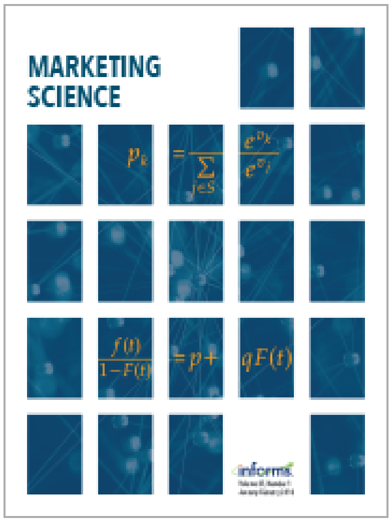

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Research Note

Vertical Information Sharing in a Volatile Market

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When demand is uncertain, manufacturers and retailers often have private information on future demand, and such information asymmetry impacts strategic interaction in distribution channels. In this paper, we investigate a channel consisting of a manufacturer and a downstream retailer facing a product market characterized by short product life, uncertain demand, and price rigidity. Assuming the firms have asymmetric information about the demand volatility, we examine the potential benefits of sharing information and contracts that facilitate such cooperation. We conclude that under a wholesale price regime, information sharing might not improve channel profits when the retailer underestimates the demand volatility but the manufacturer does not. Although information sharing is always beneficial under a two-part tariff regime, it is in general not sufficient to achieve sharing, and additional contractual arrangements are necessary. The contract types we consider to facilitate sharing are profit sharing and buyback contracts.

Key words: channels of distribution; decisions under uncertainty; game theory; supply chains
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1. Introduction

Demand uncertainty is ubiquitous in essentially any marketplace. Understanding it is one of the constant challenges firms face on the road toward success, and failure to do so often has devastating effects on the bottom line. In many product categories, ranging from fashion apparel and fresh produce to movie rentals, matching supply and demand is complicated by the large and increasing volatilities in demand. Even when firms have a relatively clear picture of the average demand, the level of uncertainty will have a significant impact on firms' decisions. Some of the numerous factors that influence the volatility of demand are weather, opinion leaders' attitudes, popularity of competing products, etc. Put differently, there is a range of possibilities surrounding the average demand so that the actual demand realization can be either higher or lower than the average demand. Thus, the range of the actual demand realization is impacted by so many different factors beyond the firms' control that the only appropriate notion is that it is determined by nature.

In distribution channels, information asymmetry across channel members with respect to demand uncertainty further complicates matters. In industries ranging from grocery to aerospace, manufacturers and retailers often make independent demand estimates with different degrees of accuracy. Many factors, such as the proximity to consumers, the availability and quality of customer databases, sophistication of decision support tools, and experience, contribute to the accuracy of the demand estimate. We motivate the core issue of this paper in the context of a distribution channel of fashion apparel. Before the season begins, the retailer needs to negotiate purchasing prices and place an order with the manufacturer. The retailer knows that if she orders too late (say, after the season begins), she will forgo sales. At this point, the only information available is the demand estimates (private information) of the manufacturer and the retailer and each party's profile (public information). However, neither the manufacturer nor the retailer knows the other party's estimate unless it is purposely revealed. Is there any value in sharing the two parties' demand estimates? If the answer is yes, what mechanism(s) can help accomplish information sharing?

There is ample evidence that members of a distribution channel can greatly benefit by sharing demand information. According to an A. T. Kearney report

(Field 2005), the average manufacturer has enjoyed benefits equivalent to \$1 million in savings for every \$1 billion of sales by synchronizing their demand databases with their retailers. However, it is not clear that information sharing is always feasible in decentralized channels because it is marred by incentive and credibility problems. For example, in the PC industry, manufacturers often suspect their distributors of submitting "phantom orders," i.e., forecasts of high future demand that do not materialize (Zarley and Damore 1996). Hence, the value of information sharing and the mechanisms for facilitating information sharing are topics of great managerial importance and have received considerable attention in the literature (e.g., Amaldoss and Rapoport 2005; Cachon and Fisher 2000; Cachon and Lariviere 2001; Chen 2003; Gal-Or 1986; Gu and Chen 2005; Kulp et al. 2004; Lee et al. 1997, 2000; Li 2002, 2005; Niraj and Narasimhan 2002; Villas-Boas 1994; Vives 1984).

In this paper, we focus on a product market characterized by short product life, uncertain demand, and price rigidity (lack of price promotion). A catalogue marketer of fashion goods is a prototypical example of such a market. Because of the inherent uncertainty about consumer tastes, fashion goods are synonymous with rapid change and subject to significant demand variability. We investigate a distribution channel with one manufacturer and one retailer, each with private information about the distribution of future demand. More precisely, we consider multiplicative demand uncertainty, uniformly distributed between an upper and a lower bound about which the members of the channel have asymmetric information. To capture the impact of uncertainty, we model the retailer as a newsvendor problem with endogenous pricing. This allows us to balance the expected cost of ordering too much with the expected opportunity cost of ordering too little, when maximizing the retailer profits. The manufacturer is assumed to operate under a constant marginal cost, without any capacity constraints.

Our objective is to examine the benefits of sharing information about future demand volatility and contracts that facilitate such cooperation. To facilitate our analysis, we make a few important assumptions. First, we assume that firms cannot refine their demand estimates by using historical data. Second, we assume that the correlation between the firms' demand estimates is unknown, and therefore there is no obvious way to combine or pool them into a more accurate estimate. Thus, we can view the environment under consideration as a one-shot, highly volatile setting, where firms engage in short-term relationships. We note that, unlike a long-term relationship where reputation can support truthful information revelation, in a short-term relationship incentive and credibility problems are far more prevalent.

Within the resulting framework, we find that sharing information about market demand volatility does not always improve channel profits. In particular, under a wholesale-price-only regime, when the retailer underestimates the demand variability but the manufacturer does not, sharing can lead to lower channel profits. In addition, we show that the feasibility of information sharing depends not only on the asymmetric estimates of the demand volatility, but also on the channel members' knowledge of the quality of each member's demand estimate. Specifically, we demonstrate that a profit-sharing contract is a viable mechanism when each channel member is aware of the quality of the other member's demand estimate relative to its own, whereas buyback contracts can improve channel coordination when only one member knows whose demand estimate is more accurate.

We also find that under a two-part tariff regime, although sharing information about market demand volatility always improves channel profits, additional contractual arrangements are needed for sharing to occur. In contrast to the symmetric case, under asymmetric information about demand volatility, a two-part tariff does not always coordinate the channel.

Three streams of literature are relevant to our study: the literature on channel coordination, the literature on newsvendor models with endogenous pricing decisions, and the emerging literature on information sharing. Next, we briefly review this literature and relate it to our current work. The extant channel literature generally assumes deterministic demand (e.g., Jeuland and Shugan 1983, McGuire and Staelin 1983, Coughlan 1985). The limited channel literature that incorporates demand uncertainty usually assumes that uncertainty is a white noise and has no consequence as firms maximize expected profits (e.g., Lal 1990), or models uncertainty as consisting of a high state and a low state (e.g., Biyalogorsky and Koenigsberg 2004, Desai 2000, Padmanabhan and Png 1997, Gu and Chen 2005). As opposed to our work, which focuses on the impact of asymmetric information about demand volatility, these papers primarily consider the impact of uncertainty in the demand level (i.e., the mean). Such treatment allows researchers to obtain a high level of parsimony, which facilitates the analysis of complex issues such as channel structure, upstream/downstream competition, multiperiod interaction, etc. However, this parsimony is obtained at the cost of generality. In particular, the actual demand realization may be either above or below the average, and firms incur costs in either case. By focusing on demand average but ignoring volatility, one assumes that the costs associated with undershooting and overshooting are identical (we shall revisit this point in §3.3), which might significantly distort firms' decisions when demand volatility is large. We complement this literature by looking at demand uncertainty from a different perspective, focusing on the impact of asymmetric estimates of the demand volatility in a newsvendor setting with uniformly distributed demand uncertainty.

The classical newsvendor approach offers an intuitive way to incorporate the effect of demand volatility into the analysis of channel behavior. In a one-period setting, the retailer (newsvendor) trades off the marginal cost of understocking with that of overstocking when determining how much to order. In its traditional formulation, the newsvendor model determines the quantity to order under the assumption that price is an exogenously set parameter that does not affect demand.[1] The impact of adding pricing decisions to the newsvendor problem was first considered by Whitin (1955). Mills (1959) considers this problem under the assumption of additive demand uncertainty, whereas Karlin and Carr (1962) assume multiplicative demand uncertainty. For a comprehensive review of the newsvendor problem with endogenous pricing, we refer to Petruzzi and Dada (1999), who propose a unified view of the abovementioned approaches.

From an information-sharing perspective, it is well known that demand uncertainty and the use of local demand information often lead to severe distortion and loss of channel profits. A related issue is the inherent amplification of demand variability as local demand information is transmitted along a distribution channel. The phenomenon, which stems from successive distortion of the demand information, is often referred to as the *bullwhip effect*. It was first illustrated in Forrester (1958) and more recently analyzed by Lee et al. (1997), the latter spawning a large number of publications on this issue, for which one remedy is information sharing.

Lee et al. (2000) study information sharing in supply chains with long-term relationships and find that the value of information sharing is high when the demand correlation over time is high and when the demand variance within each time period is high. However, information sharing is complicated by incentive and credibility problems that arise from information asymmetry. Cachon and Lariviere (2001) explore capacity decisions in a supply chain with one manufacturer and one supplier (retailer). They show that the use of forcing contracts (involuntary compliance) versus self-enforcing contracts (voluntary compliance) has a significant impact on the outcome of demand forecast sharing. Li (2002) examines the incentives for firms to share information vertically in a supply chain with one manufacturer and many retailers. He shows that voluntary information sharing is often infeasible when the retailers are engaged in a Cournot competition and are endowed with some private information. For excellent reviews of information sharing and contracts in supply chain coordination, readers are referred to Chen (2003) and Cachon (2003).

Our paper differs from the abovementioned literature in two aspects. First, we study the value of information sharing in a distribution channel in which the members have asymmetric information about demand volatility. Second, we examine the mechanisms for facilitating information sharing in the context of short-term relationships, where cooperative behavior is rare and forcing contracts of any kind are difficult to implement.

The remainder of the paper is organized as follows. Section 2 lays out the key elements of the model. Section 3 analyzes the basic model, in which a manufacturer and a retailer operate under a wholesale-price-only regime without sharing information about demand volatility. The model is analyzed for the cases of symmetric and asymmetric information. Section 4 explores the value of sharing this type of information, and how to facilitate sharing using different contractual agreements. Section 5 considers the impact of sharing information under a two-part tariff regime instead of a wholesale price mechanism. In §6, we conclude with some overall thoughts on this research, its limitations, and possible directions for future research. Discussions of proofs of propositions are given in the regular appendix, whereas the proofs of lemmas are deferred to the technical appendix.

2. Assumptions and Model Setup

The distribution channel we consider consists of a manufacturer and a downstream retailer; both firms are risk neutral and maximize their expected profits. Given that p represents the retail price, end-customer demand is given by $D(p) = y(p)\varepsilon$, where $y(p) = ap^{-b}$ (defined for $a > 0, b > 1$) is a price-dependent deterministic function, and ε is a uniformly distributed random variable with mean of 1. More precisely, $\varepsilon \in U[1-L, 1+L]$ for $0 \le L \le 1$, with $f(.)$ and $F(.)$ denoting its pdf and cdf. Hence, end-customer demand is determined by a random draw from the distribution $U[1-L, 1+L]$, where nature determines the extent of uncertainty L. The demand is intrinsically stochastic with an average of $y(p)$, a standard deviation of $y(p)L/\sqrt{3}$, and a volatility that decreases (increases) as L tends to zero (one). It follows that the average

[1] See Porteus (1990) for a comprehensive review of general newsvendor problems.

demand $y(p)$ tends to zero as p grows very large and goes to infinity as p approaches zero. This property is innocuous and is equivalent to the usual assumption that the demand reaches the market potential (usually a constant) when the product is free. Parameter b measures price sensitivity. We assume that the price elasticity of the average demand b is common knowledge and that $b > 1$ so that the demand is sufficiently elastic.

From this model description it is clear that the random variable ε captures the demand uncertainty. We assume that the functional form of its distribution (uniform) and its mean are common knowledge. The only unknown is the variance of ε, which is characterized by the lower and upper bounds of the distribution $1 - L$ and $1 + L$. Because L is determined by nature, neither the manufacturer nor the retailer knows its exact value, but they can develop independent estimates of L based on their private market information. We denote the manufacturer's estimate of L by L_m and the retailer's estimate by L_r. These estimates determine the random variables ε_m and ε_r, which represent the manufacturer's and retailer's asymmetric information about demand uncertainty ε. Clearly, the distributions of ε_m and ε_r are dependent on the characterization of L_m and L_r.

Next we provide a general overview of the steps in our model. First, the manufacturer determines the wholesale price w. We assume that the manufacturer has a constant marginal cost c and does not have any capacity constraints. Subsequently, the retailer, with the wholesale price w at hand, sets the retail price, p, and places an order, q. Finally, the demand $D(p)$ is realized. If $D(p) > q$, the retailer experiences a shortage and incurs an opportunity cost in terms of profits lost, $(p - w)[D(p) - q]$; if $D(p) < q$, the retailer has leftover products over which it incurs a loss, $w[q - D(p)]$. We assume that neither the retailer nor the manufacturer incurs any goodwill cost in the event of shortage, and that any leftover products have zero salvage value. It would be possible, however, to extend our model to incorporate these features.

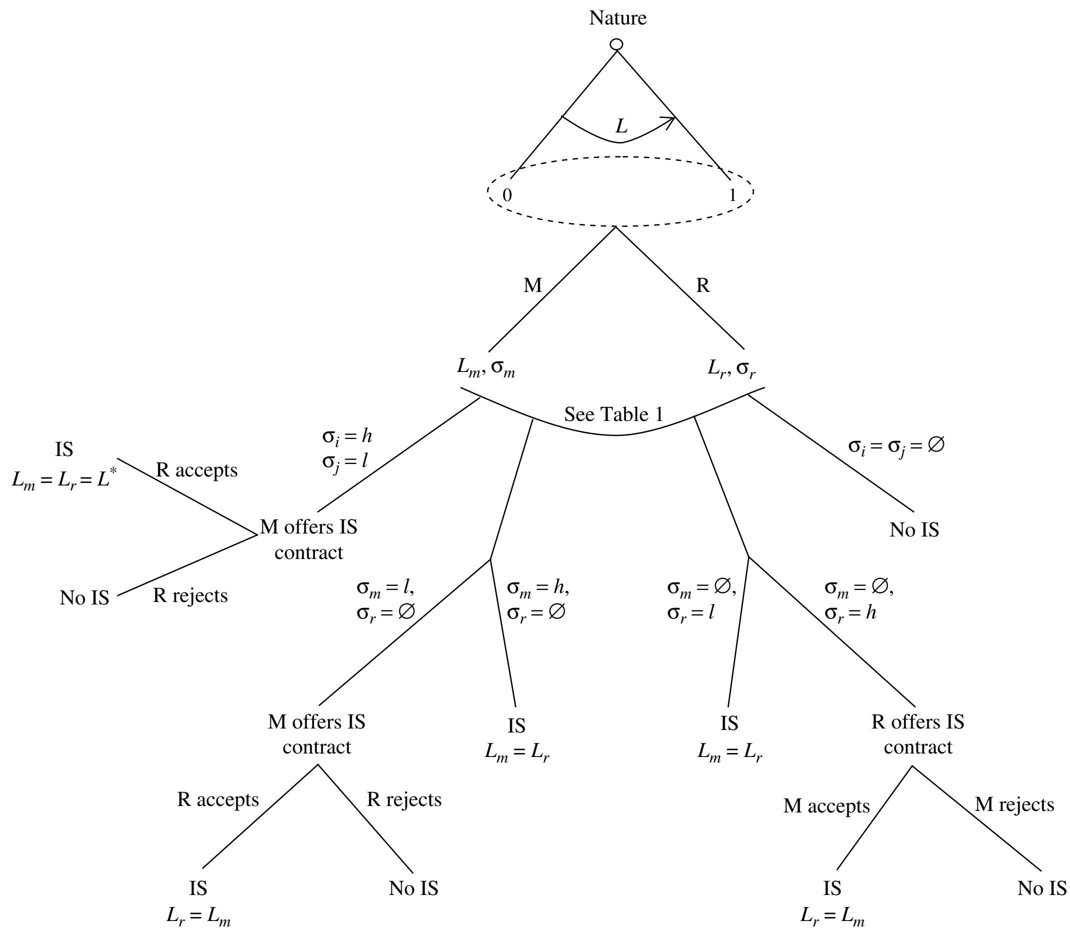
The resulting framework can be viewed as a one-period game of incomplete information, and the appropriate solution concept in this setting would be the Bayesian-Nash equilibrium. Specifically, the firms' optimal strategies need to be consistent with their beliefs derived from Bayes rule. To allow for an analysis of their strategies within this framework, however, we make two critical assumptions.

First, we assume that L_m and L_r are single-valued point estimates of L. This implies that the firms' beliefs ε_m and ε_r are uniformly distributed, because it is common knowledge that ε is uniform. As a result, we have that $\varepsilon_m \in U[1 - L_m, 1 + L_m]$ for $0 \le L_m \le 1$, and $\varepsilon_r \in U[1 - L_r, 1 + L_r]$ for $0 \le L_r \le 1$. It is important to acknowledge that this assumption limits the generality of our approach by not recognizing that firms might be uncertain about the quality of their estimate of L. A more inclusive method would be to explicitly treat L_m and L_r as stochastic variables; as a result, the firms' beliefs ε_m and ε_r would be characterized by integrals of uniform distributions. Although such a representation could admit a high level of generality in belief updating, the resulting analysis would be considerably more complex. Thus, we choose to sacrifice generality for tractability in our quest to examine the nature of information sharing about future demand volatility.

Similarly, we also assume that the correlation between the firms' demand estimates is unknown, and therefore there is no obvious way to combine or pool them into a more accurate estimate. As a result, the firms will use their own estimates. This follows because the manufacturer's wholesale price w is uninformative and the retailer's estimate has no impact on the manufacturer's decision. As we will discuss in §3, in our model the optimal wholesale price w is independent of L_m because the manufacturer's marginal cost is constant and there is no capacity constraint. This ensures that the retailer cannot extract any information about the manufacturer's estimate through the wholesale price w. The manufacturer, on the other hand, may deduce the retailer estimate L_r. This, however, does not affect the optimal wholesale price (again, this is shown in §3), and the equilibrium solution will remain unchanged. Without information sharing, it is therefore rational for the manufacturer and the retailer to use their own estimate. By the same token, with information sharing a firm will use the other party's estimate provided that the information is credible and doing so is incentive compatible. As with the distributional assumption of L_i, the unknown correlation assumption limits the scope of our analysis. Nevertheless, we believe that it yields valuable insights in one-shot game settings with short-term relations, where historical information is of limited use and belief updating is less applicable.

Given the model setup outlined above, suppose that the manufacturer and the retailer each form their point estimates L_m and L_r of L? As explained, their beliefs on ε are then given by $\varepsilon_m \in U[1 - L_m, 1 + L_m]$ and $\varepsilon_r \in U[1 - L_r, 1 + L_r]$, respectively. Without information sharing, the manufacturer will use its private demand estimate, ε_m, to predict the retailer's reaction. Moreover, the retailer sets the retail price and places an order using its own demand estimate ε_r. It is possible, however, that $L_i \le L$ or $L_i \ge L$, where $i = r, m$. In other words, the manufacturer and the retailer can either overestimate or underestimate L. Because the mean of the demand distribution is known, we say

Figure 1 Game Tree



that a firm's demand estimate is superior if its estimated variance is closer to the true state. According to our definition, L_i is superior to L_j if $|L - L_i| < |L - L_j|$. At the same time that the firms form their beliefs on L, the manufacturer and the retailer each receive a signal that reveals the type of the other player with respect to the relative quality of its demand estimate. For simplicity, we assume that each player can be of three types $\{h, \varnothing, l\}$, where type h has a demand estimate of superior quality, type $\varnothing$ has the same quality as the other player or the quality is unknown, and type l has inferior quality. In sum, the information set of each player is given by $\{L_i, \sigma_i\}$ (see Figure 1).

Although information about the firm's own demand volatility estimate (L_m or L_r) is always private, information about which estimate is superior (if it exists) can be either private or common knowledge. Put differently, a firm's demand estimate is known only to itself, but the quality of this estimate might be known to the other firm. For example, when forecasting the sales of a new novel, a national book store such as Amazon might have a demand estimate of $n \pm x$ units, whereas a regional publisher's demand estimate is $n \pm y$ units. This information is strictly private unless purposely revealed. On average, one would expect Amazon's estimate to be superior because of its sophisticated CRM (customer relationship management) solutions and national presence (thus $\sigma_r = l$, $\sigma_m = h$). However, the regional publisher can generate a superior estimate through proprietary marketing research (this may or may not be known to Amazon; thus, $\sigma_r = h$ or $\varnothing$, $\sigma_m = l$). If the regional publisher deals with a local bookstore that has marketing capability similar to its own, this dictates that the manufacturer is of type $\varnothing$ and vice versa, etc. Note that the cases where $\sigma_r = \sigma_m = l$, $\sigma_r = \sigma_m = h$ are equivalent to $\sigma_r = \sigma_m = \varnothing$. In these cases, the credibility problem cannot be resolved, and hence information sharing cannot occur. We summarize the alternative information structures in Table 1. These information structures reflect all the possible states of the world (12 permutations). Note that one can embed a more elaborate signal-generating process for each information structure. We abstract from such processes and focus on whether information sharing can occur under each of these states of the world, under what conditions, and how information sharing can be accomplished.

Table 1 Alternative Information Structures

Whose estimate of demand volatility is superior	Firm's knowledge of the quality of the demand estimate			
	Only M knows	Only R knows	Neither firm knows	Both firms know
M	Scenario 1a $\sigma_m = l, \sigma_r = \varnothing$	Scenario 2a $\sigma_m = \varnothing, \sigma_r = h$	Scenario 3 $\sigma_i = \sigma_j = \varnothing$	Quality is common knowledge $\sigma_i = h$ $\sigma_j = l$
R	Scenario 1b $\sigma_m = h, \sigma_r = \varnothing$	Scenario 2b $\sigma_m = \varnothing, \sigma_r = l$		

When the quality of the demand estimates is private information, there are three possible scenarios (see Table 1): (1) the manufacturer knows whose estimate is superior but the retailer does not, (2) the retailer knows whose information is superior but the manufacturer does not, and (3) neither firm knows who has a better demand estimate. As we shall see, these alternative information structures generate various incentive and credibility issues and hence impact the feasibility of information sharing. To better understand the incentive and credibility problems in information sharing, we outline the taxonomy of alternative information structures, summarized in Table 1. We discuss each of these scenarios in turn.

In Scenario 1 only the manufacturer knows which estimate is superior. If the manufacturer's estimate is superior (Scenario 1a), he needs to credibly convey this information to the retailer when doing so improves his profit. The incentive problem arises because the manufacturer wants to share his better information only if the retailer's order quantity is too low and hence hurts his profit. However, the manufacturer might also have an incentive to induce the retailer to order too much. Thus, the credibility problem also arises because the retailer does not know whose estimate is superior and would suffer from a lower profit if he orders too much. If the retailer's estimate is superior (Scenario 1b), no action is necessary. The manufacturer simply complies with the retailer's order and the retailer's information is transferred to the manufacturer costlessly. Neither credibility nor incentive problems are present because the retailer has no incentive to manipulate the order quantity, given his lack of knowledge on whose demand estimate is superior. In Scenario 2, where only the retailer knows which estimate is superior, credibility and incentive problems arise when the manufacturer possesses a better demand estimate (Scenario 2a), but no action is necessary if the retailer's demand estimate is superior (Scenario 2b). The underlying logic is similar to that discussed in Scenario 1. In Scenario 3, it is not clear that information sharing is at all feasible. In sum, the game unfolds as follows (see Figure 1). In Scenario 3 ($\sigma_r = \sigma_m = \varnothing$), no information sharing (IS) occurs. In Scenarios 1b and 2b ($\sigma_m = h$, $\sigma_r = \varnothing$ and $\sigma_m = \varnothing$, $\sigma_r = l$), the manufacturer updates its demand estimate to the retailer's ($L_m = L_r$) without the need of information-sharing contract. In Scenario 1a, the manufacturer must offer a contract to induce the retailer to engage in information sharing. If the retailer accepts, the retailer updates its demand estimate to the manufacturer's ($L_r = L_m$); otherwise, no information sharing occurs. In Scenario 2a, the roles of the manufacturer and the retailer switch.[2] Finally, when the quality of the demand estimates is common knowledge, the manufacturer and retailer may negotiate an information-sharing contract. If successful, information sharing occurs and the party whose demand estimate is inferior updates to the superior one ($L_m = L_r = L^*$).

3. The Basic Model

The basic model examined in this section focuses on situations where the manufacturer and the retailer interact using a wholesale-price-only regime. Situations in which the manufacturer and the retailer interact using a two-part tariff mechanism are analyzed in §5. The wholesale-price-only contract implies that the only interaction between the retailer and the manufacturer occurs when the manufacturer posts its wholesale price and when the retailer places its order. Our basic model considers the impact of demand volatility and asymmetric information in situations where information sharing does not occur. As such, the results obtained here serve as the basis for analyzing the value and feasibility of information sharing in §4.

To analyze the framework and determine the equilibrium decisions, we use backward induction. To illustrate the impact of demand volatility, we first consider the case in which both the retailer and the manufacturer have symmetric and accurate information, that is, $L_r = L_m = L$. Section 3.1 derives the retailer's profit-maximizing strategy for this case, given the wholesale price determined by the manufacturer. Based on these results, the manufacturer's decision problem is analyzed in §3.2. Subsequently, §3.3 provides insights as to the impact of demand

[2] We consider only Scenario 1a and the common knowledge case in subsequent analysis.

volatility on the equilibrium strategies. Finally, §3.4 discusses the impact of information asymmetry on the equilibrium strategies. Although §§3.1 and 3.2 are integral components of our analysis, they focus on the technical aspects of the model and are relatively self-contained. Readers who are not interested in the underlying mathematics of the model development can go directly to §§3.3 and 3.4 for key insights from the model.

3.1. Symmetric Information: Retailer Profit-Maximizing Strategy

The retailer profit for the period, π_r, is the difference between its sales revenues and purchase costs. Assuming a wholesale price w, a retail price p, an order quantity q, and the demand $D(p)$, π_r can be expressed as follows:

$$\pi_r(q, p, w) = \begin{cases} pD(p) - wq & \text{for } D(p) \le q \\ (p-w)q & \text{for } D(p) > q. \end{cases} \tag{1}$$

Following the approach outlined, for example, in Petruzzi and Dada (1999), we express all quantities relative to the deterministic price-dependent component $y(p)$ by defining what we refer to as the mean-adjusted order quantity $z = q/y(p)$. This results in an alternative mean-adjusted representation, which clarifies the impact of demand uncertainty and simplifies the analysis to come

$$\pi_r(z, p, w) = y(p) \cdot \begin{cases} (p-w)\varepsilon - w(z-\varepsilon) & \text{for } \varepsilon \le z \\ (p-w)\varepsilon - (p-w)(\varepsilon - z) & \text{for } \varepsilon > z. \end{cases} \tag{2}$$

The expected profit that the retailer attempts to maximize when deciding p and z (or equivalently q) is given in (3) below (recall that $L_r = L$)

$$E_\varepsilon\{\pi_r(z, p, w)\} = y(p)\left[\int_{1-L}^{1+L} (p-w)xf(x)\,dx - w\int_{1-L}^{z} (z-x)f(x)\,dx - (p-w)\int_{z}^{1+L} (x-z)f(x)\,dx\right]. \tag{3}$$

Defining $\Psi(p, w) = y(p)(p-w)$ and

$$\Lambda_\varepsilon(z, p, w) = y(p)\left[w\int_{1-L}^{z} (z-x)f(x)\,dx + (p-w)\int_{z}^{1+L} (x-z)f(x)\,dx\right] = y(p)[LpF^2(z) + (p-w)(1-z)],$$

we can also write

$$E_\varepsilon\{\pi_r(z, p, w)\} = \Psi(p, w) - \Lambda_\varepsilon(z, p, w). \tag{4}$$

Hence, the expected profit can be expressed as the riskless profit, $\Psi(p, w)$, which represents the profit obtained by the retailer in the deterministic problem (e.g., $L = 0$), less the expected loss that results from the presence of uncertainty, expressed by the loss function $\Lambda_\varepsilon(z, p, w)$. Note that the expected loss equals the sum of the expected cost of ordering too much and the expected opportunity cost of ordering too little.

To determine the optimal price $p_r^*(w)$ and mean-adjusted order quantity $z_r^*(w)$ that maximize (3) and (4) for a given w, we consider the first-order optimality conditions

$$\frac{\partial E_\varepsilon\{\pi_r(z, p, w)\}}{\partial z} = -\frac{\partial \Lambda_\varepsilon(z, p, w)}{\partial z} = y(p)[(p-w) - pF(z)] = 0,$$

$$\frac{\partial E_\varepsilon\{\pi_r(z, p, w)\}}{\partial p} = y(p)\left[z\left(1 - b\frac{p-w}{p}\right) + (b-1)LF^2(z)\right] = 0.$$

Note that for any given p the optimal mean-adjusted order quantity $z_r^*(p, w)$ corresponds to the standard newsvendor result, that is,

$$z_r^*(p, w) = F^{-1}\left(\frac{p-w}{p}\right) = 1 - L + 2L\frac{p-w}{p}. \tag{5}$$

It is easy to see from (5) that $z_r^*(p, w)$ is increasing in p for any given w. Intuitively, the explanation for this is that the opportunity cost for every unsatisfied demand $(p-w)$ increases with p, whereas the cost of every surplus item remains constant at w.

Similarly, for any given z we can use the first-order optimality conditions to determine the optimal price $p_r^*(z, w)$

$$p_r^*(z, w) = w\left(\frac{b}{b-1}\right)\left[\frac{z}{z - LF^2(z)}\right]. \tag{6}$$

Note that whenever demand is deterministic (e.g., $L = 0$), the optimal riskless price $p_r^*(w) = w(b/(b-1))$. Comparing with (6), we note that $z - LF^2(z) < z$ because both L and $F(z)$ are nonnegative. Using the definition of $F(z)$, we can also conclude that $z - LF^2(z) > 0$ because $L \le 1$ and $F^2(z) \le F(z) \le z$. Thus, Equation (6) illustrates the well-known result (Karlin and Carr 1962) that the introduction of uncertainty will yield a price that is larger than the optimal riskless price, i.e., $p_r^*(w) \ge w(b/(b-1))$.

Using (5) (or (6)), the retailer's profit maximization problem can be reduced to an optimization problem over a single variable. Substituting the expression for $z_r^*(p, w)$ into the expected profit function (4) renders the expression

$$E_\varepsilon\{\pi_r(z_r^*(p, w), p, w)\} = y(p)\left[(p-w)\left(1 - L\frac{w}{p}\right)\right],$$

which is decreasing in the demand volatility L. Using the first-order optimality condition with respect to p renders $p_r^*(w)$ as specified in Lemma 1.

Lemma 1. *For any given w, the optimal retail price is obtained as*

$$p_r^*(w) = w\frac{b}{b-1}H(b, L), \tag{7}$$

where

$$H(b, L) = \frac{1+L}{2} + \sqrt{\left(\frac{1-L}{2}\right)^2 + \frac{L}{b^2}} > 1. \tag{8}$$

Note that $[b/(b-1)]H(b, L)$ can be viewed as a generalized double-marginalization factor, which is minimized for the special case of deterministic demand (i.e., $L = 0$) where it degenerates to $b/(b-1)$. From Lemma 1 it is easy to determine the optimal mean-adjusted order quantity $z_r^*(w)$ by substituting $p_r^*(w)$ for p in (5)

$$\begin{aligned} z_r^*(w) &= F^{-1}\left(1 - \frac{b-1}{bH(b, L)}\right) \\ &= 1 - L + 2L\left(1 - \frac{b-1}{bH(b, L)}\right). \end{aligned} \tag{9}$$

The corresponding actual order quantity, $q_r^*(w)$, follows directly as $q_r^*(w) = z_r^*(w)y(p_r^*(w))$.

3.2. Symmetric Information: Manufacturer Profit-Maximizing Strategy

The manufacturer has to determine an optimal wholesale price w_m^*. Given that, in the current case, the retailer and manufacturer have symmetric and accurate information ($L_r = L_m = L$), the manufacturer can accurately predict the retailer's response to any given order quantity he chooses. Consequently, the manufacturer's profit function, as a function of the wholesale price, can be expressed as

$$\begin{aligned} \pi_m(w) &= (w-c)q_r^*(p_r^*(w), w) \\ &= (w-c)\left(1 + L - 2L\frac{b-1}{b}\frac{1}{H(b, L)}\right) \\ &\quad \cdot \left(\frac{b}{b-1}H(b, L)\right)^{-b} y(w). \end{aligned} \tag{10}$$

Note that $\pi_m(w)$ is a deterministic function, that is, the manufacturer's profit is determined by how much the retailer orders instead of actual sales during the period. This implies that the manufacturer does not expose itself to any risk associated with demand uncertainty. To determine the manufacturer's optimal wholesale price w_m^*, we use the first-order optimality condition for $\pi_m(w)$ with respect to w,

$$\begin{aligned} \frac{\partial \pi_m(w)}{\partial w} &= \left(1 - b\frac{w-c}{w}\right)\left(1 + L - 2L\frac{b-1}{bH(b, L)}\right) \\ &\quad \cdot \left(\frac{b}{b-1}H(b, L)\right)^{-b} y(w) = 0. \end{aligned}$$

Solving for w yields

$$w_m^* = \frac{b}{b-1}c. \tag{11}$$

Note that w_m^* is independent of the demand volatility L.[3] We also note that in the case of deterministic demand ($L = 0$), (11) together with (6) illustrates the well-known double-marginalization principle.

3.3. Symmetric Information: Impact of Demand Volatility

From the above, we conclude that the profit-maximizing strategy for the manufacturer is to set a wholesale price w_m^*, and the optimal response for the retailer is to order $q_r^*(w_m^*)$ units which are sold at a retail price of $p_r^*(w_m^*)$. To analyze the value of information sharing, an important question is how changes in the demand volatility estimates impact these decisions and the associated profits. In the remainder of this section we provide some structural properties that help answer these questions. First, however, we note that because the manufacturer's optimal wholesale price w_m^* is independent of L (see (11)), its profit-maximizing strategy is unaffected by changes in the demand volatility. We therefore concentrate on how changes in demand volatility impact the retailer's optimal strategy.

Starting with a comparison to the deterministic case, we conclude that in the presence of demand volatility, the order quantity generally differs from the average demand. The reason is the differences in the costs associated with understocking and overstocking.

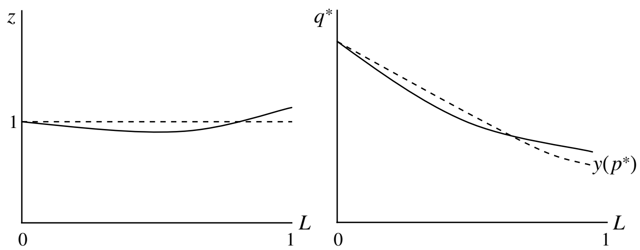
Lemma 2. *For any given L, $q_r^*(w) > y(p_r^*(w))$ if and only if $H(b, L) > 2((b-1)/b)$.*

This is illustrated in Figure 2, which shows both the mean-adjusted and the actual order quantity as a function of L. Clearly, $q_r^*(w) = y(p_r^*(w))$ when $L = 0$. However, as L increases $z^*(w)$ will initially decrease below one (and therefore $q_r^*(w) < y(p_r^*(w))$), until we reach the value of L for which $H(b, L) = 2((b-1)/b)$. For larger values of L, $z^*(w)$ will be larger than 1. Similarly, we can conclude that the retail price $p_r^*(w)$ generally differs from the optimal riskless price $p_r^*(w) = w(b/(b-1))$. The explanation in this case is that the retailer, ex ante, can use the retail price to fine-tune the expected costs of overstocking and understocking.

As discussed in the introduction of this paper, the conventional approach to model demand uncertainty in the channel literature focuses on the mean but fails

[3] It is worth pointing out that this is unlikely to hold if the manufacturer faces constrained capacity, which typically creates a complex relationship between c and the quantity ordered. As shown in Ray et al. (2006), changes in c could lead to asymmetric wholesale prices.

Figure 2 Impact of Demand Volatility on Order Quantity



to explicitly account for additional trade-offs caused by the introduction of demand volatility, such as those discussed above. This could become problematic when demand volatility is an important factor. We note that although a two-point distribution can also account for the effect of demand volatility, it is difficult to disentangle the effect of the mean from that of variance in such distributions, because change in the variance will generally lead to a change in the mean, unless the two points change symmetrically.

Turning to the impact that demand volatility has on the retailer's strategy, Lemma 3 specifies how changes in L affect the optimal retail price.

LEMMA 3. *The profit-maximizing retail price $p_r^*(w)$ is strictly increasing in L.*

Intuitively, by increasing the retail price, the retailer can reduce the demand variability (recall that its standard deviation is $y(p)L/\sqrt{3}$ and that $y(p)$ is decreasing in p) and counter the effect of an increase in L on the loss term $\Lambda_\varepsilon(z, p, w)$. Of course, an increase in the retail price also reduces the mean demand, $y(p)$, which implies a reduction in the riskless profit $\Psi(p, w)$.

Similarly, Lemma 4 specifies how changes in L affect the retailer's optimal order quantity $q_r^*(w)$.

LEMMA 4. *The profit-maximizing order quantity $q_r^*(w)$ is strictly decreasing in L.*

Intuitively, Lemma 4 is based on the fact that, although the mean-adjusted order quantity $z_r^*(p, w)$ is increasing in p, the actual order quantity $q_r^*(p, w) = y(p)z_r^*(p, w)$ will have a maximum. This is because any increase in $z_r^*(p, w)$ is countered by a decrease in the mean demand $y(p) = ap^{-b}$ as p increases. The lemma follows because we can show that the optimal profit-maximizing retail price $p_r^*(w)$ is always strictly greater than the price for which the order quantity is maximized.

3.4. Impact of Information Asymmetry

Let us now consider the situation in which the retailer and the manufacturer have asymmetric demand estimates, which may both be different from the true demand volatility L. Thus, the retailer's estimate L_r may be different from the manufacturer's estimate L_m.

In this case, the basic model is again derived from backward induction. However, when the retailer makes its decisions about retail price and order quantity to maximize its expected profits (given w), it does so ex ante without knowing $D(p)$. Instead, it has to rely on its best demand estimate $D_r(p)$. The associated profit function, and consequently the expected profit, are equivalent to (2) and (3) after substituting $D_r(p)$ for $D(p)$ and ε_r for ε, respectively. In the asymmetric case, the optimal retail price is given by $p_r^*(w) = w(b/(b-1))H(b, L_r)$, whereas the optimal mean-adjusted order quantity $z_r^*(w) = 1 - L_r + 2L_r(1 - (b-1)/bH(b, L_r))$. In §3.2, we showed that the manufacturer's optimal strategy is in fact independent of its demand estimate. Thus, even with asymmetric information the optimal wholesale price $w_m^* = (b/(b-1))c$.

To analyze the impact of information asymmetry, we first observe that Lemmas 3 and 4 imply that whenever the retailer underestimates demand volatility, the result will be a retail price that is too low and an order quantity that is too high. Conversely, if the retailer overestimates the demand volatility, the retail price will be too high and the order quantity too low. The impact on channel profits, however, is somewhat more complicated. After the profit-maximizing strategies (w_m^*, $q_r^*(w_m^*)$ and $p_r^*(w_m^*)$) are revealed, the manufacturer's profit, $\pi_m(w_m^*) = (w_m^* - c) \cdot q_r^*(w_m^*)$, is unambiguously defined. Note that $\pi_m(w_m^*)$ depends on L_r via $q_r^*(w_m^*)$, but that it is independent of L and L_m. The retailer's expected profit, on the other hand, is a bit more ambiguous. From the retailer's perspective, the demand estimate, ε_r, is correct. Under this demand estimate, its perceived expected profit ex ante is $E_{\varepsilon_r}\{\pi_r(z_r^*(w_m^*), p_r^*(w_m^*), w_m^*)\}$ as defined in (3) and (4). However, objectively, the true demand uncertainty is ε (unknown to the retailer). Under the true demand distribution the retailer's actual expected profit is $E_\varepsilon\{\pi_r(z_r^*(w_m^*), p_r^*(w_m^*), w_m^*)\}$. In analogy with (4), we have

$$E_\varepsilon\{\pi_r(z_r^*(w_m^*), p_r^*(w_m^*), w_m^*)\}$$
$$= \Psi(p_r^*(w_m^*), w_m^*) - \Lambda_\varepsilon(z_r^*(w_m^*), p_r^*(w_m^*), w_m^*), \quad (12)$$

where

$$\Lambda_\varepsilon(z, p, w) = y(p)\left[w\int_{1-L}^{G(L,z)}(z-x)f(x)\,dx + (p-w)\int_{G(L,z)}^{1+L}(x-z)f(x)\,dx\right], \quad (13)$$

and

$$G(L, z) = \begin{cases} 1-L & \text{if } z < 1-L \\ z & \text{if } 1-L \le z \le 1+L \\ 1+L & \text{if } z > 1+L. \end{cases} \quad (14)$$

Clearly, if the retailer's estimate is correct, i.e., $\varepsilon_r = \varepsilon$ and $L_r = L$, the retailer's perceived expected profit coincides with its actual expected profit.

Proposition 1. *Under the equilibrium strategies w_m^*, $q_r^*(w_m^*)$, and $p_r^*(w_m^*)$:*

1. *The manufacturer's profit, $\pi_m(w_m^*)$ and the retailer's perceived expected profit, $E_{\varepsilon_r}\{\pi_r(z_r^*(w_m^*), p_r^*(w_m^*), w_m^*)\}$, are decreasing in L_r.*
2. *The retailer's actual expected profit, $E_\varepsilon\{\pi_r(z_r^*(w_m^*), p_r^*(w_m^*), w_m^*)\}$, is maximized when the retailer's estimate of the demand distribution is correct, i.e., when $L_r = L$.*
3. *When the retailer's demand estimate is correct ($L_r = L$), the retailer's actual expected profit is decreasing in the demand volatility L.*

Given the assumptions underlying our framework, we conclude that if the retailer overestimates the demand volatility ($L_r > L$), it has a negative impact on the profits of both the retailer and the manufacturer. On the other hand, an underestimation ($L_r < L$), will benefit the manufacturer. Proposition 1 also asserts that increased volatility, even when correctly estimated, reduces profits of both the retailer and manufacturer. The implications of this proposition on the potential benefits for the channel to share information about demand volatility are further discussed in §4.

4. Information Sharing in a Wholesale-Price-Only Regime

For information sharing to occur within our model setup, at least one firm should be able to evaluate the expected improvement in profits when sharing occurs. Such judgment, however, cannot be made if neither firm knows whose demand estimate is the most accurate (or superior as we have deemed it). Specifically, information sharing is feasible when at least one firm knows the quality of the demand estimates and when the firms can overcome the incentive and credibility problems. In the information-sharing scenarios we outlined in §2, each firm knows its own estimate of demand volatility (L_m or L_r). In addition, a firm may have information about the quality of the other firm's estimate relative to its own. Thus, a firm might know (or be convinced) which estimate is superior, that is, whether L_m or L_r is closer to the true state L. However, as discussed in §2, we assume that L as well as the correlation between the estimates are unknown. Moreover, it is important to reiterate that we assume belief updating does not occur for the situations we consider.

Under this information asymmetry, the firm with a superior estimate needs a mechanism to convey its information (about L_m or L_r) to the other firm when it is profitable to do so. The transmission of this information can be successful only if the other firm finds itself better off, or at least no worse off, to use such information. Throughout this paper, we say that information sharing occurs when such transmission is successful, that is, when the firms share their private information about demand volatility (L_m or L_r).

In a coordinated channel, the two firms act as if they were a single entity, which implies the absence of double marginalization and a retail price and order quantity that maximize the channel profits. As we demonstrate in §3, the wholesale price by itself neither coordinates the channel nor achieves information sharing. Iyer and Villas-Boas (2003) show that, under deterministic demand and complete information, a wholesale-price-only contract coordinates the channel when the retailer's bargaining power is sufficiently large. A bargaining framework, however, is beyond the scope of this paper. An alternative pricing scheme, the two-part tariff consisting of a fixed fee and a variable fee, coordinates the channel under symmetric information. However, it is not clear whether a two-part tariff achieves information sharing in the presence of information asymmetry. For the remainder of this section, we examine the potential value of information sharing under a wholesale price regime, and explore how information can be shared in a mutually beneficial manner using profit sharing and buyback contracts. A parallel analysis under a two-part tariff regime is provided in §5.

4.1. The Value of Information Sharing

In §3 we analyzed the impact of the manufacturer and retailer having asymmetric estimates of the demand volatility under a wholesale-price-only regime without information sharing. In this section we examine the potential value of sharing such information in terms of increased channel profits. We also consider the consequences for the profit-maximizing strategies in terms of pricing and order quantities.

The fundamental questions in our model are whether information sharing always has the potential to improve channel profits and how information sharing impacts each firm's expected profit. To simplify the analysis without sacrificing insights, we henceforth consider a situation where the manufacturer's estimate of demand volatility is perfect (i.e., $L_m = L$), but the retailer's estimate deviates from the true state. The potential value of information sharing is obtained by comparing the situation of no information sharing (analyzed in §3) with the situation of perfect information sharing. The latter refers to the situation where both firms use the best available estimate L_m. (Recall that, as discussed in §2, information sharing takes care of itself whenever L_r is superior and is of little interest to analyze further.)

Proposition 2. *Suppose $L_m = L$ and let $L_r = L_m + \delta$, where δ denotes the deviation from the true state, L_m, and satisfies the regularity condition $0 \le L_m + \delta \le 1$. Under a wholesale-price-only regime, information sharing improves* *expected channel profits when $\delta > 0$, but can either increase or decrease channel profits when $\delta < 0$. More precisely, when $\delta < 0$ information sharing increases expected channel profits if and only if the information-sharing condition (ISC) is satisfied*

$$\frac{\Omega(L_m,\delta,b)+(\widehat{H}(b,L_m,\delta)/(b-1))(1-b\widehat{H}(b,L_m,\delta)/4L_m)}{\Omega(L_m,0,b)} \cdot \left(\frac{H(b,L_m)}{H(b,L_m+\delta)}\right)^{b+1} \le 1, \tag{ISC}$$

where $\widehat{H}(b,L_m,\delta)$ and $\Omega(b,L_m,\delta)$ depend only on b, L_m, and δ.

To appreciate the above proposition, we identify the sources of distortion in the channel. Compared to a coordinated channel with complete information, the current channel suffers from three types of distortion: double marginalization, demand uncertainty, and miscalculation of demand uncertainty. Whereas the first two types of distortion are detrimental to both firms (the effect of demand uncertainty on firms' profits is delineated in Proposition 1), the effect of the third type of distortion on the two firms can be asymmetric. As asserted in Lemmas 3 and 4, both the profit-maximizing retail price $p_r^*(w_m^*)$ and order quantity $q_r^*(w_m^*)$ are distorted by uncertainty. By contrast, the wholesale price is unaffected by the demand volatility. In the absence of information sharing, the manufacturer takes the retailer's order quantity as given and produces exactly that amount. Hence, the manufacturer does not bear any risk associated with demand volatility. When $\delta > 0$, which means that the retailer overestimates the demand uncertainty, it leads to a higher retail price and a lower order quantity than what would otherwise be the case (see discussion in §3). The opposite is true when $\delta < 0$. An interesting conclusion from Proposition 2 is that whenever the retailer underestimates the demand volatility (i.e., $\delta < 0$), it is only the price elasticity b and the manufacturers estimate L_m that determine whether information sharing causes channel profits to increase or decrease (see (ISC)). Hence, using Proposition 2, the manufacturer can assess for which δ (or equivalently L_r estimates) sharing its superior information about the demand volatility would increase channel profits and when it would reduce them.

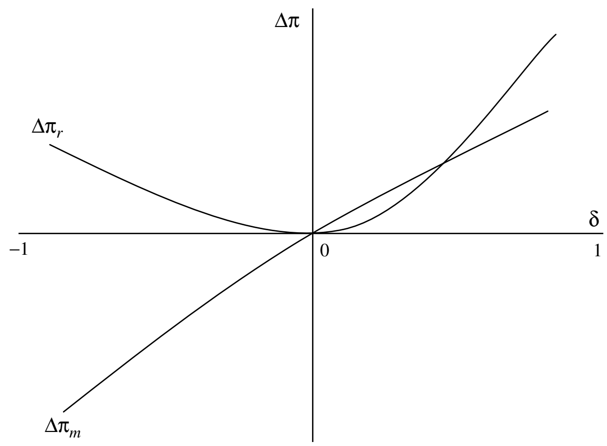
To illustrate these points, Figure 3 shows the difference in the manufacturer's and the retailer's expected profits when perfect sharing takes place ($L_r = L_m = L$) compared to when no information sharing occurs. We use the notation

$$\Delta\pi_m = \pi_m(z_m^*(w_m^*), p_m^*(w_m^*), w_m^*) - \pi_m(z_r^*(w_m^*), p_r^*(w_m^*), w_m^*),$$

and

$$\Delta\pi_r = E_\varepsilon\{\pi_r(z_m^*(w_m^*), p_m^*(w_m^*), w_m^*)\} - E_\varepsilon\{\pi_r(z_r^*(w_m^*), p_r^*(w_m^*), w_m^*)\},$$

Figure 3 The Value of Information Sharing Under a Wholesale-Price-Only Regime



where $E_\varepsilon\{\pi_r(z_m^*(w_m^*), p_m^*(w_m^*), w_m^*)\}$ is the retailer's actual expected profit when the optimal strategies are based on the superior estimate L_m (which in our case happens to coincide with the true state, L). $E_\varepsilon\{\pi_r(z_r^*(w_m^*), p_r^*(w_m^*), w_m^*)\}$ is the actual expected retailer profit when no information sharing takes place. A positive $\Delta\pi_r$ (or $\Delta\pi_m$) implies that the firm's expected profit increases when information is shared, whereas a negative value means it decreases.

From Figure 3 we can see that information sharing increases both the retailer's and the manufacturer's profits when the retailer overestimates the demand uncertainty (when $\delta > 0$), a result that follows from Proposition 1. In this case, information sharing is incentive compatible and improves channel profits (Proposition 2). That is, both parties are better off with respect to their expected profits when using L_m. On the other hand, when the retailer underestimates the demand uncertainty ($\delta < 0$), we can see that information sharing decreases the manufacturer's profit although it still benefits the retailer (and $\Delta\pi_r > 0$ when $\delta < 0$). This result also follows from Proposition 1. Moreover, as asserted in Proposition 2, Figure 3 indicates that the loss in the manufacturer's profit of sharing the information on demand volatility can exceed the gain in the retailer's profit (when $\delta < 0$), i.e., condition (ISC) is not satisfied. This causes a conflict of interest and information sharing reduces channel profits. Thus, we conclude that information sharing might or might not be valuable in an uncoordinated channel, and it depends in a complicated way on the price elasticity b and the demand estimates L_m and L_r.

Note that before the firms actually share their information, they do not know with certainty whether they are facing a situation where it is beneficial to do so. This implies incentive issues for the manufacturer to share its superior information. To illustrate this further, consider the manufacturer's situation prior to information sharing. Given that it has no prior knowledge of the retailer's estimate L_r (beyond the fact that it deviates from the true volatility L_m), one can argue that from the manufacturer's perspective, L_r is a stochastic variable with a range $0 \leq L_r \leq 1$ (or equivalently $0 \leq L_m + \delta \leq 1$). Using Proposition 2 and (ISC), the manufacturer may determine the range of δ where information sharing increases and decreases expected channel profits, respectively, and thus determine when information sharing would be beneficial.

Given our model setup, we can therefore conclude that it is not obvious that the manufacturer is always willing to share its superior information because doing so could improve the retailer's profit at the expense of reducing its own profit. Although information sharing reduces or eliminates the distortion caused by the miscalculation of demand uncertainty, its impact on the profits of the manufacturer and the retailer is asymmetric. In particular, information sharing is not incentive compatible when the retailer underestimates demand volatility.

4.2. Information-Sharing Contracts

As discussed earlier, firms need to overcome incentive and credibility problems to achieve information sharing. Next we investigate two alternative contractual arrangements that help achieve information sharing. In particular, these contracts are relatively easy to implement. We first analyze the profit-sharing contract when the quality of the demand estimates is common knowledge; we then examine the buyback contract when only one firm knows whose demand estimate is superior. In addition, we study the effect of information sharing on pricing, firms' profits, and channel profits.

4.2.1. The Profit-Sharing Contract. When both the manufacturer and the retailer know which demand estimate is superior, credibility is not an issue, but the incentive problem remains. A profit-sharing contract is a simple mechanism to facilitate information sharing under such circumstances. Because information sharing takes care of itself when the retailer's estimate is superior, we only consider the case when the manufacturer's estimate is superior. Our analysis presumes that the manufacturer has an interest in sharing. (As explained in §3.1, this is not always the case because the manufacturer might conclude before the fact that the risk of reducing the expected channel profit is too high.) The sequence of actions is as follows. First, the manufacturer and the retailer negotiate for a division of the combined gain in profits when information sharing occurs. The gain (loss) in profit for each firm is relative to the no-information-sharing case, where the firms use their own demand estimates. Although the division can be arbitrary depending on each firm's bargaining power, we assume without loss of generality that both firms split the gain equally. Second, if the negotiation is successful, both firms submit their demand estimates simultaneously. Otherwise, the firms do not reveal their demand estimates and the game proceeds as in the no-information-sharing case described in §3. The solution concept in the profit-sharing contract is one of Nash bargaining. Without information sharing, the equilibrium strategy $(z_r^*(w_m^*), p_r^*(w_m^*), w_m^*)$ is based on the retailer's demand estimate. With information sharing, both firms use the superior estimate L_m when determining the optimal strategy $(z_m^*(w_m^*), p_m^*(w_m^*), w_m^*)$. Third, after the demand estimates are revealed, both parties agree that L_m is the best available estimate of the true demand volatility. Under this estimate the retailer's expected profit with and without information sharing are $E_{\varepsilon_m}\{\pi_r(z_m^*(w_m^*), p_m^*(w_m^*), w_m^*)\}$ and $E_{\varepsilon_m}\{\pi_r(z_r^*(w_m^*), p_r^*(w_m^*), w_m^*)\}$, respectively. Similarly, the manufacturer's profit with and without information sharing are $\pi_m(z_m^*(w_m^*), p_m^*(w_m^*), w_m^*)$ and $\pi_m(z_r^*(w_m^*), p_r^*(w_m^*), w_m^*)$. Hence, after the contract is signed (in our case after the fifty-fifty split is agreed on), the firms' perceived change in the expected total channel profits is

$$\begin{aligned}\Delta\Pi = {} & E_{\varepsilon_m}\{\pi_r(z_m^*(w_m^*), p_m^*(w_m^*), w_m^*)\} \\ & - E_{\varepsilon_m}\{\pi_r(z_r^*(w_m^*), p_r^*(w_m^*), w_m^*)\} \\ & + [\pi_m(z_m^*(w_m^*), p_m^*(w_m^*), w_m^*) \\ & \quad - \pi_m(z_r^*(w_m^*), p_r^*(w_m^*), w_m^*)], \end{aligned} \tag{15}$$

and the profit-sharing contract dictates that the manufacturer and the retailer each receives $(1/2)\Delta\Pi$ in equilibrium.

A prominent feature of the profit-sharing contract is that although the agreement on how to split the gain in channel profits is reached ex ante, before the demand is realized, the actual profit sharing occurs ex post, after the demand realization. Note that $\Delta\Pi$ in (15) represents the expected actual gain in profits if $L_m = L$. Given the intrinsic stochasticity of the demand, a profit-sharing contract can lead to either an increase or a decrease of the profits of both firms in realization. This means that under this contract the manufacturer and the retailer share the risk associated with the demand uncertainty.[4] As outlined in Lemma 3, the optimal retail price and order quantity can either increase or decrease depending on whether information sharing reduces the retailer's overestimation or underestimation. Furthermore, from Proposition 2 and Figure 3, we can conclude that the sign of $\Delta\Pi$ as defined in (15) is ambiguous (note that $\Delta\Pi$ is equivalent to $\Delta\pi_r + \Delta\pi_m$ under the presumption that

[4] Under a wholesale-price-only contract the retailer bears this risk on his own.

the manufacturer's estimate is correct). This suggests that after signing the contract the firms might realize that the perceived change in expected profits due to information sharing, $\Delta\Pi$, is negative. Profit sharing in this case means that the retailer has to give up profits to the manufacturer, and both parties end up being worse off. Consequently, the retailer has incentives to break the contract, to use the manufacturer's estimate, which it now knows, and leave the manufacturer to take the entire profit loss. Hence, some kind of enforcing mechanisms might be required to secure the contract.

4.2.2. The Buyback Contract. When only the manufacturer knows the quality of the demand estimates, and the retailer overestimates the demand volatility, the manufacturer can offer a buyback contract to induce the retailer to order more and credibly convey his information to the retailer in the process.

When the manufacturer offers a return policy, s, the retailer's profit function is given by

$$\pi_r(z, p, w, s) = \begin{cases} y(p)[(p-w)\varepsilon_r-(w-s)(z-\varepsilon_r)], & \varepsilon_r \le z \\ y(p)[(p-w)\varepsilon_r-(p-w)(\varepsilon_r-z)], & \varepsilon_r > z; \end{cases} \tag{16}$$

the retailer's profit maximization problem, given w and s, can be written as

$$\begin{aligned}\max_{z,p} E_{\varepsilon_r}\{\pi_r(z, p, w, s)\} &= y(p)\bigg\{\int_{1-L_r}^{z}(p-w)xf_{\varepsilon_r}(x)\,dx-\int_{1-L_r}^{z}(w-s)(z-x)f_{\varepsilon_r}(x)\,dx \\ &\quad+\int_{z}^{1+L_r}(p-w)xf_{\varepsilon_r}(x)\,dx \\ &\quad-\int_{z}^{1+L_r}(p-w)(x-z)f_{\varepsilon_r}(x)\,dx\bigg\} \\ &= y(p)\bigg\{(p-w)-\int_{1-L_r}^{z}(w-s)(z-x)f_{\varepsilon_r}(x)\,dx \\ &\quad-\int_{z}^{1+L_r}(p-w)(x-z)f_{\varepsilon_r}(x)\,dx\bigg\}. \end{aligned} \tag{17}$$

Noting that a return policy is activated only when the mean adjusted demand falls below $z_r^* = z_r^*(w, s)$, we can write the manufacturer's profit maximization problem as

$$\begin{aligned}\max_{w,s} E_{\varepsilon_m}\{\pi_m(w, s, q_r^*)\} &= y(p_r^*)\bigg\{(w-c)z_r^* - s\int_{1-L_m}^{G(L_m, z_r^*)}(z_r^*-x)f_{\varepsilon_m}(x)\,dx\bigg\} \\ &= y(p_r^*)\begin{cases}(w-c)\cdot z_r^*, & z_r^* < 1-L_m \\ \left\{(w-c)\cdot z_r^* - \dfrac{s[z_r^*-(1-L_m)]^2}{4L_m}\right\}, & 1-L_m \le z_r^* \le 1+L_m \\ (w-c)\cdot z_r^* - s\cdot(z_r^*-1), & z_r^* > 1+L_m, \end{cases}\end{aligned} \tag{18}$$

where $G(L_m, z_r^*)$ is similarly defined as Equation (14). The optimal wholesale price, return policy, and retail price can be obtained through a standard backward induction approach. However, because of the complexity of the profit function, closed-form expressions for these parameters do not exist in the general case. To attain an understanding of the behavior of $p_r^*(w, s)$ and $q_r^*(w, s)$, we therefore focus on the special case where $L_r = 1$, and we can derive analytical results.

Proposition 3. *Given w, and $L_r = 1$, the optimal retail price $p_r^*(w, s)$ is decreasing in the return policy s, and the optimal order quantity $q_r^*(w, s)$ is increasing in the return policy s.*

Proposition 3 asserts that for any given wholesale price, the manufacturer can offer a return policy to induce the retailer to charge a lower retail price and order more. Hence, when pricing is endogenous a return policy will stimulate larger retailer orders. The manufacturer will offer only a return policy that improves its expected profit (18). Similarly, the retailer will accept only a policy that improves its expected profit (17). This implies that by offering a return policy, the retailer's overestimation of demand volatility is reduced, and the expected profits for both firms are improved. Although we can demonstrate these relationships analytically only for $L_r = 1$, our numerical studies suggest that Proposition 2 holds for $L_r > L_m$. Padmanabhan and Png (1997) and Emmons and Gilbert (1998) show similar relationships under symmetric demand information. Consequently, our results demonstrate that a return policy helps to achieve information sharing under asymmetric information and continues to be an effective tool for channel coordination. Note, however that a return policy is generally not as efficient as other types of contracts, such as the profit-sharing contract and the two-part tariff (discussed in §5). The intuition is as follows. A return policy impacts the optimal wholesale price and retail price, thereby inducing the retailer to place a larger order. The distortion of the pricing decisions results in deadweight loss. By contrast, a profit-sharing contract achieves information sharing through a fixed fee, which is free from distortion and deadweight loss. However, the key advantage of the return policy is the ease of implementation, which probably explains the popularity of this type of policy in real-world practice.

5. A Two-Part Tariff Regime

In §4, we examined the value of information sharing and some contracts to facilitate sharing in an uncoordinated channel operating under a wholesale-price-only regime. We now turn to an alternative two-part tariff regime. Under a bilateral monopoly and symmetric information, it is well known (e.g., Locay and Rodriguez 1992, Raju and Zhang 2005) that the optimal two-part tariff is in the form of the manufacturer charging the retailer a fixed fee and a wholesale price at the marginal cost. A wholesale price at the marginal cost eliminates double marginalization and ensures maximum channel profits. The fixed fee serves to split the channel profits between the manufacturer and the retailer. Note that given asymmetric information about the demand volatility the firms have different perceptions of the expected channel profits. From the manufacturer's perspective the expected channel profit before information sharing is $E_{\varepsilon_m}\{\pi_r(z_m^*(c), p_m^*(c), c)\}$, and the fixed fee can be expressed as $\theta_m E_{\varepsilon_m}\{\pi_r(z_m^*(c), p_m^*(c), c)\}$, where $\theta_m \in (0, 1)$. Because the wholesale price is c, without the fixed fee the manufacturer's profit is zero. From the retailer's perspective the expected channel profit is $E_{\varepsilon_r}\{\pi_r(z_r^*(c), p_r^*(c), c)\}$ and the fixed fee is $\theta_r E_{\varepsilon_r}\{\pi_r(z_r^*(c), p_r^*(c), c)\}$, with $\theta_r \in (0, 1)$. The actual expected channel profit, unknown to the firms, is $E_\varepsilon\{\pi_r(z_r^*(c), p_r^*(c), c)\}$. To do business, the firms must agree on the fixed fee, i.e., $\theta_m E_{\varepsilon_m}\{\pi_r(z_m^*(c), p_m^*(c), c)\} = \theta_r E_{\varepsilon_r}\{\pi_r(z_r^*(c), p_r^*(c), c)\}$. Note that unless $L_r = L_m$, the negotiated fee constitutes different portions of the firms' perceived channel profits, i.e., $\theta_m \neq \theta_r$. The size of the fee clearly depends on the firms' bargaining power, which can be influenced by the quality of the demand information and knowledge thereof, i.e., which firm has the superior demand estimate and which knows about this. However, as we asserted in §4, a detailed treatment of bargaining is beyond the scope of this paper.

Clearly, a two-part tariff coordinates the channel when the manufacturer and the retailer have symmetric information (i.e., $L_r = L_m$ and $\theta_m = \theta_r$). This is because the wholesale price is set to the marginal cost and the manufacturer derives his profit solely from the fixed fee, which is a portion of the retailer's expected profit. As a result, maximizing the retailer's expected profit amounts to maximizing the expected channel profits. In the absence of information asymmetry, the manufacturer concurs with the retailer's perceived expected profit. Thus, there is no disagreement about the portion of the channel profits that constitute the fixed fee.

As under the wholesale price regime in §4, a fundamental question under a two-part tariff regime with asymmetric information about demand volatility is the potential for information sharing to improve expected channel profits, and the impact of that on the firms' individual profits. Noting that the expected channel profit equals the retailer's expected profit, it follows that information sharing as defined in this paper affects the channel profit only when the manufacturer's estimate L_m is superior. To assess the value of information sharing, we therefore follow the approach in §4 and compare the situation of no information sharing with that of perfect information sharing, where both firms use the superior estimate $L_m = L$.

Lemma 5. *Under a two-part tariff, perfect information sharing always improves the expected channel profits.*

Without information sharing, the expected channel profit is equivalent to the retailer's actual expected profit $E_\varepsilon\{\pi_r(z_r^*(c), p_r^*(c), c)\}$, where the pricing and order decisions are based on the retailer's demand estimate, L_r. Consistent with Proposition 1, both overestimation and underestimation of the demand volatility are detrimental to the retailer's actual expected profit and therefore also to the channel. When the manufacturer shares its superior demand information L_m with the retailer, the expected channel profit increases and creates an opportunity for both firms to be better off than before. It is not clear, however, whether a two-part tariff suffices to achieve information sharing when the manufacturer and the retailer have different demand estimates, which is the case in our model. We therefore need to further examine when (if ever) a two-part tariff coordinates the channel under asymmetric demand information. We address these issues next, for each option in our information sharing taxonomy outlined in Table 1.

Proposition 4. (i) *If the quality of the demand volatility estimates is private information, a two-part tariff achieves information sharing and coordinates the channel in Scenario* 1b *and Scenario* 2a; *in Scenario* 1a, *Scenario* 2b, *and Scenario* 3, *it does not achieve information sharing, but it may coordinate the channel if there is no dispute about the fixed fee*. (ii) *If the quality of the estimates of demand volatility is common knowledge, a two-part tariff achieves information sharing and coordinates the channel when combined with a profit-sharing contract*.

When firms have asymmetric demand estimates, a two-part tariff does not always achieve information sharing and fails to coordinate the channel under certain conditions. This is in contrast to the situation under symmetric information, where a two-part tariff always coordinates the channel. The intuitions are as follows. When each firm has its own demand estimate, it also has an asymmetric estimate of the total channel profits, and this can lead to disagreement on the amount of fixed fee. When the quality of the demand estimates is private information, a two-part tariff by itself cannot resolve such dispute.

Under a two-part tariff, the incentive problem in a profit-sharing contract is relatively simple. Because information sharing always improves the expected channel profits, the firms need only to negotiate an agreement on how to split the benefits from information sharing. However, a profit-sharing contract is feasible only when the quality of demand estimates is common knowledge. It is interesting to compare the properties of a two-part tariff with those of a profit-sharing contract. A two-part tariff is strictly an ex ante contract; both the wholesale price and the fixed fee are set before the demand realization. By contrast, a profit-sharing contract has both ex ante and ex post components. Although the terms of the contracts are determined before the demand realization, the execution of the contract occurs after the demand realization. Therefore, a two-part tariff is risk free to the manufacturer, whereas a profit-sharing contract leads to risk sharing between the manufacturer and the retailer.

6. Conclusion

As Padmanabhan and Png (1997, p. 82) eloquently put it, "one of the few certainties about the demand for products such as new books, CDs, software, fashion wear, and winter clothing is that it is uncertain." Fortunately, many of the results from the extant channel literature remain robust with or without demand uncertainty. However, important questions arise when firms in a distribution channel face asymmetric demand uncertainty: Should this information be shared, what is the value of sharing, and how can sharing be accomplished?

In this paper, we provide insights into some of these issues. Rather than looking at uncertainty about demand level, we focus on firms' asymmetric information on demand volatility. We consider a situation with price-dependent multiplicative demand uncertainty where firms are correct in estimating the average demand, but they might miscalculate the extent of demand volatility. In addition, our setup assumes that firms cannot refine their demand estimates using historical data and that the correlation between the firms' demand estimates is unknown. Thus, our setup might apply to one-shot, highly volatile settings, where firms engage in short-term relationships.

Within this context, the value of information sharing stems from the fact that one member of the distribution channel could have a superior estimate of the demand volatility compared to the other member. However, the firms might not have the same information on whose demand estimate is superior. This asymmetric information on the quality of the demand estimates further complicates information sharing. Within the confines of our modeling framework, we demonstrate that demand volatility can have substantial impact on retail price, order quantity, and the firms' profits. Although information sharing always improves channel profits in a coordinated channel, it is not necessarily so if the channel is uncoordinated because of asymmetric demand information. Depending on the specific information structure, there are different strategies and contracts that firms can use to facilitate information sharing. Two prominent examples that we consider in this work are profit-sharing contracts and return policies.

Our model could be extended in several directions. In this paper, we consider a channel of bilateral monopoly in a single-period setting, it is interesting to investigate how upstream and downstream competition moderate information sharing; it is also interesting to use a signaling framework to examine information sharing in a multiperiod setting.[5] Although pricing is a decision variable in our model, we do not consider retail promotion. An important form of uncertainty not covered in the paper is the uncertainty stemming from lead-time constraint and capacity constraint. It would also be interesting to investigate the impact of using other types of demand models, additive demand uncertainty, alternative distributions, etc.[6] Finally, many alternative contracts, such as quantity discount contracts, are good candidates for achieving information sharing. We leave these issues to future research.

Appendix. Proofs of Propositions

Proof of Proposition 1. (i) When the manufacturer only charges a wholesale price, the manufacturer's expected profit is given by $\pi_M(z_m^*, p_m^*, w) = (w-c)q_r^*$; hence, the sign of $\partial\pi_M(z_m^*, p_m^*, w)/\partial L_r$ is determined by $\partial q_r^*(w)/\partial L_r$. It follows from Lemma 3 that the manufacturer's expected profit is strictly decreasing for all L_r.

To show that the retailer's perceived expected profit, $E_{\varepsilon_r}\{\pi_r(z_r^*(w_m^*), p_r^*(w_m^*), w_m^*)\}$, is decreasing in L_r, we consider its derivative with respect to L_r. For notational convenience, let $H = H(b, L_r)$, $H' = \partial H(b, L_r)/\partial L_r$, $p_r^* = p_r^*(w_m^*)$, $y = y(p_r^*(w_m^*))$, $y' = \partial y(p_r^*(w_m^*))/\partial L_r$

$$\frac{\partial E_{\varepsilon_r}\{\pi_r(z_r^*(w_m^*), p_r^*(w_m^*), w_m^*)\}}{\partial L_r}$$
$$= \frac{\partial y(p_r^*(w_m^*))\{(p_r^*(w_m^*) - w_m^*)[1 - L_r(w_m^*/p_r^*(w_m^*))]\}}{\partial L_r}$$
$$= y'\left\{(p_r^* - w_m^*)\left[1 - L_r\frac{w_m^*}{p_r^*}\right]\right\} + y\left[1 - L_r\frac{w_m^*}{p_r^*}\right]p'$$
$$- (p_r^* - w_m^*)\left[\frac{w_m^*}{p_r^*} + L_r\frac{\partial}{\partial L_r}\left(\frac{w_m^*}{p_r^*}\right)\right]$$

[5] See Mayzlin (2006) for a recent example that deals with information exchange among consumers in a multiperiod setting.

[6] Lee and Staelin (1997) and Sudhir (2001) show that the functional forms of demand may impact the behavior of certain strategic variables.

$$= y'\left[w_m^*(H-1)\left(1-\frac{L_r}{H}\right)\right]$$

$$+y\left\{w_m^* H'\left(1-\frac{L_r}{H}\right)-w_m^*(H-1)\left[\frac{1}{H}+L_r\frac{\partial}{\partial L_r}\left(\frac{1}{H}\right)\right]\right\}$$

$$= w_m^* y\left\{\frac{-bH'(H-1)[H-L_r]+H'H[H-L_r]-(H-1)[H-L_rH']}{H^2}\right\}$$

$$= w_m^* y\left\{\frac{H'[-bH^2+bHL_r+bH-bL_r+H^2-L_r]-H^2+H}{H^2}\right\}$$

$$= -w_m^*\left(\frac{H-1}{H}\right)y.$$

Clearly, $E_{\varepsilon_r}\{\pi_r(z_r^*(w_m^*), p_r^*(w_m^*), w_m^*)\}$ is decreasing in L_r because from Lemma 1 we know that $H>1$.

(ii) Let $p^*(w_m^*)$ and $z^*(w_m^*)$ denote the retail price and mean-adjusted order quantity, which are optimal under the true demand uncertainty ε. Suppose that $E_\varepsilon\{\pi_r(z_r^*(w_m^*), p_r^*(w_m^*), w_m^*)\} \ge E_\varepsilon\{\pi_r(z^*(w_m^*), p^*(w_m^*), w_m^*)\}$ for some $L_r \ne L$. This implies, however, that $p^*(w_m^*)$ and $z^*(w_m^*)$ are not optimal for the true state L, which is a contradiction.

(iii) This result follows directly from (i) when $L_r = L$ and the perceived expected profit coincides with the actual expected profit. □

Proof of Proposition 2. Denote the gain in expected manufacturer, retailer, and channel profits due to perfect information sharing, $\Delta\pi_r = E_{\varepsilon_m}\{\pi_r(z_m^*(w_m^*), p_m^*(w_m^*), w_m^*)\} - E_{\varepsilon_m}\{\pi_r(z_r^*(w_m^*), p_r^*(w_m^*), w_m^*)\}$, $\Delta\pi_m = \pi_m(z_m^*(w_m^*), p_m^*(w_m^*), w_m^*) - \pi_m(z_r^*(w_m^*), p_r^*(w_m^*), w_m^*)$, and $\Delta\Pi = \Delta\pi_m + \Delta\pi_r$, respectively. It follows from Proposition 1(i) that $\Delta\pi_m \ge 0$ for $\delta \ge 0$ and $\Delta\pi_m < 0$ for $\delta < 0$. Furthermore, because $L_m = L$, Proposition 1(ii) asserts that $\Delta\pi_r \ge 0$ for all δ such that $0 \le L_m + \delta \le 1$. Hence, it is clear that information sharing always improves channel profits when the retailer overestimates the demand variability, i.e., $\Delta\Pi > 0$ for $\delta \ge 0$. To prove that information sharing may either decrease or increase channel profits when $\delta < 0$, we show that the sign of $\Delta\Pi$ is ambiguous. For notational simplicity we use $z_i^* = z_i^*(w_m^*)$ and $p_i^* = p_i^*(w_m^*)$ for $i = m, r$.

When $\delta < 0$ it follows that $1 - L_m \le z_r^* \le 1 + L_m$, and by definition $1 - L_m \le z_m^* \le 1 + L_m$. We get

$$E_{\varepsilon_m}\{\pi_r(z_r^*, p_r^*, w_m^*)\}$$
$$= y(p_r^*)\left\{(p_r^* - w_m^*) - w_m^*\int_{1-L_m}^{z_r^*}(z_r^* - x)f_m(x)\,dx - (p_r^* - w_m^*)\int_{z_r^*}^{1+L_m}(x - z_r^*)f_m(x)\,dx\right\}$$
$$= c^{-b+1}y\left(\frac{b^2H(b,L_m+\delta)}{(b-1)^2}\right)\left(\frac{b}{b-1}\right)\left\{\left(\frac{bH(b,L_m+\delta)}{b-1}-1\right)\cdot\left(1-\frac{(1+L_m-z_r^*)^2}{4L_m}\right)-\frac{(z_r^*-1+L_m)^2}{4L_m}\right\},$$

and

$$E_{\varepsilon_m}\{\pi_r(z_m^*, p_m^*, w_m^*)\}$$
$$= c^{-b+1}y\left(\frac{b^2H(b,L_m)}{(b-1)^2}\right)\left(\frac{b}{b-1}\right)\cdot\left\{\left(\frac{bH(b,L_m)}{b-1}-1\right)\left(1-\frac{(1+L_m-z_m^*)^2}{4L_m}\right)-\frac{(z_m^*-1+L_m)^2}{4L_m}\right\}.$$

Recall that $\varepsilon_m \in U[1-L_m, 1+L_m]$, $y(p) = ap^{-b}$, $w_m^* = c(b/(b-1))$, $p_r^* = w_m^*(b/(b-1))H(b, L_m+\delta)$, and $p_m^* = w_m^*(b/(b-1))H(b, L_m)$. Similarly,

$$\pi_m(z_r^*, p_r^*, w_m^*) = c^{-b+1}y\left(\frac{b^2H(b,L_m+\delta)}{(b-1)^2}\right)\left(\frac{1}{b-1}\right)z_r^*,$$

and

$$\pi_m(z_m^*, p_m^*, w_m^*) = c^{-b+1}y\left(\frac{b^2H(b,L_m)}{(b-1)^2}\right)\left(\frac{1}{b-1}\right)z_m^*.$$

Let the expected channel profit with and without perfect information sharing be $\Pi(z_m^*, p_m^*, w_m^*)$ and $\Pi(z_r^*, p_r^*, w_m^*)$, where

$$\Pi(z_i^*, p_i^*, w_m^*) = \pi_m(z_i^*, p_i^*, w_m^*) + E_{\varepsilon_m}\{\pi_r(z_i^*, p_i^*, w_m^*)\}.$$

Starting from the expressions for the expected manufacturer's and retailer's profits above, simplified expressions for the channel profits can be derived, omitting the algebraic details we get (note that z_r^* and z_m^* are given by (9))

$$\Pi(z_m^*, p_m^*, w_m^*) = c^{-b+1}y\left(\frac{b^2H(b,L_m)}{(b-1)^2}\right)\left(\frac{b-1}{bH(b,L_m)}\right)\Omega(L_m,0,b),$$

and

$$\Pi(z_r^*, p_r^*, w_m^*)$$
$$= c^{-b+1}y\left(\frac{b^2H(b,L_m+\delta)}{(b-1)^2}\right)\left(\frac{b-1}{bH(b,L_m+\delta)}\right)\cdot\left[\Omega(L_m,\delta,b)+\frac{\widehat{H}(L_m,\delta,b)}{b-1}\left(1-\frac{b\widehat{H}(L_m,\delta,b)}{4L_m}\right)\right],$$

where $\widehat{H}(b, L_m, \delta) = \delta(bH(b, L_m+\delta)/(b-1) - 2)$, and

$$\Omega(b,L_m,\delta) = \frac{b}{b-1}\left(\frac{b^2H(b,L_m+\delta)^2}{(b-1)^2}-L_m\right) - \left(\frac{b(1+L_m)H(b,L_m+\delta)}{(b-1)}-2L_m\right).$$

The condition $\Delta\Pi = \Pi(z_m^*, p_m^*, w_m^*) - \Pi(z_r^*, p_r^*, w_r^*) \ge 0$ can now be simplified into (ISC), which holds if and only if $\Delta\Pi \ge 0$. (Note that by definition $\Pi(z_m^*, p_m^*, w_m^*) \ge 0$.)

$$\frac{\Omega(L_m,\delta,b)+(\widehat{H}(b,L_m,\delta)/(b-1))(1-b\widehat{H}(b,L_m,\delta)/4L_m)}{\Omega(L_m,0,b)}\cdot\left(\frac{H(b,L_m)}{H(b,L_m+\delta)}\right)^{b+1}\le 1. \tag{ISC}$$

It follows that the sign of the expected gain in channel profits $\Delta\Pi$ is a function of b, L_m, and δ, but independent of c and a. By example, it is easy to show that condition (ISC) might or might not be satisfied for $\delta < 0$. For example, if $b = 2$ and $L_m = 1$, (ISC) is satisfied (i.e., $\Delta\Pi \ge 0$) for all possible δ $(-1 < \delta < 0)$. On the other hand, for $b = 1.05$, $L_m = 1$, (ISC) is not satisfied for any relevant δ $(-1 < \delta < 0)$, i.e., $\Delta\Pi < 0$. Finally, if $b = 1.5$ and $L_m = 1$, (ISC) is satisfied for $-0.48 \le \delta < 0$, but not satisfied for $-1 < \delta \le -0.49$. □

Proof of Proposition 3. Given w, s, and $L_r = 1$, we determine a solution to the maximization problem (17) using the first-order optimality conditions. First, the partial derivative of $E_{\varepsilon_r}\{\pi_r(z, p, w, s)\}$ with respect to z renders the optimal mean-adjusted order quantity for any given retail price $p \ge w$: $z_r^*(p, w, s) = 1 + ((p+s)/(p-s))L_r - 2wL_r/(p-s)$. Substituting this expression back into the retailer's profit function and solving for p using the first-order optimality condition we obtain the optimal retail price as a function of w and s

$$p_r^*(w, s) = \frac{1}{2(b-1)}[(b+1)w + (b-2)s + A],$$

where

$$A = \sqrt{(b+1)^2w^2 + (b-2)^2s^2 - (2b^2 - 2b + 4)ws}.$$

Under the necessary condition $p_r^*(w, s) \ge w \ge s$, it is possible to show that A is real for all $b > 1$ and that the solution is unique. Omitting the algebraic details, it is straightforward to show that

$$\frac{\partial p_r^*(w, s)}{\partial s} = \frac{(b-2)A + (b-2)^2 s - (b^2 - b + 2)w}{2A(b-1)} \le 0$$

for all $b > 1$ and $w \ge s$.

Similarly, for the mean-adjusted order quantity $z_r^*(w, s)$ (obtained by substituting $p_r^*(w, s)$ into the expression for $z_r^*(p, w, s)$), it can be shown that after defining $g = (b+1)w - bs + A$,

$$\frac{\partial z_r^*(w, s)}{\partial s} = 4(b-1)\left[\frac{A + 3(b+1)w - (3b-2)s}{g^2 A}\right] \ge 0$$

for all $b \ge 1$ and $w \ge s$.

We also have

$$\frac{\partial y(p_r^*(w, s))}{\partial s} = y(p_r^*(w, s))\left(-\frac{b}{p_r^*(w, s)}\right)\frac{\partial p_r^*(w, s)}{\partial s} \ge 0,$$

where the last inequality is a consequence of the result that $\partial p_r^*(w, s)/\partial s \le 0$. Because $z_r^*(w, s) \ge 0$ and $p_r^*(w, s) \ge 0$, it follows that

$$\begin{aligned}\frac{\partial q_r^*(w, s)}{\partial s} &= \frac{\partial}{\partial s}[z_r^*(w, s) y(p_r^*(w, s))] \\ &= y(p_r^*(w, s))\left[\frac{\partial z_r^*(w, s)}{\partial s} - \frac{b z_r^*(w, s)}{p_r^*(w, s)}\frac{\partial p_r^*(w, s)}{\partial s}\right] \ge 0\end{aligned}$$

for $b \ge 1$ and $w \ge s$. □

Proof of Proposition 4. Under a two-part tariff and symmetric demand estimates (i.e., $\varepsilon_r = \varepsilon_m$), the manufacturer's profit is given by $\theta E_{\varepsilon_r}\{\pi_r(z_r^*(c), p_r^*(c), c)\}$, where $\theta \in (0, 1)$ is determined by the bargaining power of the manufacturer. We first consider the situation where the quality of the demand estimates is private information.

Scenario 1. The manufacturer knows whose estimate is superior, but the retailer does not:

(a) If the manufacturer's estimate is superior, it would expect a higher fixed fee if it reveals it to the retailer, because by using it the retailer can increase the expected channel profits. However, the retailer has no knowledge of the quality of the demand estimates, and therefore has no reason to abandon its own estimate and use the manufacturer's instead. Because the manufacturer has no means to convince the manufacturer to use its superior estimate without reducing the fixed fee, and thereby lower its own profit, a two-part tariff by itself does not achieve information sharing. Even if the firms use their own demand estimates a two-part tariff may still coordinate the chain. An agreement can be reached if the smallest fee that the manufacturer is willing to accept is $\theta_m E_{\varepsilon_m}\{\pi_r(z_m^*(c), p_m^*(c), c)\}$, and this amount is lower than $\theta \cdot E_{\varepsilon_r}\{\pi_r(z_r^*(c), p_r^*(c), c)\}$.

(b) If the retailer's estimate is superior, the manufacturer simply accepts that, and both firms negotiate a fixed fee of $\theta \cdot E_{\varepsilon_r}\{\pi_r(z_r^*(c), p_r^*(c), c)\}$ based on the best available estimate of the expected channel profits. In doing so, information sharing occurs and the two firms share the benefits of the superior information.

Scenario 2. The retailer knows whose information is superior, but the manufacturer does not:

(a) If the manufacturer's estimate is superior, the retailer simply agrees to use that estimate and negotiate a fixed fee of $\theta \cdot E_{\varepsilon_m}\{\pi_r(z_m^*(c), p_m^*(c), c)\}$ based on the best available estimate of the expected channel profits. In doing so, information sharing occurs, and the two firms share the benefits of the superior information.

(b) If the retailer's estimate is superior, the retailer agrees to pay a fixed fee of no more than $\theta \cdot E_{\varepsilon_r}\{\pi_r(z_r^*(c), p_r^*(c), c)\}$, but it has no means to convince the manufacturer that its information renders the best available estimate of the channel profits. The manufacturer therefore uses its own demand estimate to determine the expected channel profit as a basis for negotiating the fixed fee. An agreement can be reached if the smallest fee that the manufacturer is willing to accept is $\theta_m E_{\varepsilon_m}\{\pi_r(z_m^*(c), p_m^*(c), c)\}$ and this amount is lower than $\theta \cdot E_{\varepsilon_r}\{\pi_r(z_r^*(c), p_r^*(c), c)\}$, but no information sharing occurs.

Scenario 3. Neither firm knows whose information is superior:

The firms can reach an agreement on the fixed fee if

$$\theta_m E_{\varepsilon_m}\{\pi_r(z_m^*(c), p_m^*(c), c)\} \le \theta_r E_{\varepsilon_r}\{\pi_r(z_r^*(c), p_r^*(c), c)\},$$

but not otherwise, because each firm has its own demand estimate and there is no incentive for either firm to accept the other firm's proposal that is perceived to make itself worse off. In either case, information sharing does not occur because neither firm has any incentive to abandon its own estimate.

When the quality of the demand estimates is common knowledge, the two firms can negotiate a profit-sharing contract to achieve information sharing, as outlined in §3.2.1. In doing so, the channel is coordinated. □

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