. Under assumptions (i)-(iv) on $g(p)$, $H(p)$ is a continuous function that is strictly positive everywhere in (c, p_{max}) and non-positive on the rest of its domain. Hence, an interior maximum exists within (c, p_{max}), and satisfies $H'(p) = 0$. Since $H''(p) = g(p)(p-c) + 2g'(p) < 0$ on this region, the solution to the first order conditions (FOC) must be unique. The FOC are precisely the conditions stated in (ii). (iii) and (iv) then follow from (i) and (ii).

PROOF OF THEOREM 3.2. By Theorem 3.1, the manager will set a retail price of $\overline{p}$ regardless of the T specified. From the newsvendor structure of the objective, for any p the profit maximizing quantity will be $\Phi^{-1}\left((p-c)/(p-s)\right) = g(p) \cdot F^{-1}\left((p-c)/(p-s)\right)$. The value of T^* specified in (3.4) is then appropriate, since $Q_M^*(T,p) = T/(p-c)$ from (3.1), which then determines (3.5). (3.6) may be obtained by direct evaluation of $E\left[Z_M\left(\overline{p}, Q_M^*(T^*, \overline{p})\right)\right]$, and (3.7) follows from (3.3).

PROOF OF THEOREM 3.3. (i) Recall from Theorem 3.1 that $\overline{p}(c)$ is defined by the condition $(\overline{p}(c) - c)\, g'(\overline{p}(c)) + g(\overline{p}(c)) = 0$. By implicit differentiation,

$$\frac{d\overline{p}(c)}{dc} = \frac{1}{2 + (\overline{p}(c) - c)\, g''(\overline{p}(c)) / g'(\overline{p}(c))}. \tag{3.17}$$

Since $g'' \leq 0$ and $g' > 0$, $0 \leq d\overline{p}(c)/dc \leq 1/2$. This implies that

$$\frac{d\left(\overline{p}(c) - c\right)}{dc} \leq -\frac{1}{2}.$$

(ii) We know that

$$Q_M^*(c) = \Phi^{-1}\left(\frac{\overline{p}(c) - c}{\overline{p}(c) - s}\right). \tag{3.18}$$

Differentiating with respect to c, we get

$$\frac{dQ_M^*(c)}{dc} = -\frac{(\overline{p}(c)-s)-(c-s)\frac{d\overline{p}(c)}{dc}}{(\overline{p}(c)-s)^2\,\phi\left(Q_M^*(T^*(c),\overline{p}(c))\right)} \leq 0.$$

The inequality follows since $0 \leq d\,\overline{p}(c)/dc \leq 1/2$ by part (i).

(iii) Since $T^*(c) = (\overline{p}(c)-c)\,Q_M^*(c)$, the previous two results indicate that $dT^*(c)/dc \leq 0$.

(iv) For a given c, the retail manager's optimal probability of achieving the profit target is

$$\theta^*(c) = 1-\Phi\left(Q_M^*(c)\right) = \frac{c-s}{\overline{p}(c)-s}. \tag{3.19}$$

By the chain rule,

$$\frac{d\theta^*(c)}{dc} = -\,\phi\left(Q_M^*(c)\right)\frac{dQ_M^*(c)}{dc} \geq 0 \tag{3.20}$$

where the inequality is due to part (ii).

(v) Equation (3.6) provides the owner's optimal expected profit, which we rewrite in the following way to highlight the dependence on c:

$$\pi_M^*(c) = (\overline{p}(c)-s)\int_0^{Q_M^*(c)} D\phi(D)dD,$$

where $Q_M^*(c) = \Phi^{-1}\left((\overline{p}(c)-c)/(\overline{p}(c)-s)\right)$. By taking the total derivative of $\pi_M^*(c)$,

$$\frac{d\pi_M^*(c)}{dc} = \frac{d\pi_M^*(c)}{d\overline{p}(c)}\frac{d\overline{p}(c)}{dc} + \frac{\partial\pi_M^*(c)}{\partial c}.$$

Now

$$\frac{\partial\pi_M^*(c)}{\partial c} = \frac{\partial\pi_M^*(c)}{\partial Q_M^*(c)}\frac{dQ_M^*(c)}{dc}$$

$$= \left[(\overline{p}(c)-s)Q_M^*(c)\,\phi\left(Q_M^*(c)\right)\right]\left[\frac{-1}{(\overline{p}(c)-s)\,\phi\left(Q_M^*(c)\right)}\right] = -Q_M^*(c),$$

and

$$\frac{d\pi_M^*(c)}{d\overline{p}(c)} = (\overline{p}(c)-s)\left[Q_M^*(c)\,\phi\left(Q_M^*(c)\right)\frac{dQ_M^*(c)}{d\overline{p}(c)}\right] +$$

$$\int_0^{Q_M^*(c)} D\phi(D)dD.$$

Since

$$\frac{dQ_M^*(c)}{d\overline{p}(c)} = \frac{c-s}{(\overline{p}(c)-s)^2\,\phi\left(Q_M^*(c)\right)},$$

this simplifies to

$$\frac{d\pi_M^*(c)}{d\overline{p}(c)} = \frac{c-s}{\overline{p}(c)-s}Q_M^*(c) + \int_0^{Q_M^*(c)} D\phi(D)\,dD.$$

So,

$$\begin{aligned}\frac{d\pi_M^*(c)}{dc} &= \left[\frac{c-s}{\overline{p}(c)-s}Q_M^*(c) + \int_0^{Q_M^*(c)} D\phi(D)\,dD\right]\frac{d\overline{p}(c)}{dc} - Q_M^*(c)\\ &\le \frac{1}{2}\left[\frac{c-s}{\overline{p}(c)-s}Q_M^*(c) + \int_0^{Q_M^*(c)} D\phi(D)\,dD\right] - Q_M^*(c)\end{aligned}$$

$$\le \frac{1}{2}\left[\frac{c-s}{\overline{p}(c)-s}Q_M^*(c) + Q_M^*(c)\,\Phi\left(Q_M^*(c)\right)\right] - Q_M^*(c) = -\frac{1}{2}Q_M^*(c) \le 0.$$

This first inequality follows from part (i) of this theorem. The second is obtained by noting that the integral is defined on $D \le Q_M^*(c)$, so that $\int_0^{Q_M^*(c)} D\phi(D)\,dD \le Q_M^*(c)\int_0^{Q_M^*(c)} \phi(D)\,dD$. The subsequent equality follows from the fact that $\Phi\left(Q_M^*(c)\right) = (\overline{p}(c)-c)\,/\,(\overline{p}(c)-s)$.

PROOF OF THEOREM 3.4. We examine how $\Lambda_M(c) = (c-m)\,Q_M^*(c)$ changes as c increases. By differentiation we obtain

$$\frac{d\Lambda_M(c)}{dc} = (c-m)\frac{dQ_M^*(c)}{dc} + Q_M^*(c)$$

At $c = m$, $d\Lambda_M(c)/dc = Q_M^*(c) > 0$, which verifies that the manufacturer prefers a wholesale price higher than the manufacturing cost. And as $c \to p_{max}$, $Q_M^*(c) \to 0$, while $dQ_M^*(c)/dc < 0$, so $d\Lambda_M(c)/dc < 0$. Hence, there exists some $c \in (m, p_{max})$ that maximizes manufacturer profit.

PROOF OF THEOREM 5. Part (i) follows from the newsvendor structure. For (ii) and (iii), to obtain p_R^* we characterize the shape of $\pi_R(p, Q_R^*(p))$, which by (3.8) has the form

$$\pi_R\left(p, Q_R^*(p)\right) =$$

$$(p-s)\,\widehat{\mu}-(c-s)\,Q_R^*(p)-(p-s)\,g(p)\int_{Q_R^*(p)/g(p)}^{\infty}[1-F(y)]\,dy \quad (3.21)$$

First, note that $\pi_R(p, Q_R^*(p)) = 0$ at both $p = c$ and $p = p_{max}$. This is intuitively obvious, and may also be obtained directly from (3.21). Then, applying the Envelope Theorem (cf. [33]) to (3.21) and using the notation $\nu(p)$ and $X(p)$ as specified, we get

$$\frac{\partial \pi_R(p, Q_R^*(p))}{\partial p} = -(c-s)\,\nu(p)\,g'(p) + \left[(p-s)\,g'(p) + g(p)\right] X(p), \quad (3.22)$$

which may be rewritten (by adding and subtracting $cg'(p)\,X(p)$) as

$$\frac{\partial \pi_R(p, Q_R^*(p))}{\partial p} =$$

$$(c-s)\,g'(p)\,[X(p)-\nu(p)] + \left[(p-c)\,g'(p)+g(p)\right] X(p) \quad (3.23)$$

We know $g'(p) < 0$ for all p, and $[(p-c)\,g'(p) + g(p)] \geq 0$ on $p \leq \overline{p} = p_M^*$ by the definition of $\overline{p}$. And since $X(p) < \nu(p)$ by construction[9], we conclude that $\partial\pi_R(p, Q_R^*(p))/\partial p > 0$ on $c \leq p \leq \overline{p}$. Hence, it must be the case that the retailer's optimal price, denoted as p_R^* and obtained by setting (3.23) equal to zero, must lie somewhere in $(\overline{p}, p_{max})$ since the endpoints of this interval each yield exactly zero profit.

We note that the first order condition is necessary but not sufficient to uniquely characterize the p_R^* that will result. That is, without additional restrictions on the problem, the existence of multiple candidate selling prices cannot be ruled out. But we do know that all of these candidates will be greater than the price that occurs under system M.

(iv) follows by analogy to equation (3.6).

PROOF OF THEOREM 6. The proof is identical to that of Theorem 5, except that the cost of the product is the manufacturing cost m, rather than the wholesale price c.

OUTCOMES FOR EXPONENTIALLY DISTRIBUTED N.
The decisions and outcomes under systems M and R for any fixed wholesale price (c) are presented below.

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Retail Price	$p^*_M(c) = \overline{p} = \left(c + \sqrt{c^2 + \frac{3a}{b}}\right)/3$
Retail Order Quantity	$Q^*_M(c) = \mu \cdot g(\overline{p}) \cdot ln\left(\frac{\overline{p}-s}{c-s}\right)$
Profit Target Set by Retail Owner	$T^*(c) = \mu \cdot (\overline{p} - c) \cdot g(\overline{p}) \cdot ln\left(\frac{\overline{p}-s}{c-s}\right)$
Expected Retail Profit	$\pi^*_M(c) = \mu \cdot g(\overline{p}) \cdot \left[(\overline{p} - c) - (c - s)\, ln\left(\frac{\overline{p}-s}{c-s}\right)\right]$
Prob{Retail Profit≥ T^*}	$\theta^*(c) = \frac{c-s}{\overline{p}-s}$ (this is independent of the distribution of N)
Manufacturer Profit	$\Lambda_M(c) = \mu \cdot g(\overline{p}) \cdot (c - m) \cdot ln\left(\frac{\overline{p}-s}{c-s}\right)$

Table 3.3. Decisions and Outcomes for a Given c in System M.

Retail Price	$p^*_R(c)$ is the p that solves $\frac{3p^2 - 2ps - \frac{a}{b}}{2p(c-s)} = \frac{\mu \cdot ln\left(\frac{p-s}{c-s}\right)}{1 - \mu \cdot \left(\frac{c-s}{p-s}\right)}$ (from (3.10))
Retail Order Quantity	$Q^*_R(c) = \mu \cdot g(p^*_R) \cdot ln\left(\frac{p^*_R - s}{c-s}\right)$
Expected Retail Profit	$\pi^*_R(c) = \mu \cdot g(p^*_R) \cdot \left[(p^*_R - c) - (c - s)\, ln\left(\frac{p^*_R - s}{c-s}\right)\right]$
Manufacturer Profit	$\Lambda_R(c) = \mu \cdot g(p^*_R) \cdot (c - m) \cdot ln\left(\frac{p^*_R - s}{c-s}\right)$

Table 3.4. Decisions and Outcomes for a Given c in System R.

Retail Price	p^*_C is the p that solves $\frac{3p^2 - 2ps - \frac{a}{b}}{2p(m-s)} = \frac{\mu \cdot ln\left(\frac{p-s}{m-s}\right)}{1 - \mu \cdot \left(\frac{m-s}{p-s}\right)}$ (from (3.13))
Retail Order Quantity	$Q^*_C = \mu \cdot g(p^*_C) \cdot ln\left(\frac{p^*_C - s}{m-s}\right)$
Total Supply Chain Expected Profit	$\Lambda^*_C = \mu \cdot g(p^*_C) \cdot \left[(p^*_C - m) - (m - s)\, ln\left(\frac{p^*_C - s}{m-s}\right)\right]$

Table 3.5. Decisions and Outcomes in System C.

for comments that have greatly assisted in the refining of our ideas. Any errors remain the responsibility of the authors.

Notes

1. Decision-making that focuses on achieving some threshold level of utility (rather than, say, maximizing the expected utility) has been termed "satisficing" ([24]).

2. The reward for achieving the target may take the concrete form of a monetary bonus, or simply the retention of the owner's goodwill. An empirical account of the latter is provided by [2], and our analysis will focus primarily on this case. Non-monetary incentive systems are common. In fact, some of the popular business literature on workforce motivation suggests that employees are more effectively motivated by rewards that cost very little in real terms, such as public recognition, greater job responsibilities, etc. (e.g., [15]). Similarly, employee stock options are an increasingly common incentive tool that do not have an immediate cost consequence to the firm, at least per the current accounting standards ([5]). The value of the options is tied that of the company's stock, which oftentimes is greatly influenced by whether profit expectations have been met.

3. Sales quotas, common in sales and merchandising settings ([21]), are one manifestation of this concept, as the quota essentially maps into a profit figure.

4. In the newsvendor setting, the ex post profit is largest when the demand outcome exactly matches the available quantity, thus avoiding both shortage and excess. In such a scenario, the full profit margin is earned on every unit stocked, for a total profit of $(p-c)\,Q$.

5. It is relatively straightforward to show that if the owner uses a cash bonus payment to motivate the manager, the order quantity will go up, yet another source of inefficiency. This will be true even though any bonus is merely an internal transfer of funds within the retail entity, due to the distortion of individual incentives. We do not present these details here since they are not the main thrust of our analysis. They are available from the authors by request.

6. The assumption of exponential distribution is made strictly for convenience. Similar outcomes follow if, for example, the uniform distribution is used.

7. This specific form of $g(p)$ satisfies the conditions specified in §2, with $p_{max} = \sqrt{a/b}$.

8. Analytically, it can be shown that (i) $\pi_R^* \geq \pi_M^*$, and, (ii) $\Omega_C^* \geq \Omega_R^*, \Omega_M^*$. Since control system R does not suffer from goal incongruence between the retail owner and manager, its expected retail profit is higher than that of control system M. However, the effect of the retail manager's actions on the manufacturer's profit is indeterminate. Hence the relative magnitudes of Ω_R^* and Ω_M^* are indeterminate as well. Thus, while it is clear that the total system profit is the highest in the first-best case, it is difficult to analytically compare the system profits under systems R and M.

9. The strictness of the inequality in the statement of $X\,(p)$ is required to make some of the claimed inequalities strict. Strictness is reasonable for all $p > c$ because this requires only that there is some $y < \nu\,(p)$ for which $F() > 0$ on the neighborhood around y. Only at $p = c$ is strictness lost, for at this point $X\,(p) = \nu\,(p) = 0$.

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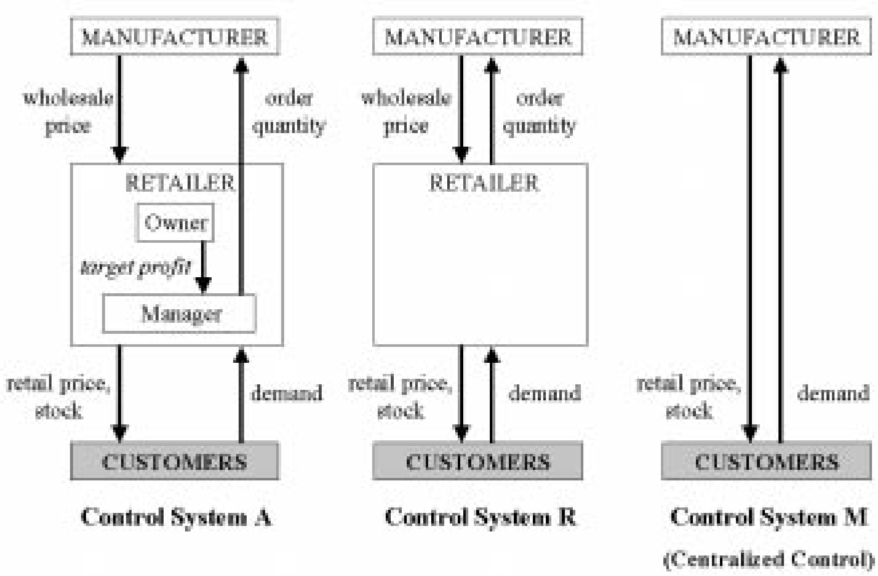

Figure 3.1. The Supply Chain (arrows represent decision control)

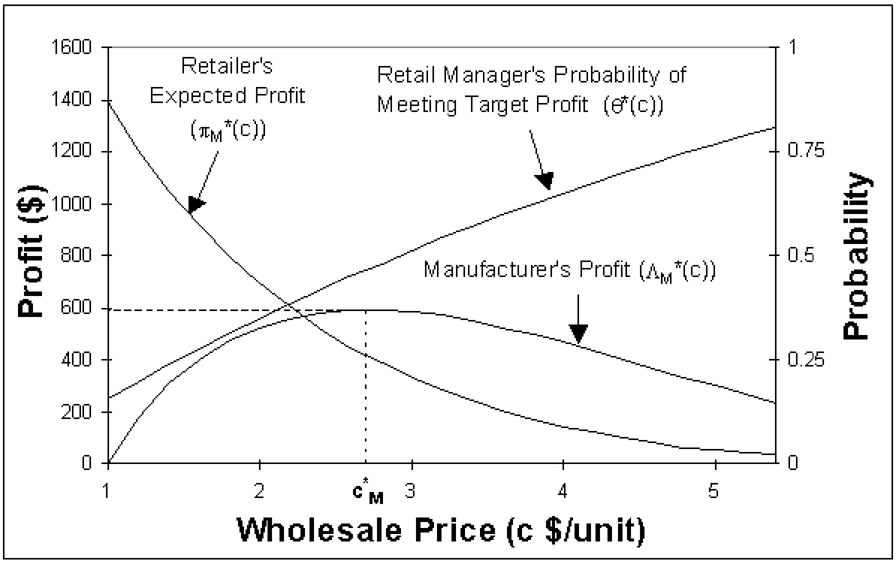

Figure 3.2. Manufacturer's Profit, Retailer's Expected Profit, and Retail Manager's Probability of Meeting Profit Target vs. Wholesale Price (Control System M)

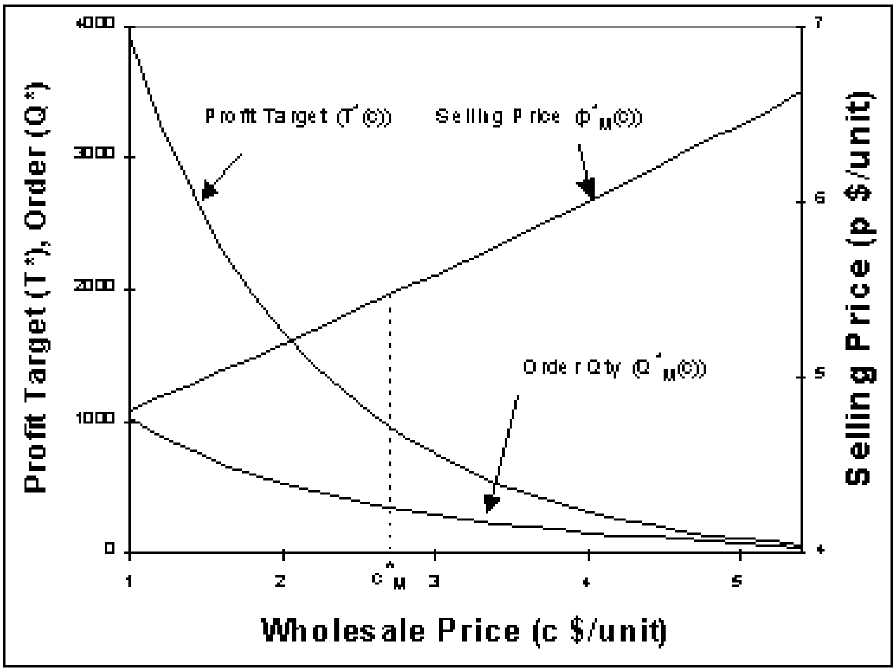

Figure 3.3. Profit Target, Order Quantity, and Selling Price vs. Wholesale Price (Control System M)

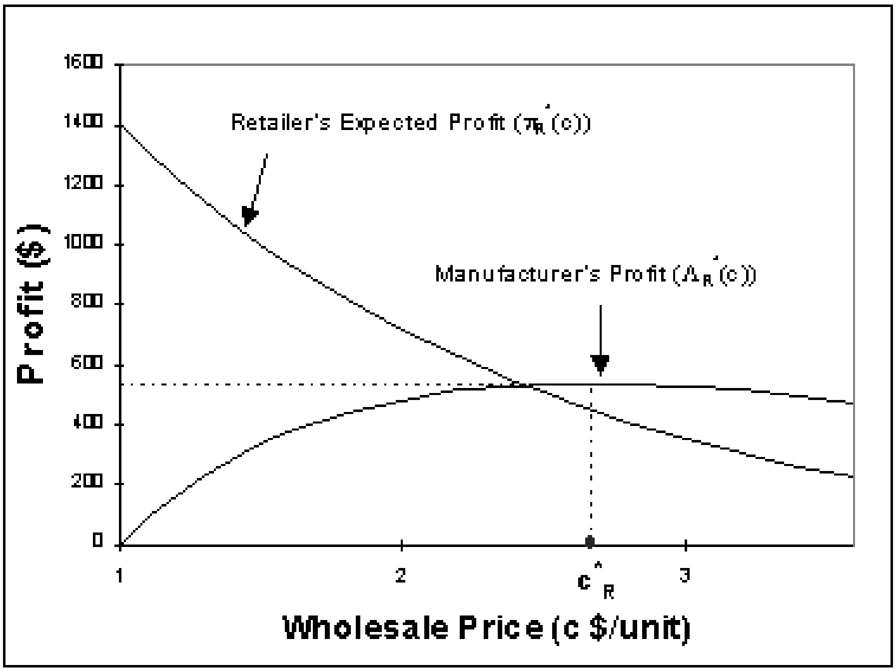

Figure 3.4. Manufacturer's Profit and Retailer's Expected Profit vs. Wholesale Price (Control System R)

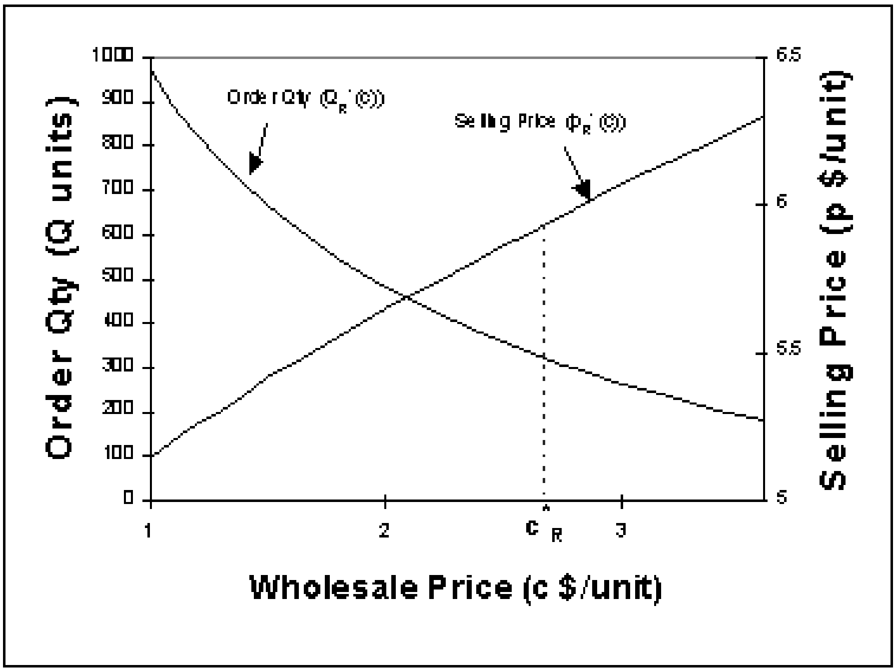

Figure 3.5. Order Size and Selling Price vs. Wholesale Price (Control System R)

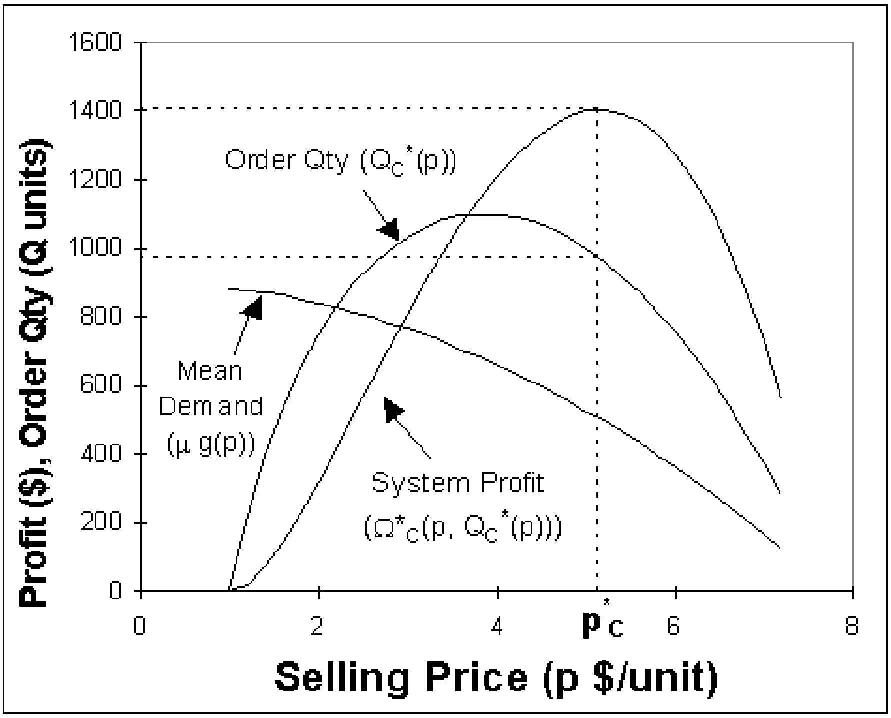

Figure 3.6. Manufacturer's Profit and Order Quantity vs. Selling Price (Control System C)