Information Sharing in a Supply Chain with a Common Retailer

Weixin Shang
School of Management, Fudan University, shangwx@ust.hk
Albert Y. Ha
School of Business and Management, The Hong Kong University of Science and Technology, imayha@ust.hk
Shilu Tong
Australian School of Business, The University of New South Wales, tongsl@ust.hk

July 2011

We consider the problem of sharing retailer's demand information in a supply chain with two competing manufacturers selling substitutable products through a common retailer. We examine several scenarios with either the retailer or the manufacturers as leaders in offering information (sharing) contracts. We show that a larger production diseconomy or higher competition intensity induces more information sharing. The retailer may benefit from a larger production diseconomy, which is not possible without information contracting. Information contracting always benefits the retailer, and the benefit is larger when she offers contracts sequentially rather than simultaneously to the manufacturers. Information contracting benefits the manufacturers only when they offer the contracts and production diseconomy is large. When either demand uncertainty or production diseconomy is large, the retailer invests more in improving information accuracy. When competition is more intense, she invests more except under some conditions that we fully characterize.

1. Introduction

With the advance of information technology, retailers routinely and efficiently acquire rich market data to obtain information about product demand. Many large retailers have started sharing such information with their suppliers to improve collaboration. One example is the ConsumerInsight for Wal-Mart program offered by SymphonyIRI, a company specialized in market intelligence services. Under this program, Wal-Mart and its selected suppliers have access to the same set of consumer and category information based on the market data collected by the retailer. Similarly, Costco and 7-Eleven offer data-sharing programs to some of their suppliers through SymphonyIRI. Under the

CRX data sharing program, Costco maintains a centralized POS (point-of-sale) data base, which covers several food and consumer packaged goods categories, for all its stores. A supplier who wants to participate in the program needs to be first approved by Costco. An approved supplier can then get access to selected data (such as the total sales of a product category) by paying an annual subscription fee[1].

It is well known that information sharing can improve supply chain efficiency. However, firms do not always have incentive to share information with their partners because of the concern that these partners may abuse the information and use it for their own benefits, for instance, in price negotiations. For fee-based data sharing programs, firms may not want to participate if the fee is too high. What is the incentive for manufacturers to participate in data sharing programs offered by a dominant retailer? How does that incentive depend on the competition between the manufacturers? What about the case when the manufacturers instead of the retailer offer contracts for information sharing? How do information (sharing) contracts affect a retailer's investment in improving information accuracy? We hope to shed light on these questions.

We consider the problem of sharing retailer's demand information in a supply chain with two competing manufacturers selling substitutable products through a common retailer. The manufacturers face production diseconomy, i.e., the marginal cost is increasing in production quantity. Before observing a private demand signal, the retailer contracts with the manufacturers on sharing this information. We formulate a multistage game to study the firms' information sharing, wholesale price and retail price decisions. We consider three different versions of the multistage game to study the effect of information contracting leadership. In Model RSC (*Retailer Stackelberg with concurrent offers*), the retailer makes concurrent and identical offers of selling information for a fixed payment to the manufacturers. In Model RSS (*Retailer Stackelberg with sequential offers*), the retailer makes sequential offers of selling information for a fixed payment to the first manufacturer, then to the second manufacturer after the first manufacturer's decision of whether accepting

[1] For the details of the data sharing programs offered through SymphonyIRI, see http://www.symphonyiri.com.

the offer becomes public information. In Model MS (*Manufacturer Stackelberg*), the manufacturers simultaneously offer fixed payments for buying information from the retailer.

Models RSC and RSS are motivated by the data sharing programs offered by retailers to manufacturers, where a manufacturer typically has to pay a fixed fee for participation[2]. Model RSS corresponds to the case when a retailer can adopt an approval process to offer the program sequentially to different manufacturers (as in the CRX example) and whether a manufacturer participates in the program is publicly known (e.g., through industry channels or public media). Model RSC corresponds to the case when a retailer cannot offer the program sequentially or whether a manufacturer participates in the program is not publicly known. Model MS serves a benchmark to investigate the impact of contracting leadership when the manufacturers are the leaders in information contracting. We solve these information contracting models to obtain the following insights.

1. Without information contracting, the retailer does not have incentive to share information. With information contracting, a larger production diseconomy or higher competition intensity induces more information sharing. This is because (a) information sharing lowers production cost by reducing the variability of the production quantity, and the cost saving becomes more significant when production diseconomy is larger; (b) information sharing makes the double marginalization effect of linear wholesale price more damaging, but more intense competition between the manufacturers may suppress the double marginalization effect.

2. Without information contracting, a larger production diseconomy increases production costs and softens manufacturers' competition in their wholesale prices. Because both effects hurt the retailer, she is always worse off. With information contracting, however, a larger production diseconomy makes information sharing more valuable. Because of this and the competition between the manufacturers, the retailer can benefit by either selling information to more manufacturers or charging a higher payment for the information.

[2] We assume that a retailer offers the program either on her own or through a third-party service provider who takes an insignificant portion of the fixed fee for the service.

3. Information contracting benefits the retailer because she can refuse to sell information otherwise. Information contracting benefits the manufacturers only when they are the leaders in offering the contracts and production diseconomy is large. Although partial information sharing (i.e., the retailer sells information to only one manufacturer) does not maximize supply chain profit, it may occur in equilibrium when production diseconomy takes some intermediate values. In these cases, the manufacturers are willing to pay more to be the only informed manufacturer who then has a competitive advantage over the other manufacturer. Partial information sharing may allow the retailer to extract more profit from the manufacturers, sometimes at the expense of the overall supply chain efficiency.

4. With information contracting, the retailer prefers to be the leader and to offer the contracts sequentially because this allows her to extract more profit from the manufacturers. When production diseconomy is not large, the manufacturers prefer to have the retailer as the leader offering contracts concurrently. When production diseconomy is large and both manufacturers buy information in equilibrium, they prefer to be the leaders in offering information contracts. In this case, each manufacturer only needs to pay the retailer for her incremental loss due to disclosing information and they can keep the remaining surplus.

5. When the retailer can invest in improving information accuracy, she will invest more if either demand uncertainty or production diseconomy is large. If competition becomes more intense, she will invest more except when (a) the manufacturers are the leaders in information contracting, (b) full information sharing is the equilibrium[3] and (c) production diseconomy is small.

For each of the three information contracting models (i.e., RSC, RSS and MS), we repeat our analysis by assuming that wholesale prices and retail prices are determined simultaneously under Vertical Nash (Jeuland and Shugan 1983, Choi 1991). This is the case when the manufacturers and the retailer have similar power in determining wholesale prices. All the main insights listed above (that are based on the assumption of manufacturers' leadership in offering wholesale prices)

[3] In our model, the equilibrium information sharing decision (i.e., the number of manufacturers who buy information from the retailer) does not depend on information accuracy though the firms' profits do.

remain valid for the case of Vertical Nash. The only exception is that for Model RSS and Model MS, when competition intensity is low and production diseconomy takes some intermediate values, an increase in competition intensity can induce less information sharing[4].

This paper is most related to the literature on incentive for vertical information sharing under different supply chain structures. Most of the papers in the literature consider information sharing in a supply chain with one manufacturer selling to several competing retailers. The focus of this stream of work is on the incentive for the retailers to share demand information with the manufacturer (Li 2002, Li and Zhang 2002, Zhang 2002) and how that incentive depends on confidentiality (Li and Zhang 2008) and the product buy-sell contracts (Shin and Tunca 2010, Tang and Girotra 2010). Several papers consider information sharing in a one-to-one supply chain and investigate issues such as signaling unverifiable information (Cachon and Lariviere 2001), dual distribution channels (Yue and Liu 2006) and bilateral information sharing (Mishra et al. 2009). Ha and Tong (2008) and Ha et al. (2011) study information sharing in two competing supply chains. Zhang (2006) examines the issue of sharing inventory information among suppliers who produce different components for a manufacturer in a two-echelon assembly system. Özer et al. (2011) consider the role of trust in information sharing between a supplier and a manufacturer. Zhao et al. (2011) study the issue of information sharing in outsourcing. To the best of our knowledge, our paper is the first that considers information sharing in a supply chain with competing manufacturers selling through a common retailer. Such a supply chain structure leads to a richer set of information contracting issues that have not been explored in the literature.

Although both Ha et al. (2011) and this paper examine the impact of production diseconomy on information sharing, most of the results are quite different because of the different supply chain structures considered. For example, Ha et al. (2011) show that when two supply chains compete at the retailer level and the manufacturers are leaders in information contracting, more intense

[4] For the case of Vertical Nash, it remains true that more intense competition induces more information sharing when at least one of the two conditions does not hold.

competition induces less information sharing and the retailers cannot benefit from a larger production diseconomy. In this paper, we show that more intense competition at the manufacturer level induces more information sharing and the common retailer may benefit from a larger production diseconomy. The two papers also differ in their focus. Ha et al. (2011) mainly consider the drivers of the incentive for information sharing while the issue of information contracting between a manufacturer and a retailer is relatively straightforward. In this paper, with a common retailer contracting on information sharing with two competing manufacturers, we show that the information contracting decisions depend strongly on leadership (who offers the contract) and contracting sequence (concurrent versus sequential offers).

In economics, there is a related literature on information sharing in an oligopoly. See, for example, Vives (1984), Gal-Or (1985) and Li (1985). This body of research focuses on the incentive for a firm to share information with its competitors in an oligopoly and it does not consider interaction between firms in a vertical chain.

Our paper is also related to the literature on supply chain coordination and competition when there are multiple manufacturers selling through a common retailer. Choi (1991) and Lee and Staelin (1997) consider channel competition under linear wholesale price contracts. More recently, Cachon and Kök (2010) study the impact of other contract forms (quantity discount and two-part pricing) on channel competition and coordination. See Cachon and Kök (2010) for a detailed discussion of this literature. None of the papers in this literature considers the issue of information sharing, which is the focus of this paper.

2. The Basic Model

Consider a supply chain with two identical manufacturers (indexed by 1 or 2) selling substitutable products through a common retailer. The demand function of product i is given by:

$$q_i = a + \theta - \frac{1}{1-\gamma}p_i + \frac{\gamma}{1-\gamma}p_j,$$

where p_i is the retail price of product i, $\gamma \in (0,1)$ is a parameter for competition intensity (larger γ means more intense competition), and the random variable θ, with zero mean and variance σ^2, represents demand uncertainty.

The retailer has a constant marginal retailing cost, which is normalized to zero. Production exhibits diseconomy, i.e., marginal production cost is increasing in volume, due to limited capacity or input. The production cost[5] incurred by manufacturer i for producing q units of product i is given by cq^2, where a larger c corresponds to a greater production diseconomy. See Ha et al. (2011) for examples of production diseconomy in practice and justification of the quadratic production cost function. The cost structure is common knowledge.

The retailer has access to a demand signal Y, which is an unbiased estimator of θ. We assume a linear-expectation information structure: the expectation of θ conditional on signal Y is a linear function of the signal. This information structure includes well-known conjugate pairs like normal-normal, beta-binomial, and gamma-Poisson. Define the signal accuracy as $t = 1/E[Var[Y|\theta]]$. It can be shown (Ericson 1969) that $E[\theta|Y]$ is a weighted average of the prior mean $E[\theta]$ and the signal Y :

$$E[\theta|Y] = \frac{1}{1+t\sigma^2}E[\theta] + \frac{t\sigma^2}{1+t\sigma^2}Y = \beta(t,\sigma)Y,$$

where $E[\theta] = 0$ as assumed earlier and $\beta(t,\sigma) = t\sigma^2/(1+t\sigma^2)$ is the weight for the signal Y. Note that $\beta(t,\sigma)$ is larger when the signal becomes more accurate (larger t). The information structure is common knowledge. For more details of the linear-expectation information structure, refer to Vives (1999, §2.7.2).

We consider three multistage games, labelled as Model RSC (*Retailer Stackelberg with concurrent offers*), Model RSS (*Retailer Stackelberg with sequential offers*) and Model MS (*Manufacturer Stackelberg*), with different assumptions on how the firms contract on information sharing. The sequence of events for any of these models is given below.

1. Before the retailer observes any demand signal, the retailer and the manufacturers contract on information sharing. In Model RSC, the retailer makes concurrent and identical offers to the manufacturers by charging each a side payment T for the information. In Model RSS, the retailer

[5] A more general production cost function is $bq + cq^2$. We can normalize b to zero by redefining $a' = a - b$ as the demand intercept in the linear demand function and all the main results will remain valid.

makes sequential offers by charging the first manufacturer a fixed payment T_f for the information, then charging the second manufacturer a payment T_s. In Model MS, the manufacturers simultaneously offer side payments T_1 and T_2 (where T_i is from manufacturer i) for buying information from the retailer.

2. The retailer observes a demand signal Y and truthfully discloses it to a manufacturer if an information sharing contract has been signed in the previous stage. A manufacturer who receives the demand signal is said to be *informed*. Otherwise he is said to be *uninformed*. Let $X_i = S$ if manufacturer i is informed (i.e., retailer shares information with him) and $X_i = N$ if he is uninformed. Let n be the number of informed manufacturers, where $n = 0, 1$, or 2.

3. Each manufacturer i determines his wholesale price w_i, and then the retailer determines retail prices p_1 and p_2.

4. Market demands q_1 and q_2 realize, each manufacturer i supplies q_i to the retailer and finally firms receive their payoffs[6].

The three models differ only in the information contracting stage (first event in the sequence), after which they are identical. In Section 4, we will provide more details about how the firms make information contracting decisions under each model.

In our models, information sharing contracts are long-term while wholesale prices are short-term decisions. This is because if firms agree to share information, they have to set up systems for information transmission. After that, they may engage in product buy-sell contracting over multiple product generations. Therefore the manufacturers and the retailer do not negotiate information sharing contracts and wholesale price contracts simultaneously. The demand signal can be interpreted as information about a product's potential demand that can be derived from either past sales data of similar products or consumer data collected by the retailer. The firms use such information, if available, to determine the wholesale and retail prices of the product. For each model, we solve it backward by first solving for the equilibrium wholesale and retail prices, and based

[6] We can show that, when σ and c are small relative to a, it is optimal for manufacturer i, with a probability very close to one, to fully meet the retailer's order.

on these, compute the ex-ante profits of the firms under different information sharing agreements. The ex-ante profits are then used to solve for the equilibrium information contracting decisions in the first stage.

3. Wholesale and Retail Price Decisions

In this section, we solve for the equilibrium wholesale and retail pricing decisions for any given set of information sharing decisions (X_1, X_2). The analysis here is the same for all the three contracting models. This is because these models differ only in how information contracting decisions are made. If the firms have committed on the same set of information sharing decisions, the side payments (that may differ under different models) won't have any impact on their subsequent pricing decisions.

3.1. Equilibrium Analysis

Suppose a set of information sharing decisions (X_1, X_2) is given. Knowing the wholesale prices w_1 and w_2 as well as the demand signal Y, the retailer chooses p_1 and p_2 to maximize her expected profit

$$(p_1 - w_1)\left(a + E[\theta|Y] - \frac{1}{1-\gamma}p_1 + \frac{\gamma}{1-\gamma}p_2\right) + (p_2 - w_2)\left(a + E[\theta|Y] - \frac{1}{1-\gamma}p_2 + \frac{\gamma}{1-\gamma}p_1\right),$$

where $E[\theta|Y] = \beta(t,\sigma)Y$. The retailer's best-response retail price is

$$\hat{p}_i(w_i, w_j) = \frac{1}{2}\left(a + \beta(t,\sigma)Y + w_i\right),$$

and the resulting sales is

$$q_i(w_i, w_j) = \frac{1}{2}\left(a + \beta(t,\sigma)Y - \frac{1}{1-\gamma}w_i + \frac{\gamma}{1-\gamma}w_j\right) + \left(\theta - \beta(t,\sigma)Y\right).$$

Next, we consider how the manufacturers simultaneously determine their wholesale prices in anticipation of the retailer's response. We first derive manufacturer i's best-response wholesale price to manufacturer j's wholesale price $w_j(Y)$ (w_j is a function of Y if manufacturer j is informed). For convenience, we will simply write $w_j(Y)$ as w_j in the subsequent analysis. If manufacturer i is informed, he seeks to maximize his expected profit

$$w_i E[q_i(w_i, w_j)|Y] - cE[q_i^2(w_i, w_j)|Y],$$

by choosing the best-response wholesale price

$$\hat{w}_i(w_j) = \frac{(1-\gamma)(c+1-\gamma)(a+\beta(t,\sigma)Y) + \gamma(c+1-\gamma)w_j}{c+2-2\gamma}.$$

If manufacturer i is uninformed, his expected profit equals

$$w_i E[q_i(w_i, w_j)] - cE[q_i^2(w_i, w_j)],$$

and his best-response wholesale price is given by

$$\hat{w}_i(w_j) = \frac{(1-\gamma)(c+1-\gamma)a + \gamma(c+1-\gamma)E[w_j]}{c+2-2\gamma}.$$

An equilibrium $(w_1^*, w_2^*, p_1^*, p_2^*)$ can be found by solving $w_i^* = \hat{w}_i(w_j^*)$ and $p_i^* = \hat{p}_i(w_i^*, w_j^*)$. Let $\overline{w}$ and $\overline{p}$ be the deterministic solutions when $\sigma = 0$, where $\overline{w} = (c+1-\gamma)a/(c+2-\gamma)$ and $\overline{p} = (2c+3-2\gamma)a/[2(c+2-\gamma)]$.

Lemma 1. *Given n, the number of informed manufacturers, there exists a unique equilibrium such that*

$$w_i^* = \begin{cases} \overline{w} + \alpha_w(n)Y & \text{if } n = 0 \text{ or } 2, \\ \overline{w} + \alpha_w^{X_i}(1)Y & \text{if } n = 1, \end{cases}$$
$$p_i^* = \begin{cases} \overline{p} + \alpha_p(n)Y & \text{if } n = 0 \text{ or } 2, \\ \overline{p} + \alpha_p^{X_i}(1)Y & \text{if } n = 1, \end{cases}$$

where

$$\alpha_w(0) = \alpha_w^N(1) = 0, \alpha_w^S(1) = \frac{(1-\gamma)(c+1-\gamma)}{(c+2-2\gamma)}\beta(t,\sigma), \alpha_w(2) = \frac{(c+1-\gamma)}{(c+2-\gamma)}\beta(t,\sigma),$$
$$\alpha_p(0) = \alpha_p^N(1) = \frac{\beta(t,\sigma)}{2}, \alpha_p^S(1) = \left[2-\gamma-\frac{(1-\gamma)^2}{c+2-2\gamma}\right]\frac{\beta(t,\sigma)}{2}, \alpha_p(2) = \left[2-\frac{1}{c+2-\gamma}\right]\frac{\beta(t,\sigma)}{2}.$$

The above lemma shows that, in equilibrium, the retailer and an informed manufacturer adjust, respectively, the retail prices and the wholesale price in response to the demand signal by following a linear strategy. Let the variance of the production quantity q_i be denoted by $V_q(n)$ for $n = 0$ or 2, and by $V_q^{X_i}(1)$ for $n = 1$.

Lemma 2.

(a) $\alpha_w(0) = \alpha_w^N(1) < \alpha_w^S(1) < \alpha_w(2)$.

(b) $\alpha_p(0) = \alpha_p^N(1) < \alpha_p^S(1) < \alpha_p(2)$.

(c) $V_q^S(1) < V_q(2) < V_q(0) < V_q^N(1)$.

(d) $\alpha_w^S(1), \alpha_w(2), \alpha_p^S(1)$ *and* $\alpha_p(2)$ *are increasing in* c, t *and* σ, *but decreasing in* γ. $\alpha_p(0)$ *and* $\alpha_p^N(1)$ *are increasing in* t *and* σ.

In part (a), an uninformed manufacturer's wholesale price obviously does not respond to the demand signal. Because wholesale prices are strategic complements, an informed manufacturer's wholesale price responds more strongly to the demand signal when the other manufacturer is also informed and adjusts his wholesale price in response to the demand signal. When a manufacturer adjusts his wholesale price, the retailer will adjust the price of his product in the same direction. Therefore a more responsive wholesale price induces the retail price to be more responsive too. Thus part (b) follows from part (a). For part (c), suppose n changes from 0 to 1 and manufacturer j becomes informed. From (b), p_j becomes more responsive to Y while the responsiveness of p_i remains unchanged. From the demand function, because θ and Y are positively correlated, q_i becomes more variable while q_j becomes less variable. This explains the ordering of $V_q^S(1) < V_q(0) < V_q^N(1)$. Now suppose n changes from 0 to 2. Both retail prices p_i and p_j become more responsive and from the demand function, because p_i has a larger impact than p_j does on q_i, and θ and Y are positively correlated, the net effect is that q_i becomes less variable. This explains the ordering $V_q(2) < V_q(0)$. Finally, suppose n changes from 2 to 1 and only manufacturer i remains informed. This makes w_j non-responsive while w_i less responsive, which in turn makes both p_i and p_j less responsive. A less responsive p_i makes q_i more variable while a less responsive p_j has the opposite effect. It turns out that the impact of a less responsive p_j is more significant, and the net effect is that q_i becomes less variable. Therefore $V_q^S(1) < V_q(2)$. For part (d), it is intuitive that a firm responds more strongly to the signal when it is more accurate. When production diseconomy is larger, the effect of order variability on production cost becomes more significant and therefore an informed manufacturer makes his wholesale price more responsive, which in turn induces the retail price more responsive, to dampen order variability. When competition is more intense, sales is more sensitive to wholesale prices and therefore an informed manufacturer responds less strongly to the demand signal.

3.2. Firms' Ex-Ante Profits

Based on the equilibrium pricing decisions, for a given n, we take expectations with respect to the demand signal Y to obtain the firms' ex-ante profits before the demand signal is observed. Let manufacturer i's profit be denoted by $\pi_M(n)$ when $n=0$ or 2, and by $\pi_M^{X_i}(1)$ when $n=1$. Let the retailer's profit be denoted by $\pi_R(n)$.

$$
\begin{aligned}
\pi_M(0) &= \overline{\pi}_M - \frac{c\beta(t,\sigma)\sigma^2}{4} - c[1-\beta(t,\sigma)]\sigma^2, \\
\pi_M^N(1) &= \overline{\pi}_M - \frac{c}{4}\left[1+\left(\frac{c+1-\gamma}{c+2-2\gamma}\right)\gamma\right]^2 \beta(t,\sigma)\sigma^2 - c[1-\beta(t,\sigma)]\sigma^2, \\
\pi_M^S(1) &= \overline{\pi}_M + \frac{(1-\gamma)^2}{4(c+2-2\gamma)}\beta(t,\sigma)\sigma^2 - c[1-\beta(t,\sigma)]\sigma^2, \\
\pi_M(2) &= \overline{\pi}_M + \frac{c+2-2\gamma}{4(c+2-\gamma)^2}\beta(t,\sigma)\sigma^2 - c[1-\beta(t,\sigma)]\sigma^2, \\
\pi_R(0) &= \overline{\pi}_R + \frac{\beta(t,\sigma)\sigma^2}{2}, \\
\pi_R(1) &= \overline{\pi}_R + \left[1+\gamma+\frac{(1-\gamma)^3}{(c+2-2\gamma)^2}\right]\frac{\beta(t,\sigma)\sigma^2}{4}, \\
\pi_R(2) &= \overline{\pi}_R + \frac{\beta(t,\sigma)\sigma^2}{2(c+2-\gamma)^2},
\end{aligned}
$$

where $\overline{\pi}_M = (c+2-2\gamma)\,a^2/[4\,(c+2-\gamma)^2]$ and $\overline{\pi}_R = a^2/[2\,(c+2-\gamma)^2]$ are the profits in the deterministic model. Note that $\beta(t,\sigma)=0$ when $t=0$ (demand signal has no information) and $\beta(t,\sigma)$ approaches to one when t approaches infinity (demand signal becomes perfect). We may interpret $\beta(t,\sigma)$ as the fraction of demand uncertainty predictable by the demand signal. For the retailer or an informed manufacturer, the second term of the profit function is positive because the firm can adjust either the retailer price or the wholesale price in response to the demand signal. As a result, the firm benefits from the predictable demand uncertainty. For an uninformed manufacturer, without the ability of adjusting his wholesale price, the second term is negative because he is hurt by the order variability caused by the predictable demand uncertainty. After the retailer has determined the retail prices, additional order variability will be caused by the residual demand uncertainty that cannot be predicted by the demand signal. This explains the last term in a manufacturer's profit function, $c[1-\beta(t,\sigma)]\sigma^2$, which accounts for the resulting higher production cost.

3.3. Effect of Information Sharing

LEMMA 3.

(a) $\pi_M(2) > \pi_M^S(1) > \pi_M(0) > \pi_M^N(1)$.

(b) $\pi_R(0) > \pi_R(1) > \pi_R(2)$.

(c) $\pi_R(1) - \pi_R(2) > \pi_R(0) - \pi_R(1)$.

The following result follows immediately from the above lemma.

PROPOSITION 1. *Information sharing benefits a manufacturer but hurts the retailer. It benefits the other manufacturer if he is informed and hurts him otherwise. Without information contracting (i.e., no side payment), the retailer will not share information with the manufacturers.*

Refer to Lemma 2, which compares the responsiveness of wholesale price and order variability under different information sharing agreements. When a manufacturer's wholesale price becomes more responsive to the demand signal, its double marginalization effect becomes more severe[7]. When the retailer discloses information to manufacturer i, (i) double marginalization of w_i becomes more severe, (ii) double marginalization of w_j becomes more severe if manufacturer j is informed and remains the same if he is uninformed, (iii) order variability faced by manufacturer i becomes smaller, and (iv) order variability faced by manufacturer j becomes larger. Because more severe double marginalization hurts the retailer but benefits a manufacturer, and smaller order variability benefits a manufacturer, the results follow[8].

4. Information Contracting Decisions

In this section, we consider the equilibrium contract payment and information sharing decisions made by the firms (refer to the first event of the sequence of events presented in Section 2). For

[7] The average wholesale price remains the same under different information sharing agreements. When the wholesale price is more responsive, it becomes higher when the signal is high and lower when it is low. On average, this allows the manufacturer to capture a larger share of the total profit but also has a more damaging effect in distorting retail decisions.

[8] For an informed manufacturer j, he benefits because the positive double marginalization effect dominates the negative order variability effect.

each of the three information contracting models, we will provide more details on how the firms engage in contracting and how they make decisions in anticipation of the ex-ante profits (given in Section 3) they will receive in the subsequent stages of the model. To facilitate our analysis, we define

$$V_{R+M}^N = [\pi_M^S(1) + \pi_R(1)] - [\pi_M(0) + \pi_R(0)], \text{ and}$$
$$V_{R+M}^S = [\pi_M(2) + \pi_R(2)] - [\pi_M^N(1) + \pi_R(1)]$$

as the value of information sharing to the retailer and a manufacturer if the other manufacturer is, respectively, uninformed and informed.

LEMMA 4. *There exist* $0 < c^I < c^S < c^{II} < \sqrt{2} - 1$ *such that:*

(a) $V_{R+M}^N \geq 0$ *iff* $c \geq c^I$.

(b) $V_{R+M}^S \geq 0$ *iff* $c \geq c^{II}$.

(c) $\pi_R(2) + 2\pi_M(2) \geq \pi_R(0) + 2\pi_M(0)$ *iff* $c \geq c^S$.

(d) c^S, c^I *and* c^{II} *are decreasing in* γ.

4.1. Model RSC: Retailer Stackelberg with Concurrent Offers

In this model, the retailer is the Stackelberg leader who makes concurrent and identical offers to the manufacturers by charging each a side payment T for the information. The manufacturers then simultaneously decide whether to accept the offers. We solve Model RSC backward by solving the manufacturer game for a given payment T. Denote a manufacturer's decision by $X_i = S$ if he agrees to pay the retailer for sharing information and $X_i = N$ otherwise. Based on the ex-ante profits in Section 3 and the side payment T, we construct the payoff matrix of the manufacturer game and then solve for the equilibrium of the game, (X_1^*, X_2^*), as a function of T. When there are multiple equilibria, we can show that a Pareto-optimal equilibrium always exists and we assume that it is the outcome of the manufacturer game. We can then compute the retailer's profit in the equilibrium induced by T, and hence solve the retailer's problem of finding T that maximizes her profit. Let n^{RSC} be the optimal number of informed manufacturers that maximizes the retailer's profit and

T^{RSC} be the corresponding optimal payment charged by the retailer. The following proposition shows that n^{RSC} also maximizes the total profit of the firms.

PROPOSITION 2.

(a) If $0 < c < c^S$, $n^{RSC} = 0$.

(b) If $c^S \leq c$, $n^{RSC} = 2$ *with* $T^{RSC} = \pi_M(2) - \pi_M(0)$.

(c) n^{RSC} *maximizes the total profit of the three firms.*

4.2. Model RSS: Retailer Stackelberg with Sequential Offers

In this model, the retailer is the Stackelberg leader who makes sequential offers to the manufacturers for selling information. First, the retailer randomly picks one of the two manufacturers and offers to charge him a payment T_f for the information. Next, the first manufacturer decides whether to accept the offer. Let $X_f = S$ if the first manufacturer agrees to accept the offer and $X_f = N$ otherwise. Then the retailer makes an offer to the second manufacturer, who has observed X_f, by charging another payment T_s for the information. Finally, the second manufacturer decides whether to accept the offer.

Here we assume that the retailer cannot credibly commit on charging the second manufacturer the same payment T_f, which is reasonable because the retailer gives these offers at different times. However, as shown in Proposition 3 below, when it is optimal for the retailer to sell information to both manufacturers, she charges them the same payments in equilibrium.

We solve the model backward by considering the optimal decision of a firm in each stage, given the decisions made in the previous stages and in anticipation of other firms' best responses in the subsequent stages. The firms' payoffs are determined based on the ex-ante profits given in Section 3 and the side payments T_f and T_s. Let n^{RSS} be the optimal number of informed manufacturers that maximizes the retailer's profit and $T_k^{RSS}(n^{RSS})$, where $k = f$ or s, be the corresponding optimal payment charged by the retailer.

PROPOSITION 3.

(a) If $0 < c < c^I$, $n^{RSS} = 0$.

(b) If $c^I \le c < c^{II}$, $n^{RSS} = 1$ *with* $T_f^{RSS}(1) = \pi_M^S(1) - \pi_M^N(1)$.

(c) If $c^{II} \le c$, $n^{RSS} = 2$ *with* $T_f^{RSS}(2) = T_s^{RSS}(2) = \pi_M(2) - \pi_M^N(1)$.

4.3. Model MS: Manufacturer Stackelberg

In this model, the manufacturers are the Stackelberg leaders who simultaneously offer side payments T_1 and T_2 (where T_i is offered by manufacturer i) for buying information. The retailer then decides whether to accept any of these offers. The firms' payoffs can be determined based on the ex-ante profits given in Section 3 as well as the side payments T_1 and T_2. We solve the model backward by first considering the retailer's optimal decision given the manufacturers' offers. Then we solve for the simultaneous game played by the two manufacturers in anticipation of the retailer's best response. When there are multiple equilibria in the manufacturer game, we can show that a Pareto-optimal equilibrium always exist and we assume that it is the outcome of the game. Let n^{MS} be the number of informed manufacturers and $T_i^{MS}(n^{MS})$ be the corresponding payment offered by manufacturer i in equilibrium.

Proposition 4. *An equilibrium always exists. When there are multiple equilibria, a unique Pareto-optimal equilibrium always exists. The unique equilibrium or Pareto-optimal equilibrium can be characterized as follows.*

(a) If $0 < c < c^I$, $n^{MS} = 0$.

(b) If $c^I \le c < c^{II}$, $n^{MS} = 1$ *with* $T_1^{MS}(1) = T_2^{MS}(1) = \pi_M^S(1) - \pi_M^N(1)$.

(c) If $c^{II} \le c$, $n^{MS} = 2$ *with* $T_1^{MS}(2) = T_2^{MS}(2) = \pi_R(1) - \pi_R(2)$.

5. Comparing the Three Models

We illustrate the equilibrium information sharing decisions of the three models in Figure 1.

The following proposition follows from part (d) of Lemma 4 and Propositions 2, 3 and 4.

Proposition 5. *In any of the three models, larger production diseconomy or more intense competition induces more information sharing.*

Ha et al. (2011) show that when a retailer shares private demand information with a manufacturer who faces production diseconomy, it lowers both the supply chain's revenue (by exacerbating

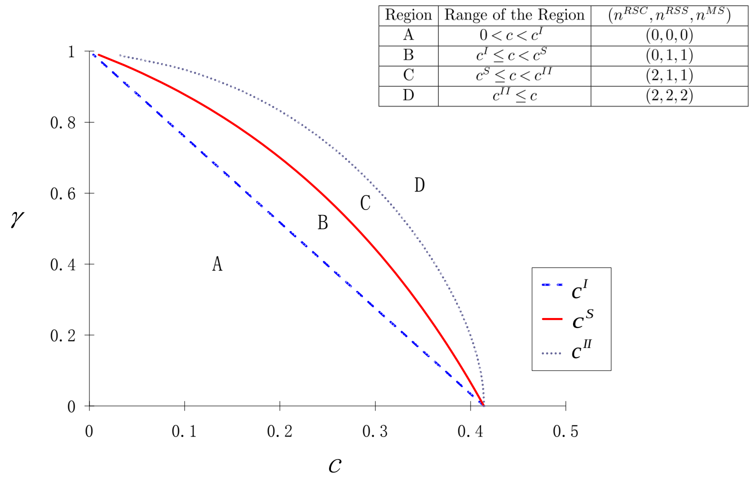


Figure 1 Equilibrium Information Sharing Decisions

the double marginalization effect of linear wholesale price) and its production cost (by reducing the order variability). They further show that a larger production diseconomy or less intense retail competition between two supply chains induces more information sharing. In our setting, a larger production diseconomy still induces more information sharing because the cost saving due to a smaller order variability becomes more significant. However, unlike the case of two supply chains engaging in retail competition, more intense competition at the manufacturer level induces more information sharing. This can be explained as follows. For Models RSS and MS, the value of information sharing between the retailer and manufacturer i is driven by their total profit. When competition is more intense, manufacturer i's cost saving caused by information sharing becomes higher. The impact of competition intensity on cost saving is larger than that on revenue loss. As a result, information sharing becomes more valuable. For Model RSC, the value of information sharing is driven by the total supply chain profit, and the order variability effect (for the two manufacturers combined) is less sensitive to competition intensity when compared with the other two models. In this case, more intense wholesale price competition mitigates the double marginalization effect and makes the revenue loss caused by information sharing less significant. Therefore information sharing becomes more valuable.

For a given model Z, where Z = RSC, RSS or MS, let Π_M^Z and Π_R^Z be respectively the manufacturer's and the retailer's ex-ante profits after accounting for the side payments, if any, under the equilibrium information sharing decisions. When partial information sharing (i.e., $n^Z = 1$) is the equilibrium, we take the average of the profits of the informed manufacturer and the uninformed manufacturer when we compute Π_M^Z. Let Π^Z be the system profit, where $\Pi^Z = 2\Pi_M^Z + \Pi_R^Z$.

LEMMA 5. *For $c \geq c^{II}$, there exists $\tilde{c}$ such that $\Pi_M^{MS} \leq \Pi_M^{RSC} = \pi_M(0)$ iff $c \leq \tilde{c}$ and $\Pi_R^{MS} \geq \Pi_R^{RSC}$ iff $c \leq \tilde{c}$.*

Region	System Profit	Manufacturers' Average Profit	Retailer Profit
A	$\Pi^{MS} = \Pi^{RSC} = \Pi^{RSS}$	$\Pi_M^{MS} = \Pi_M^{RSC} = \Pi_M^{RSS}$	$\Pi_R^{MS} = \Pi_R^{RSC} = \Pi_R^{RSS}$
B	$\Pi^{MS} = \Pi^{RSS} < \Pi^{RSC}$	$\Pi_M^{MS} = \Pi_M^{RSS} < \Pi_M^{RSC}$	$\Pi_R^{RSC} < \Pi_R^{MS} = \Pi_R^{RSS}$
C	$\Pi^{MS} = \Pi^{RSS} < \Pi^{RSC}$	$\Pi_M^{MS} = \Pi_M^{RSS} < \Pi_M^{RSC}$	$\Pi_R^{RSC} < \Pi_R^{MS} = \Pi_R^{RSS}$
D	$\Pi^{MS} = \Pi^{RSC} = \Pi^{RSS}$	$\Pi_M^{RSS} < \Pi_M^{MS} \leq \Pi_M^{RSC}$ if $c \leq \tilde{c}$ $\Pi_M^{RSS} < \Pi_M^{RSC} < \Pi_M^{MS}$ if $c > \tilde{c}$	$\Pi_R^{RSC} \leq \Pi_R^{MS} < \Pi_R^{RSS}$ if $c \leq \tilde{c}$ $\Pi_R^{MS} < \Pi_R^{RSC} < \Pi_R^{RSS}$ if $c > \tilde{c}$

Table 1 Comparison of the System's and Firms' Profits

We compare the firms' and system's profits in Table 1. Based on Figure 1 and Table 1, several observations can be made regarding the firms' preference of the three contracting models.

1. In Model RSC, the equilibrium information sharing decisions maximize the total profit of the three firms. Although partial information sharing is never optimal for the system, it may occur in Model RSS or Model MS when production diseconomy is neither too small nor too large ($c^I \leq c < c^{II}$). In this case, the incremental value of information sharing to the retailer and the second manufacturer is negative, after the retailer has agreed to share information with the first manufacturer ($V_{R+M}^S < 0 \leq V_{R+M}^N$). Because neither manufacturer wants to be the only uninformed manufacturer, in Model RSS, the retailer can charge a high payment to extract profit from the system at the expense of a less efficient outcome. Similarly, in Model MS, the manufacturers bid aggressively to be the only informed one and an inefficient outcome occurs due to fierce manufacturer competition. When production diseconomy is sufficiently small or large ($c < c^I$ or $c \geq c^{II}$), both models achieve the system-wide optimal information sharing outcome.

2. When the retailer is the Stackelberg leader in information contracting, she prefers Model RSS to Model RSC while the manufacturers' preference is reversed. By sequentially offering information contracts and publicly revealing the contracting outcome, the retailer can make a credible threat of leaving a manufacturer as the only uninformed one, who will be worse off than the case when both manufacturers are uninformed. As a result, in Model RSS, the retailer can charge a higher payment to extract more profit from the system, even at the expense of an inefficient outcome.

3. The retailer prefers Model RSS to the other two models. Without Model RSS, she prefers Model MS to Model RSC except when c is sufficiently large, her preference is reversed. This is because she has to make the same offers to both manufacturers in Model RSC, and she may therefore benefit more from the manufacturers' competition in Model MS.

4. The manufacturers prefer Model RSC to the other models except when c is sufficiently large, they prefer Model MS. This shows that competition makes it undesirable for the manufacturers to be the leaders in information contracting, except when production diseconomy is large. In that case, they don't need to bid aggressively to be the only informed manufacturer. Instead, they only need to pay the retailer for her incremental loss in disclosing information.

6. Impact of Information Contracting

6.1. Sensitivity Analysis

LEMMA 6.

(a) $\pi_M(0)$ *is increasing in* t *but decreasing in* σ *and* γ*. There exists* $\bar{c}$ *such that* $\pi_M(0)$ *is increasing in* c *if* $c < \bar{c}$ *and decreasing in* c *otherwise.*

(b) $\pi_R(0)$ *is decreasing in* c *but increasing in* σ, t *and* γ*.*

Without information contracting, the profits of the manufacturer and the retailer are respectively given by $\pi_M(0)$ and $\pi_R(0)$. In this case, larger production diseconomy increases the production cost but softens the manufacturers' competition in wholesale prices because the marginal cost increases at a faster rate. The above lemma shows that it benefits the manufacturers as long as the production diseconomy is not too large. However, because both effects hurt the retailer, she is always worse off. The other results are intuitive.

When contracting does not induce the retailer to disclose information, $\Pi_M^Z = \pi_M(0)$ and $\Pi_R^Z = \pi_R(0)$ (where $Z = RSC, RSS$ or MS) and Lemma 6 still applies. Therefore we focus on the case when contracting induces information sharing.

Proposition 6.

(a) When $c = c^I$, *(i)* $[\pi_R(1) + T_f^{RSS}(1)] - \pi_R(0) = [\pi_R(1) + T_1^{MS}(1)] - \pi_R(0) = \pi_M(0) - \pi_M^N(1) > 0$,

(ii) $[\pi_M^S(1) - T_f^{RSS}(1)] - \pi_M(0) = [\pi_M^S(1) - T_1^{MS}(1)] - \pi_M(0) = \pi_M^N(1) - \pi_M(0) < 0$.

(b) When $c = c^{II}, [\pi_R(2) + T_f^{RSS}(2) + T_s^{RSS}(2)] - [\pi_R(1) + T_f^{RSS}(1)] = [\pi_R(2) + T_1^{MS}(2) + T_2^{MS}(2)] - [\pi_R(1) + T_1^{MS}(1)] = \pi_M(2) - \pi_M^S(1) > 0$.

For either Model RSS or MS, the above proposition shows that, after accounting for the information contracting payments, the retailer's profit increases by respectively $\pi_M(0) - \pi_M^N(1)$ and $\pi_M(2) - \pi_M^S(1)$ at $c = c^I$ and $c = c^{II}$, and the manufacturer's profit decreases by $\pi_M(0) - \pi_M^N(1)$ at $c = c^I$. These results imply that there exists a neighborhood around $c = c^I$ or c^{II} such that when an increase in c induces more information sharing (n^Z becomes larger, where $Z = RSS$ or MS), the retailer is strictly better off. We can also find a neighborhood around $c = c^I$ such that a similar change makes the manufacturer strictly worse off[9]. Besides the cases considered in Proposition 6, Π_M^Z and Π_R^Z are continuous in c.

Now suppose n^Z remains the same when one of the parameters, c, γ, σ or t changes.

Lemma 7. *Suppose there is information contracting and* $n^Z = 1$ *or* 2.

(a) Π_M^Z *is decreasing in* σ *but increasing in* t, *and* Π_R^Z *is increasing in* σ *and* t.

(b) Except for $n^{MS} = 2$, Π_M^Z *is decreasing in* γ *and* Π_R^Z *is increasing in* γ.

(c) For $n^{MS} = 2$, *if* $a \geq \sigma$, *(i)* Π_M^{MS} *is decreasing in* γ, *(ii)* Π_R^{MS} *is increasing in* γ *but decreasing in* c.

Similar to the case of no information contracting, larger demand uncertainty (larger σ) or more intense competition (larger γ) benefits the retailer but hurts the manufacturers, while more accurate

[9] Similarly, we can show that there are cases where the retailer is strictly better off or the manufacturer is strictly worse off when an increase in γ induces more information sharing. In our model, a change in σ or t does not affect the information sharing equilibrium outcome n, though it affects the firms' profits.

signal (larger t) benefits all the firms. For the effect of production diseconomy c, we have performed an extensive numerical study to investigate, with information contracting, how a firm's profit depends on c when the relationship is not monotone. Our results lead to the following observations. First, the retailer's profit may increase when production diseconomy becomes larger. This may occur for $n^{RSC} = 2$, or $n^{RSS} = 1$ or 2, or $n^{MS} = 1$, when production diseconomy is large, competition is less intense, demand uncertainty is large and signal is accurate. Second, similar to the case of no information contracting, for all the three contracting models, the manufacturer's profit is increasing in production diseconomy when the latter is small, competition is intense, demand uncertainty is small or information is accurate.

Compared with Lemma 6, Proposition 6 and the numerical results together show that when there is information contracting, production diseconomy has an additional effect on the retailer. In Model RSC and Model RSS, a larger production diseconomy increases the value of information sharing, which benefits the retailer because she can then sell information to more manufacturers or charge a higher payment for the information. In Model MS (with the manufacturers as leaders in information contracting), this is also true as long as full information sharing is not an equilibrium. Otherwise the manufacturers only need to pay the retailer for her incremental loss due to disclosing information and they can capture the remaining surplus created by information sharing. As a result, the retailer no longer benefits from a larger production diseconomy. Note that for the case of two competing supply chains studied by Ha et al. (2011), a retailer cannot benefit from a larger production diseconomy when the manufacturers are leaders in information contracting. This is because the manufacturers do not compete in buying information from the same retailer.

6.2. Welfare Implications

From Proposition 1, the retailer has no incentive to share information when the manufacturers do not pay for the information. When the firms contract on information sharing, the retailer will refuse to share information if the side payment she receives does not make up for her loss due to disclosing her private information. Therefore the retailer cannot be worse off with information contracting.

The question remains whether information contracting makes the manufacturers or the system better off. Obviously it impacts the firms' profits only if contracting induces information sharing in the system. We obtain the following results by comparing $\pi_M(0)$ with Π_M^Z, and $2\pi_M(0)+\pi_R(0)$ with $2\Pi_M^Z+\Pi_R^Z$, where $Z=RSC, RSS$ or MS, when information sharing occurs in equilibrium.

Proposition 7. *Compared with the case of no information contracting, the impact of information contracting is as follows.*
(a) In Model RSC, for $n^{RSC}=2$, the manufacturers are indifferent and the system is better off.
(b) In Model RSS, for $n^{RSS}=1$, both the manufacturers and the system are worse off. For $n^{RSS}=2$, the manufacturers are worse off while the system is better off.
(c) In Model MS, for $n^{MS}=1$, both the manufacturers and the system are worse off. For $n^{MS}=2$, (i) the system is better off; (ii) there exists $\tilde{c}$ such that the manufacturers are worse off if $c\leq\tilde{c}$ and better off otherwise. The threshold $\tilde{c}$ is increasing in γ.

The threshold $\tilde{c}$ in part (ii) of (c) is the same as that in Lemma 5. In Model RSC, the equilibrium information sharing decisions maximize system profit and the retailer captures all the value created by information sharing, leaving the manufacturers with no incremental gain. In Model RSS, when partial information sharing $(n=1)$ is the equilibrium, on average a manufacturer is worse off due to information contracting. As we have explained earlier, partial information sharing allows the retailer to charge a high payment to extract a large share of the total profit, even though the overall supply chain efficiency may suffer. Therefore, information contracting sometimes makes the system worse off and it always makes the manufacturers worse off. In Model MS, when partial information sharing is the equilibrium, information contracting makes the manufacturers worse off because of competition. When full information sharing is the equilibrium, instead of competing aggressively to avoid being the only uninformed firm, the manufacturers just need to pay the retailer for her incremental loss due to disclosing information. In this case, information contracting benefits the manufacturers when the saving in production cost due to information sharing is sufficiently large, which is the case when c is large. When competition becomes more intense, it takes a larger c for the manufacturers to benefit from information contracting.

7. Extensions

7.1. Retailer's Investment in Improving Signal Accuracy

Consider the case when the retailer invests in data collection to improve signal accuracy (e.g., by collecting more data) before the firms engage in information contracting and pricing decisions. Let $g(t)$ be the investment cost as a function of the signal accuracy t, where $g(t)$ is increasing and convex in t with $g'(0) = 0$ (or sufficiently small) and $g'(+\infty) = +\infty$ (or sufficiently large). The retailer seeks to find t that maximizes $\Pi_R^Z(t) - g(t)$, where $Z = RSC$, RSS or MS. $\Pi_R^Z(t)$ is the same as Π_R^Z defined in Section 5, but here we explicitly show its dependence on t. Let t^Z be the optimal solution of the retailer's problem. Recall that the equilibrium information sharing decision, n^Z, does not depend on t (though the firms' profits do).

Proposition 8.

(a) $t^{Z_1} \leq t^{Z_2}$ *iff* $\Pi_R^{Z_1}(t) \leq \Pi_R^{Z_2}(t)$.

(b) t^Z *is increasing in* σ.

(c) t^Z *is increasing in* c *and* γ *except (i) when* $n^Z = 0$, t^Z *is independent of* c *and* γ, *(ii) when* $n^{MS} = 2$, *there exists* $\hat{c}$ *such that* t^{MS} *is decreasing in* γ *if* $c \leq \hat{c}$ *and increasing in* γ *otherwise.*

The above proposition shows how the retailer's optimal investment depends on the contracting models. If her profit is higher in Model Z_1 than in Model Z_2 (from Table 1), the marginal benefit of a more accurate signal is also larger and, consequently, the optimal investment is higher too. It is intuitive that the optimal investment is higher when demand becomes more uncertain. When there is no information sharing, production cost and competition intensity do not impact the marginal effect of signal accuracy on the retailer's profit. When there is information sharing, the retailer can command a higher payment when either the saving in production cost due to information sharing becomes larger (when c is larger) or competition becomes more intense. Therefore she invests more when production diseconomy becomes larger or competition becomes more intense. The only exception is when $n^{MS} = 2$ and production diseconomy is small, which also means that competition is intense. From Lemma 2, when competition becomes more intense, wholesale prices are less responsive to the demand signal. Because of this and the small production diseconomy, the marginal value of a more accurate signal becomes lower. As a result, each manufacturer offers a lower payment for the information. Note that when $n^{MS}=1$ and production diseconomy is small, more intense competition lowers the marginal value of a more accurate signal but induces the manufacturers to make more aggressive offers for the information[10]. It turns out that the net effect still benefits the retailer.

Kadiyali et al. (2000) assert that retailers become more powerful because, among other things, they have adopted advanced information technology. Our results imply that information contracting provides incentive for a dominant retailer to invest in information technology to make demand information more accurate. Thus information contracting not only allows the retailer to extract a larger portion of the supply chain profit but also makes her more powerful through the adoption of more advanced information technology.

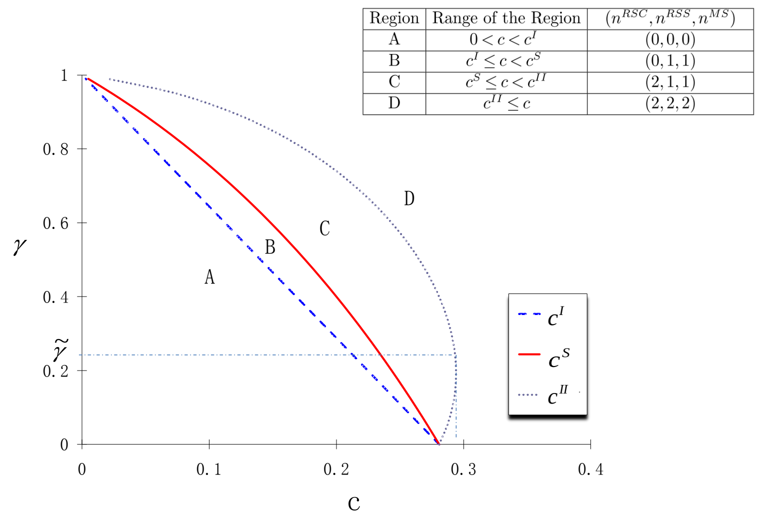
7.2. Vertical Nash for Wholesale and Retail Price Decisions

We consider the case when wholesale prices and retail prices are determined under Vertical Nash. The sequence of events is the same as that of the basic model given in Section 2 except for event 3. In event 3 of the basic model, each manufacturer is a Stackelberg leader in wholesale pricing. They simultaneously offer their wholesale prices to the retailer, who then determines the retail prices. For the case of Vertical Nash, each manufacturer determines a wholesale price for his own product, the retailer determines the retail margins for both products, and all these decisions are made simultaneously. This is the case when the manufacturers and the retailer have similar power in determining the wholesale prices.

As shown in Figure 2, the equilibrium information sharing decisions exhibit the same threshold structure as before. Indeed, except for Proposition 5, all the main results (Propositions 2 to 4, and Propositions 6 to 8) remain exactly the same.

PROPOSITION 9. *Suppose wholesale prices and retail prices are determined under Vertical Nash.*

[10] The second effect is not significant when $n^{MS}=2$.



Region	Range of the Region	$(n^{RSC}, n^{RSS}, n^{MS})$
A	$0 < c < c^I$	$(0,0,0)$
B	$c^I \le c < c^S$	$(0,1,1)$
C	$c^S \le c < c^{II}$	$(2,1,1)$
D	$c^{II} \le c$	$(2,2,2)$

Figure 2 **Equilibrium Information Sharing Decisions under Vertical Nash**

(a) In any of the three contracting models, larger production diseconomy induces more information sharing.

(b) For Model RSC, more intense competition induces more information sharing.

(c) For Model RSS or MS, there exists $\tilde{\gamma}$ such that when $\gamma \le \tilde{\gamma}$ and $c^{II}(\gamma) \le c \le c^{II}(\tilde{\gamma})$, more intense competition induces less information sharing. Otherwise more intense competition induces more information sharing.

Here $c^{II}(\gamma)$ is defined as in Lemma 4 and we show explicitly its dependence on γ. The above proposition shows that the results under Vertical Nash are almost the same as those in Proposition 5 except when γ is small and c takes some intermediate values. This can be explained as follows. For Models RSS and MS, information sharing between the retailer and manufacturer i leads to a revenue loss (due to the double marginalization effect) for the retailer and a saving in production cost (due to the order variability effect) for manufacturer i. When manufacturer j is informed, more intense competition increases both the cost saving and the revenue loss[11]. Under the conditions in (c) of Proposition 9, the impact of competition intensity on revenue loss is more significant

[11] For Model RSC, more intense competition always reduces the revenue loss caused by information sharing.

than that on cost saving[12]. As a result, the value of information sharing between the retailer and manufacturer i decreases when competition becomes more intense.

8. Concluding Remark

In this paper, we have examined the issues of information sharing and information contracting in a supply chain with two competing manufacturers selling through a common retailer. We have investigated how firms make information sharing decisions in different scenarios with different assumptions on contracting leadership and sequence. We have shown how production diseconomy and competition intensity affect the incentive for information sharing, and how information contracting impacts firms' profits. When the retailer can invest in improving information accuracy, we have shown how such an investment depends on production diseconomy, demand uncertainty and competition intensity.

One limitation of our model is the assumption of identical manufacturers. Without this assumption, we expect partial information sharing to be more likely and it would be interesting to study how the retailer should selectively contract with the manufacturers on information sharing. To analyze the case of non-identical manufacturers, we need to make major changes in the modeling framework and possibly adopt a different mode of analysis. We will leave this for future research.

Appendix: Proofs

Proof of Lemma 1. It is easy to verify that w_i^* and p_i^* satisfy $w_i^* = \hat{w}_i(w_j^*)$ and $p_i^* = \hat{p}_i(w_i^*, w_j^*)$, and hence they are an equilibrium. To show the uniqueness, it suffices to show the solution to equations $w_i^* = \hat{w}_i(w_j^*)$ (for $i = 1, 2$) is unique, because the retailer's best-response retail prices are uniquely determined by the wholesale prices. When $n = 0$ or 2, we have $E[w_j] = w_j$, and it is easy to check that the linear equations $w_i^* = \hat{w}_i(w_j^*)$ have a unique solution. When $n = 1$, without loss of generality, assume $X_i = S$. Take expectation of $\hat{w}_i(w_j)$ with respect to Y and substitute it into $\hat{w}_j(w_i)$, we can find a unique solution w_j^*. Then $w_i^* = \hat{w}_i(w_j^*)$ is also unique. □

Proof of Lemma 2 and Lemma 3. It is straightforward and details are omitted.

[12] This is not true for the basic model because wholesale prices are more sensitive to competition intensity under Vertical Nash when compared with the basic model.

Proof of Proposition 1. It follows immediately from Lemma 3.

Proof of Lemma 4. For part (a), we rewrite

$$V_{R+M}^N = \left[\frac{c}{1-\gamma} - 1 + \frac{1}{c/(1-\gamma)+2} + \frac{1}{(c/(1-\gamma)+2)^2}\right]\frac{(1-\gamma)\beta(t,\sigma)\sigma^2}{4},$$

and the right hand side is positive iff $c > c^I = (\sqrt{2}-1)(1-\gamma)$.

For part (b), it can be shown that V_{R+M}^S is convex in c, $V_{R+M}^S|_{c=0} < 0$, and $V_{R+M}^S|_{c\to\infty} > 0$. Hence, there exists a unique c^{II} such that $V_{R+M}^S \geq 0$ iff $c \geq c^{II}$.

For part (c), notice that $[\pi_R(2) + 2\pi_M(2)] - [\pi_R(0) + 2\pi_M(0)]$ can be rewritten as

$$\left[c - 1 + \frac{(c+3-2\gamma)}{(c+2-\gamma)^2}\right]\frac{\beta(t,\sigma)\sigma^2}{2},$$

which is positive iff $c > c^S = (\sqrt{8-8\gamma+\gamma^2} - 2 + \gamma)/2$.

For part (d), it is obvious that c^I and c^S are decreasing in γ. Let $\gamma(c^{II})$ denote the inverse function of $c^{II}(\gamma)$. We can show $dV_{R+M}^S/dc|_{c=c^{II}} > 0$ and $dV_{R+M}^S/d\gamma|_{\gamma=\gamma(c^{II})} > 0$. Taking derivative of γ on both sides of the equation $V_{R+M}^S = 0$, we have

$$\frac{dV_{R+M}^S}{dc}|_{c=c^{II}}\frac{dc^{II}}{d\gamma} + \frac{dV_{R+M}^S}{d\gamma}|_{\gamma=\gamma(c^{II})} = 0,$$

which implies $dc^{II}/d\gamma < 0$.

Finally, it is easy to establish the ordering of $0 < c^I < c^S$. For the ordering of $c^S < c^{II} < \sqrt{2}-1$, it follows from the convexity of V_{R+M}^S with respect to c, $V_{R+M}^S|_{c=c^S} < 0$, and $V_{R+M}^S|_{c=\sqrt{2}-1} > 0$. □

Proof of Proposition 2. Given any side payment T, the manufacturers' payoff matrix of the information sharing game is given in Table 2. From Lemma 3, when $T \leq \pi_M^S(1) - \pi_M(0)$, the

Manufacturer 1, Manufacturer 2	Share ($X_2 = S$)	Not Share ($X_2 = N$)
Share ($X_1 = S$)	$(\pi_M(2) - T, \pi_M(2) - T)$	$(\pi_M^S(1) - T, \pi_M^N(1))$
Not Share ($X_1 = N$)	$(\pi_M^N(1), \pi_M^S(1) - T)$	$(\pi_M(0), \pi_M(0))$

Table 2 Payoff Matrix of the Manufacturers under RSC

dominant-strategy equilibrium is (S,S). When $T \geq \pi_M(2) - \pi_M^N(1)$, the dominant-strategy equilibrium is (N,N). When $\pi_M^S(1) - \pi_M(0) \leq T \leq \pi_M(2) - \pi_M^N(1)$, there are two equilibria (S,S) and

(N,N). In this case, the manufacturers choose the Pareto-optimal equilibrium, which is (S,S) if $T \le \pi_M(2) - \pi_M(0)$, and (N,N) otherwise. Therefore, the optimal decision for the retailer is either $n=0$ or $n=2$ with $T = \pi_M(2) - \pi_M(0)$. The retailer prefers $n=2$ to $n=0$ iff $\pi_R(2) + 2[\pi_M(2) - \pi_M(0)] \ge \pi_R(0)$. Therefore, from Lemma 4, $n^{RSC} = 2$ if $c \ge c^S$, and $n^{RSC} = 0$ otherwise. n^{RSC} maximizes the total profit of the three firms because the total profit with $n=1$ is lower than that of either $n=0$ or $n=2$. □

Proof of Proposition 3. Without loss of generality, we assume that the retailer offers a contract to manufacturer 1 first. Now we consider the contracting outcome with manufacturer 2, given X_1. Suppose $X_1 = S$: with $n=2$, the payoffs of the three firms equal $(\pi_R(2) + T_f + T_s, \pi_M(2) - T_f, \pi_M(2) - T_s)$; with $n=1$, their payoffs equal $(\pi_R(1) + T_f, \pi_M^S(1) - T_f, \pi_M^N(1))$; manufacturer 2 agrees to buy information iff $T_s \le \pi_M(2) - \pi_M^N(1)$, and hence the retailer induces $n=2$ iff $V_{R+M}^S \ge 0$. Suppose $X_1 = N$: with $n=1$, the payoffs of the three firms equal $(\pi_R(1) + T_s, \pi_M^N(1), \pi_M^S(1) - T_s)$; with $n=0$, their payoffs equal $(\pi_R(0), \pi_M(0), \pi_M(0))$; manufacturer 2 agrees to buy information iff $T_s \le \pi_M^S(1) - \pi_M(0)$, and the retailer induces $n=1$ iff $V_{R+M}^N \ge 0$.

Then we consider the contracting outcome with manufacturer 1, in anticipation of its impact on manufacturer 2's decision. (a) If $V_{R+M}^N < 0$ (i.e., $0 < c < c^I$), manufacturer 2 will not buy information, and manufacturer 1 will buy information iff $T_f \le \pi_M^S(1) - \pi_M(0)$. Notice that $\pi_R(1) + T_f \le \pi_R(0) + V_{R+M}^N < \pi_R(0)$, it is optimal for the retailer not to share information. (b) If $V_{R+M}^N \ge 0$ and $V_{R+M}^S < 0$ (i.e., $c^I \le c < c^{II}$), whatever decision manufacturer 1 makes, the retailer will induce a different information sharing outcome with manufacturer 2. Hence, manufacturer 1 agrees to buy information iff $T_f \le \pi_M^S(1) - \pi_M^N(1)$. It is clear that the optimal decision of the retailer is to induce $n=1$ with $T_f = \pi_M^S(1) - \pi_M^N(1)$. (c) If $V_{R+M}^S \ge 0$ (i.e., $c^{II} \le c$), the retailer will share information with manufacturer 2 for sure. Manufacturer 1 agrees to buy information iff $T_f \le \pi_M(2) - \pi_M^N(1)$. Notice that $\pi_R(2) + 2[\pi_M(2) - \pi_M^N(1)] = \pi_R(1) + \pi_M(2) - \pi_M^N(1) + V_{R+M}^S > \pi_R(1) + \pi_M^S(1) - \pi_M(0)$, the retailer will induce $n=2$ by charging $T_f = T_s = \pi_M(2) - \pi_M^N(1)$. □

Proof of Proposition 4. For any payments T_1 and T_2 offered by the manufacturers, the retailer's best response can be characterized as follows: $n=0$ iff $T_i \in [0, \pi_R(0) - \pi_R(1))$ for $i=1,2$; $n=2$ iff

$T_i \in [\pi_R(1) - \pi_R(2), \infty)$ for $i = 1, 2$; and $n = 1$ in the remaining region (where the retailer shares information with manufacturer i iff $T_i \geq T_j$). In anticipation of such retailer response, for any given T_j, we can characterize manufacturer i's best-response $\hat{T}_i(T_j)$. Based on the best responses of the two manufacturers, we obtain the necessary and sufficient conditions for all the Nash equilibria as follows:

(1) $n = 0$ is an equilibrium iff $V_{R+M}^N < 0$;

(2) $n = 1$ is an equilibrium iff $\pi_R(0) - \pi_R(1) \leq \pi_M^S(1) - \pi_M^N(1) < \pi_R(1) - \pi_R(2)$;

(3) $n = 2$ is an equilibrium iff $V_{R+M}^S \geq 0$.

Nash equilibria always exist because we can show that the inequalities in (2) are satisfied in the region with $V_{R+M}^N \geq 0$ and $V_{R+M}^S < 0$. When there are multiple equilibria, we must have two equilibria with $n = 1$ being one of them, because from Lemma 4 the equilibrium conditions for $n = 0$ and $n = 2$ cannot be satisfied simultaneously. We can show that $n = 1$ is Pareto-dominated by the other information sharing equilibrium (either $n = 0$ or $n = 2$) for the manufacturers. □

Proof of Proposition 5. It is straightforward and details are omitted.

Proof of Lemma 5. When $c \geq c^{II}$, $n^Z = 2$ for Z = MS, RSC, and hence

$$\Pi_M^{MS} - \Pi_M^{RSC} = \left[c - 1 - \gamma + \frac{c + 4 - 2\gamma}{(c + 2 - \gamma)^2} - \frac{(1-\gamma)^3}{(c + 2 - 2\gamma)^2}\right] \frac{\beta(t,\sigma)\sigma^2}{4}.$$

The result follows because the right hand side has the following properties: (1) it is strictly negative for $c \in (0, \gamma]$; (2) it is increasing in c for $c \in (\gamma, \infty)$; (3) it goes to infinity when $c \to \infty$. The proof for the case of the retailer's profit is similar and therefore omitted. □

Proof of Lemma 6. We show the sensitivity of $\pi_M(0)$ with respect to c. Taking the first– and second–order derivatives, we have

$$\begin{aligned} \frac{d\pi_M(0)}{dc} &= -\frac{(c + 2 - 3\gamma)\, a^2}{4\,(c + 2 - \gamma)^3} - \frac{\beta(t,\sigma)\sigma^2}{4} - [1 - \beta(t,\sigma)]\sigma^2, \quad \text{and} \\ \frac{d^2\pi_M(0)}{dc^2} &= \frac{(c + 2 - 3\gamma)\, a^2}{2\,(c + 2 - \gamma)^4} - \frac{\gamma a^2}{2\,(c + 2 - \gamma)^4}. \end{aligned}$$

It is clear that if the first–order derivative equals zero, then the second–order derivative must be strictly negative. Note that $d\pi_M(0)/dc|_{c \to \infty} < 0$, we have $\pi_M(0)$ is either unimodal or decreasing in c. Therefore, there exist $\bar{c} \geq 0$ such that $\pi_M(0)$ is increasing in c iff $c < \bar{c}$. The other results in parts (a) and (b) can be obtained by taking derivatives of $\pi_M(0)$ and $\pi_R(0)$ with respect to the corresponding parameters. □

Proof of Proposition 6. By definition, $V_{R+M}^N = [\pi_M^S(1) + \pi_R(1)] - [\pi_M(0) + \pi_R(0)] = 0$ at $c = c^I$ and $V_{R+M}^S = [\pi_M(2) + \pi_R(2)] - [\pi_M^N(1) + \pi_R(1)] = 0$ at $c = c^{II}$. Based on these and Lemma 3 , it is straightforward to prove that the results hold. □

Proof of Lemma 7. Parts (a), (b) and (c) can be obtained by taking derivatives of Π_M^Z and Π_R^Z with respect to the corresponding parameters. □

Proof of Proposition 7. It is straightforward and details are omitted.

Proof of Proposition 8. For part (a), we can rewrite $\Pi_R^Z(t) = \bar{\pi}_R + J^Z\beta(t,\sigma)\sigma^2$, where $\bar{\pi}_R$ and J^Z are positive and independent of t. It is easy to check that $\Pi_R^Z(t)$ is concave and increasing in t. Hence $\Pi_R^Z(t) - g(t)$ is concave in t, and the maximizer t^Z is the unique solution to $d[\Pi_R^Z(t) - g(t)]/dt = 0$. By taking derivative with respect to J^Z, we can show that $dt^Z/dJ^Z > 0$ because $\Pi_R^Z(t) - g(t)$ is concave and $d^2[\Pi_R^Z(t) - g(t)]/dtdJ^Z > 0$. Since $\Pi_R^{Z_1}(t) \leq \Pi_R^{Z_2}(t)$ iff $J^{Z_1} \leq J^{Z_2}$, the result follows.

The proof of part (b) is similar to that for part (a).

For part (c), (i) when $n^Z = 0$, J^Z is independent of c and γ , so is t^Z; (ii) when $n^{MS} = 2$,

$$\frac{dJ^{MS}}{d\gamma} = \frac{1}{2}\left[1 - \frac{(1-\gamma)^2(3c+2-2\gamma)}{(c+2-2\gamma)^3} - \frac{2}{(c+2-\gamma)^3}\right],$$

which is increasing in c. Because $dJ^{MS}/d\gamma|_{c\to\infty} > 0$, there exists $\hat{c}$ such that $dJ^{MS}/d\gamma < 0$ iff $c \leq \hat{c}$. Then result (ii) follows directly according to part (a). The other results can be obtained by taking derivatives of J^Z with respect to the corresponding parameters. □

Proof of Proposition 9. We follow the approach in Choi (1991) to get the firms' expected profits in the second stage. For convenience, we abuse notations by using the same set of notations as in the basic model where the manufacturers are the leaders in offering wholesale prices. Given w_1 and w_2, the retailer maximizes her expected profit $(p_1 - w_1)\left(a + E[\theta|Y] - \frac{1}{1-\gamma}p_1 + \frac{\gamma}{1-\gamma}p_2\right) + (p_2 - w_2)\left(a + E[\theta|Y] - \frac{1}{1-\gamma}p_2 + \frac{\gamma}{1-\gamma}p_1\right)$ by setting the retail prices to $\hat{p}_i(w_i, w_j) = \frac{1}{2}(a + \beta(t,\sigma)Y + w_i)$. Given the profit margins charged by the retailer, an informed manufacturer maximizes his expected profit $w_i E[q_i(p_i,p_j)|Y] - cE[q_i^2(p_i,p_j)|Y]$ by setting the wholesale price to $\hat{w}_i(p_i,p_j) = (2c+1-\gamma)\left(a+\beta(t,\sigma)Y - \frac{1}{1-\gamma}p_i + \frac{\gamma}{1-\gamma}p_j\right)$; an uninformed manufacturer maximizes his expected profit $w_i E[q_i(p_i,p_j)] - cE[q_i^2(p_i,p_j)]$ by setting the wholesale price to $\hat{w}_i(p_i,p_j) = (2c+1-\gamma)\left(a - \frac{1}{1-\gamma}E[p_i] + \frac{\gamma}{1-\gamma}E[p_j]\right)$. Following the proof of Lemma 1, we can find a unique equilibrium

$$w_i^* = \begin{cases} \overline{w} + \alpha_w(n)Y & \text{if } n = 0 \text{ or } 2, \\ \overline{w} + \alpha_w^{X_i}(1)Y & \text{if } n = 1, \end{cases}$$
$$p_i^* = \begin{cases} \overline{p} + \alpha_p(n)Y & \text{if } n = 0 \text{ or } 2, \\ \overline{p} + \alpha_p^{X_i}(1)Y & \text{if } n = 1, \end{cases}$$

where $\bar{w} = (2c+1-\gamma)a/(2c+3-\gamma)$, $\bar{p} = (2c+2-\gamma)a/(2c+3-\gamma)$, and

$$\alpha_w(0) = \alpha_w^N(1) = 0, \alpha_w^S(1) = \frac{(1-\gamma)(2c+1-\gamma)}{(2c+3-3\gamma)}\beta(t,\sigma), \alpha_w(2) = \frac{2c+1-\gamma}{2c+3-\gamma}\beta(t,\sigma),$$
$$\alpha_p(0) = \alpha_p^N(1) = \frac{\beta(t,\sigma)}{2}, \alpha_p^S(1) = \left[2-\gamma-\frac{2(1-\gamma)^2}{2c+3-3\gamma}\right]\frac{\beta(t,\sigma)}{2}, \alpha_p(2) = \frac{2c+2-\gamma}{2c+3-\gamma}\beta(t,\sigma).$$

Based on the equilibrium pricing decisions, we obtain the firms' ex-ante profits as follows.

$$\begin{aligned}
\pi_M(0) &= \bar{\pi}_M - \frac{c\beta(t,\sigma)\sigma^2}{4} - c[1-\beta(t,\sigma)]\sigma^2, \\
\pi_M^N(1) &= \bar{\pi}_M - \frac{c}{4}\left[1+\left(\frac{2c+1-\gamma}{2c+3-3\gamma}\right)\gamma\right]^2\beta(t,\sigma)\sigma^2 - c[1-\beta(t,\sigma)]\sigma^2, \\
\pi_M^S(1) &= \bar{\pi}_M + \frac{(c+1-\gamma)(1-\gamma)^2}{(2c+3-3\gamma)^2}\beta(t,\sigma)\sigma^2 - c[1-\beta(t,\sigma)]\sigma^2, \\
\pi_M(2) &= \bar{\pi}_M + \frac{(c+1-\gamma)}{(2c+3-\gamma)^2}\beta(t,\sigma)\sigma^2 - c[1-\beta(t,\sigma)]\sigma^2, \pi_R(0) = \bar{\pi}_R + \frac{\beta(t,\sigma)\sigma^2}{2}, \\
\pi_R(1) &= \bar{\pi}_R + \left[1+\gamma+\frac{4(1-\gamma)^3}{(2c+3-3\gamma)^2}\right]\frac{\beta(t,\sigma)\sigma^2}{4}, \pi_R(2) = \bar{\pi}_R + \frac{2}{(2c+3-\gamma)^2}\beta(t,\sigma)\sigma^2,
\end{aligned}$$

where $\bar{\pi}_M = (c+1-\gamma)a^2/(2c+3-\gamma)^2$ and $\bar{\pi}_R = 2a^2/(2c+3-\gamma)^2$. The rest of the proof is similar to those for Lemma 4 and Propositions 2 to 4, and we ignore the details. □

References

Cachon, G., M. Lariviere. 2001. Contracting to Assure Supply: How to Share Demand Forecasts in a Supply Chain. *Management Sci.* **47**(5) 629–646.

Cachon, G. P., A. G. Kök. 2010. Competing Manufacturers in a Retail Supply Chain: On Contractual Form and Coordination. *Management Sci.* **56**(3) 571–589.

Choi, S. 1991. Price Competition in a Channel Structure with a Common Retailer. *Marketing Sci.* **10**(4) 271–296.

Ericson, W. A. 1969. A Note on the Posterior Mean of a Population Mean. *J. Roy. Statist. Soc.* **31**(2) 332–334.

Gal-Or, E. 1985. Information Sharing in Oligopoly. *Econometrica* **53**(2) 329–343.

Ha, A., S. Tong. 2008. Contracting and Information Sharing under Supply Chain Competition. *Management Sci.*, **49**(4) 701–715.

Ha, A., S. Tong, H. Zhang. 2011. Sharing Imperfect Demand Information in Competing Supply Chains with Production Diseconomies. *Management Sci.*, **57**(3) 566–581.

Jeuland, A., S. Shugan. 1983. Managing Channel Profits. *Marketing Sci.* **2**(3) 239–272.

Kadiyali, V., P. Chintagunta, N. Vilcassim. 2000. Manufacturer-Retailer Channel Interactions and Implications for Channel Power: An Empirical Investigation of Pricing in a Local Market. *Marketing Sci.* **19**(2) 127–148.

Lee, E., R. Staelin. 1997. Vertical Strategic Interaction: Implications for Channel Pricing Strategy. *Marketing Sci.* **16**(3) 185–207.

Li, L. 1985. Cournot Oligopoly with Information Sharing. *RAND J. Econom.* **16**(4) 521–536.

Li, L. 2002. Information Sharing in a Supply Chain with Horizontal Competition. *Management Sci.* **48**(9) 1196–1212.

Li, L., H. Zhang. 2002. Supply Chain Information Sharing in a Competitive Environment. *Supply Chain Structures: Coordination, Information and Optimization.* J.S. Song and D.D. Yao (eds.). Kluwer Academic Publishers.

Li, L., H. Zhang. 2008. Confidentiality and Information Sharing in Supply Chain Coordination. *Management Sci.* **54**(8) 1467–1481.

Mishra, B., S. Raghunathan, X, Yue. 2009. Demand Forecast Sharing in Supply Chains. *Production Oper. Management* **18**(2) 152–166.

Özer, Ö., K. Chen, Y. Zheng. 2011. Trust in Forecast Information Sharing. *Management Sci.* **57**(6) 1111–1137.

Shin H., T. Tunca. 2010. Do Firms Invest in Forecasting Efficiently? The Effect of Competition on Demand Forecast Investments and Supply Chain Coordination. *Oper. Res.* **58**(6) 1592–1610.

Tang, W., K. Girotra. 2010. Synchronizing Global Supply Chains: Advance Purchase Discounts. Working Paper, INSEAD.

Vives, X. 1984. Duopoly Information Equilibrium: Cournot and Bertrand. *J. Econom. Theory* **34**(1) 71–94.

Vives, X. 1999. *Oligopoly Pricing.* The MIT Press, Massachusetts.

Yue, X., J. Liu. 2006. Demand Forecast Sharing in a Dual-Channel Supply Chain. *European J. of Oper. Res.* **174**(1) 646–667.

Zhang, F. 2006. Competition, Cooperation, and Information Sharing in a Two-Echelon Assembly System. *Manufacturing Service Oper. Management* **8**(3) 273–291.

Zhang, H. 2002. Vertical Information Exchange in a Supply Chain with Duopoly Retailers. *Production Oper. Management* **11**(4) 531–546.

Zhao, X., L. Xue, F. Zhang. 2011. Outsourcing Competition and Information Sharing with Asymmetrically Informed Suppliers. Working Paper, Olin Business School, Washington University in St. Louis.