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Incentive-Driven Information Dissemination in Two-Tier Supply Chains

Li Jiang, Zhongyuan Hao
Faculty of Business, The Hong Kong Polytechnic University, Hong Kong SAR, China
{l.jiang@polyu.edu.hk, zy.hao@connect.polyu.hk}

We investigate information flow in two-tier supply chains, where retailers order from suppliers and sell in a market with uncertain demand. The retailers each have access to a demand signal and can exchange signals (horizontal information sharing). The suppliers can offer the retailers differential payments to gain access to their signals (vertical information acquisition). We demonstrate that retailer competition is a necessary condition to sustain information flow, whereas supplier competition precludes vertical information acquisition. Facing horizontal competition, the retailers can have an incentive to exchange signals if competition is less intense; and this incentive is stronger when they order from independent suppliers than when they order from a monopolist supplier. In the setting where two retailers order from a monopolist supplier, once the retailers exchange signals, the supplier will acquire signals from them both; otherwise, it will have an incentive to acquire signals if the signals are sufficiently correlated. It can be incentive compatible for horizontal information sharing and vertical information acquisition to coexist so that the retailers' signals are available to all parties. Under this circumstance, the supplier will profit from information flow and the retailers can earn profit gains as well, whereas the consumers will be worse off.

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1. Introduction

Over the past decades, firms across industries have made heavy investments in infrastructure to collect, clean, and analyze data such as intra-day store sales, pre-order data, and basket data. Global IT spending is expected to top US$3,507 billion in 2015 (Statista 2014). Firms rely on the data to make responsive decisions that fit market conditions, and can further leverage such advantage by sharing data with each other. In today's business world, fierce competition is no longer the only winning strategy because firms now have more opportunities to engage in various modes of collaboration to improve their resilience. Data sharing, made feasible with the advance in IT, is practical to realize. In the aviation industry, Delta Air Lines, Inc. states in its privacy policy that it "routinely" shares consumer information with SkyMiles partners that include Alaska Airlines, Hawaiian Airlines, etc. (Lazarus 2015). This allows airlines to jointly track passengers' flyer statuses to better understand their needs. In the retailing industry, Lands' End Inc., which sells clothing online and through catalogs, shares consumer information with a few companies whose products match the interests of Lands' End shoppers as well (Heun 2001). WalMart and Target have teamed up with other big retailers to develop a mobile payment system, called Merchant Customer Exchange (MCX). MCX's CurrentC supports data collection (Smith 2014). The members gain tight control of customer data and effectively cooperate by committing to the use of CurrentC as their exclusive payment system. This platform, with its standard data format and transmission processes, paves the way for the members to realize data sharing.

Data communication between firms with market access and their upstream partners is prevalent. Traditionally, suppliers obtain retailers' data through two methods. One method is through electronic data interchange (EDI) for strictly formatted data and the other is through syndicated data providers that receive and sell data together with the analysis. Since the turn of this century, retailer-direct exchange, whereby retailers disclose data directly to their suppliers in a specific format, has risen as an important mode of data transmission. To access WalMart data, for instance, suppliers have to go directly to the Retail Link data portal. Similarly, Target Corp. delivers data via Partners Online. By this method, retailers provide their own data and determine their actions in response to the information from the data. However, retailers may hesitate to disclose data because they perceive insufficient efforts by the suppliers in IT investments, or because they lack trust in the suppliers and believe they will use the data to "put one over us" (Dolley et al. 2009). Suppliers can offer payments to retailers as incentives to disclose their signals. An article in *The Guardian* notes that suppliers are willing to pay supermarkets "a lot of money" to gain access to customer purchasing information, which, as Sainsbury's and Tesco stress, is kept out of the hands of third parties (Ferguson 2013). By reaching out to negotiate with individual retailers for data acquisition, suppliers have the flexibility to tailor the relationships with retailers by varying incentives and establish information links for their benefit.

In reality, horizontal information sharing and vertical information acquisition can coexist to transmit the demand signals at downstream firms to other channel parties. CVS, Kmart, and WalMart initiated an alliance to pool up-to-the-minute sales data from their thousands of stores nationwide and major drug makers paid up to $25 million for their data to track and forecast sales trends (Heun 2001). Despite the practical relevance and importance of information sharing, the existing economics and operations management (OM) literature, by treating horizontal and vertical information sharing separately, produces a gloomy picture on the sustainability of information flow. Neither form of information flow has been shown to be sustainable under such assumptions as linear production costs at the suppliers, price-only contracts, and quantity competition between firms with market access (please refer to the literature review section, where we discuss existing results and position this paper in the literature). This gap between academic literature and industry reality motivates us to investigate information flow by incorporating more features into the existing framework. By doing so, we strive to gain a better understanding of the factors that affect the incentives for supply chain parties to engage in horizontal and vertical information sharing, and the impacts of incentive-driven information flow on the profits of individual parties and consumer welfare. These are particularly pertinent in the Big Data era, when the access to and sharing of information are of strategic importance.

We explore four representative two-tier supply chains, in which retailers order from suppliers and sell in a common market with uncertain demand. The supply chain structures (to be specified later) are differentiated by the existence of horizontal competition in either one or both tiers. The retailers each have access to an unbiased demand signal that distorts the actual market condition by a noise term. We assume the signals available to the retailers are correlated. The retailers can exchange signals (horizontal information sharing) and the suppliers can offer them possibly different payments to acquire signals (vertical information acquisition). Information agreements are signed before the signals are received. After the signals are received and communicated according to the agreement, the retailers and suppliers utilize the signals available to them in decision making.

By learning and utilizing a retailer's signal, a supplier can enhance its responsiveness in setting wholesale prices. The particular retailer will however have its flexibility in responsive ordering restrained, as the variance of its order quantity will decrease. We call this the direct effect of information acquisition. When ordering from two independent suppliers, the retailer, after disclosing its signal to a supplier, will strengthen its signal utilization to be more flexible in ordering from the other supplier. We call this the indirect effect of information acquisition. With retailer competition, vertical information acquisition by a supplier from a retailer has a carryover effect on the other retailer. Specifically, when the retailers each order from an independent supplier, the other retailer will strengthen its signal reliance in ordering from its exclusive supplier. When the retailers order from the same supplier, however, the supplier's signal-based wholesale pricing will restrain the other retailer's ordering responsiveness as well.

Horizontal information sharing has a pooling effect on the retailers. When competition is weak, the retailers' quantity decisions are not much correlated and they can flexibly use both signals available from signal exchange. As competition intensifies, a retailer's quantity will have a stronger impact on the other retailer's price. Although signal exchange grants the retailers access to more signals, the high pressure of quantity interaction will make them more cautious in utilizing the pooled signals, particularly when the signals are strongly correlated. As a consequence, the pooling effect is able to enhance the retailers' responsiveness in ordering when the market is less competitive. When the two forms of information flow coexist, the various effects of information acquisition and the pooling effect of information sharing will superimpose on one another to influence system performance, and their scales are influenced by channel structure and the established information links.

We demonstrate that channel structure, market competition, and signal structure are crucial to the sustainability of incentive-driven information flow. With a monopolist retailer, vertical signal acquisition is unsustainable. This is because once a supplier solicits signal from a retailer, the direct effect of signal acquisition will play a dominant role in making the retailer suffer a profit loss that is more than what the supplier can compensate with its profit gain. With retailer competition, information acquisition is not sustainable when the retailers each order from an exclusive supplier. We attribute this to the suppliers' unilateral decision making that makes it the dominant strategy for each supplier to forfeit information acquisition, because it is unable to afford the payment required to incentivize its exclusive retailer to disclose its signal. In this situation, however, the retailers have an incentive to exchange signals when competition is less intense and the pooling effect is positive on them.

In the setting in which two retailers order from a monopolist supplier, if the retailers forfeit signal exchange, the supplier will have an incentive to acquire signals if the signals are sufficiently correlated. Through signal acquisition, the supplier will access both signals if competition is not too intense but one signal otherwise, and its incentive to acquire both signals will strengthen with signal correlation. This is because as competition pressure on the retailers is relieved or their signals are more indicative of each other, once the supplier has access to a signal, additional signal availability to it will trigger marginal effects on channel interactions. The retailers' profit losses as a result of signal disclosure will reduce, enabling the supplier to afford more signal availability. Once the retailers share information to level their signal availability, the supplier will always solicit signals from them both. Vertical information acquisition then functions as a strategic complement to horizontal information sharing. Offering the retailers differential payments is an effective instrument for signal acquisition by the supplier. To acquire one signal, it will offer a payment to the particular retailer alone in an amount that is just enough to compensate for its loss from signal disclosure, leaving the other retailer suffering a net profit loss. To acquire both signals, it will offer differential payments to manipulate the retailer's incentives and make them dominantly prefer to disclose their signals.

A necessary condition to sustain horizontal signal exchange between the retailers in this setting is that market competition is less intense so that they can benefit from the arising pooling effect. Once they exchange signals, the supplier will acquire signals from them both and information transparency will be realized. Under this circumstance, the direct effect of information acquisition will make the suppliers better off but the customers worse off. The retailers will generally suffer profit losses as the influence of signal disclosure on their profits is usually negative and outweighs the benefit of signal exchange (and the supplier's payments). However, they can be better off as well when signal correlation is weak and signal accuracy is low, in which case the streamlined decision making resulting from information flow will be dominant in improving system profit to generate a net profit gain to every individual party.

Moreover, we examine the robustness of the results with respect to model elements and explore the impact of multiple signals available to a retailer on information flow. We show that a sufficiently large pool of weakly correlated signals at a retailer can suffice to stimulate a supplier to acquire all signals. The remainder of this section presents a review of the literature. We introduce model setting in §2. In §3, we analyze the information structures sustainable in four representative supply chains and investigate the impact of multisignal availability to a retailer. We explore the managerial implications in §4 and conclude the paper in §5. All the mathematical proofs are presented in the online appendix (available as supplemental material at http://dx.doi.org/10.1287/msom.2016.0575).

Literature Review

This paper belongs to the literature on information sharing. Chen (2003) classifies this literature into three areas. The first area centers on a central planner who obtains information about sales or production status to streamline the decision-making processes among all parties to achieve coordination. Lee and Whang (2000) provide a survey of the relevant literature. The second area regards information asymmetry that prompts either the informed party to signal or the uninformed party to screen and extract real information. Our paper relates to the less developed third area on incentive-based information sharing. This stream of literature can be classified into two substreams, horizontal sharing between informed parties and vertical sharing between informed and uninformed parties. These two substreams of work have been conducted separately. In Table 1, we group the main research articles and position our work within this literature.

Clarke (1983) considers an oligopoly model in which firms engage in Cournot competition to sell perfect substitutes and proves that there is never a mutual incentive for all firms to share private demand information. Vives (1984) analyzes a duopoly where the firms each have access to a set of observations and sell substitutable products. He discusses the mixed effects that arise from information sharing and shows the firms will not share observations under Cournot competition but will do so under Bertrand competition when they engage in a Nash game. Gal-Or (1985) analyzes an oligopoly in which each firm observes a private signal and decides whether to disclose it to the other firms. She shows no horizontal information sharing is the unique Nash equilibrium. Li (1985) show, with different assumptions about market uncertainties and information, a similar non-sustainability result. Similarly, Kirby (1988) analyzes an oligopoly model where firms hold demand information and shows horizontal information sharing is Pareto-preferred if total cost functions are sufficiently convex. Natarajan et al. (2013) include timing as a factor in establishing horizontal information sharing. They demonstrate, under certain assumptions about the demand and the signals, that firms can have an incentive to share signals after receiving them. In this paper, we treat horizontal information sharing as an ex-ante cooperative decision by the retailers and examine the pooling effect it generates.

Li (2002) considers a manufacturer selling to multiple retailers that have demand information and sell perfect

Table 1 Existing Literature on Incentive-Based Information Sharing

	Form of info sharing		Signal structure		Timing		Competition mode	
	Horizontal	Vertical	Correlated	Independent	Ex-ante	Ex-post	Price	Quantity
Clarke (1983)	×			×	×			×
Vives (1984)	×			†	×		×	×
Li (1985)	×			×	×			×
Gal-Or (1985)	×			†	×			×
Kirby (1988)	×			×	×			×
Natarajan et al. (2013)	×			×	×	×		×
Li (2002)		×		×	×			×
Zhang (2002)		×		×	×		×	×
Li and Zhang (2008)		×		×	×		×	
Ha and Tong (2008)		×		#	×			×
Ha et al. (2011)		×		×	×		×	×
Guo et al. (2014)		×		#		×	×	
This paper	×	×	×		×			×

[†]The assumptions about market uncertainties and the subjects to be shared in Vives (1984) and Gal-Or (1985) are unique and different from those in the standard literature.
[#]Ha and Tong (2008) and Guo et al. (2014) assume that the firms share realized market demand.

substitutes. He identifies two effects of vertical information sharing. Under the direct effect, the manufacturer can use better information to seek more information rent but the retailer will suffer a profit loss after signal disclosure. Under the leakage effect, a retailer will be worse off if other retailers learn its information by inferring it from the manufacturer's adjusted wholesale prices. He shows that both direct and leakage effects discourage vertical information sharing. We do not study leakage effect, but identify direct, indirect, and carryover effects of vertical information acquisition that prevail in various channel structures. Zhang (2002) studies vertical information sharing between a firm and two retailers selling differentiable products, and shows the firm benefits from having access to more signals but the retailers are placed at a disadvantageous position by disclosing signals. He states that information trading that involves all retailers will take place if and only if it increases supply chain profit. We complement this statement by showing that, with the new features included in our model setting, information flow can take place even when it causes supply chain profit to decrease. Li and Zhang (2008) consider a setting of a supplier selling to multiple retailers that engage in price competition. They discuss three scenarios on confidentiality in vertical information sharing and show that with confidentiality, all retailers have the incentives to share information with the supplier if competition is intense. We demonstrate that vertical information sharing can be sustained when the retailers engage in quantity competition under the same confidentiality scenario. Ha and Tong (2008) show in a setting of two chains each consisting of a supplier and a retailer having access to the true demand information, that vertical information sharing hurts supply chain profit under price-only contracts. They attribute this to the aggravated double marginalization effect that arises from information sharing. Ha et al. (2011) introduce production diseconomy at the suppliers to offset the effect arising from vertical information sharing, and show that system profit can improve only if production diseconomy is large. Guo et al. (2014) study ex-post vertical information sharing and show that vertical information sharing can be realized by assuming the firms have access to the true demand information with different probabilities.

In this paper, we add two main elements in our investigation of information flow. First, we assume the signals available to the retailers are correlated. This differs from the existing literature that assumes signal independence. We establish that a strong signal correlation can incentivize the suppliers to acquire signals but weaken the retailers' incentive to share signals. Second, we combine the two forms of information flow, with horizontal information sharing being a cooperative decision by the retailers and vertical information acquisition built on the interaction between the suppliers and retailers, to investigate their strategic interaction for its role in sustaining information flow. Moreover, in establishing information acquisition, the suppliers can offer the retailers differential payments to manipulate their incentives. As we will demonstrate in detail later, this instrument is crucial to sustaining vertical information flow. With these new features and other standard assumptions, we characterize conditions to sustain one or both forms of information flow. All this complements the existing literature and provides new insights into information sharing.

This paper also relates to the literature on channel structure. McGuire and Staelin (1983) analyze the effects of market competition on distribution channel design. They find that manufacturers prefer to sell through the retailers they own if product substitutability is low, but through decentralized distribution networks if product substitutability is strong. Moorthy (1988) explores the implications of the strategic cooperation between manufacturers for channel design. His main finding is that manufacturers prefer vertical integration over a decentralized structure when they cooperate, whereas a decentralized structure is the only equilibrium structure when they do not cooperate. We will explore the impacts of channel structure, with its implications for the horizontal and vertical interactions among channel parties, on the sustainable pattern of information structure.

2. The Model

We consider two-tier supply chains in which suppliers sell products through retailers in a market with uncertain demand. Figure 1 illustrates four channel structures, where a dotted arrow indicates signal flow and a solid arrow indicates product flow. System B (Figure 1(a)) is a bilateral monopoly, in which a supplier sells two products to a retailer. This setting is applicable when the supplier and retailer hold dominant power in their respective markets. In the supplier competition (SC) system (Figure 1(b)), a monopolist retailer orders products from two independent suppliers and sells them in a common market. WalMart Inc., the biggest retailer in the world, holds monopolist power in many of its serving areas and sources from numerous suppliers. In the retailer competition (RC) system (Figure 1(c)), two retailers order from a monopolist supplier. This approximates the practical situation in which few suppliers provide for major competitors in an industry. For instance, the suppliers in the automobile industry have undergone waves of consolidation in the past two decades. Ford, GM, and Toyota now all source power-trains from BorgWarner, a parts supplier headquartered in Auburn Hills, Michigan. In the supplier and retailer competition (SRC) system (Figure 1(d)), two chains, each consisting of a retailer and its exclusive supplier, compete in selling products. Shou and Li (2009) cite a case in the pharmaceutical industry in which two major companies account for 70% of the market for an anticoagulant and order from independent suppliers. Other examples can be found in the wireless service industry (Wu and Chen 2005) and fast-food chains (McGuire and Staelin 1983).

We follow the literature to assume that the inverse demand function for product i is

$$p_i = a_i + \mu - q_i - \beta q_{3-i}, \quad i = 1, 2, \tag{1}$$

where a_i is its market potential and q_i is its quantity. We use $\beta \in [0, 1)$ to model the extent of the impact on a retailer's demand of the other retailer's price, and refer to it as competition intensity. Market competition will intensify as β increases. We let μ capture the uncertainty in general market condition, which has normal prior distribution with mean zero and variance σ_μ. Let c_i be the cost of producing product i by a supplier. Each retailer has access to a demand signal for μ. We make the following assumptions about signal structure.

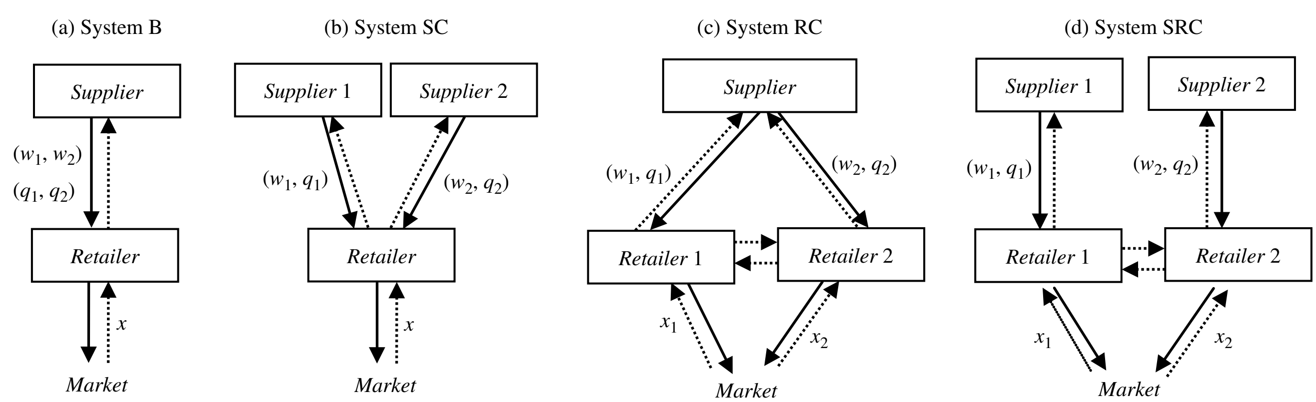
Assumptions About Signal Structure

Assumption A1. *In systems B and SC, the monopolist retailer has signal* $X = \mu + \varepsilon$, *where* ε *is the noise term and follows normal* $N(0, \sigma_\varepsilon)$. (μ, ε) *is bivariate normal, with* $\text{cov}(\mu, \varepsilon) = 0$.

Assumption A2. *In systems RC and SRC, retailer* i *has signal* $X_i = \mu + \varepsilon_i$, *where* ε_i *is the noise term and follows normal* $N(0, \sigma_\varepsilon)$. (μ, ε_i) *is bivariate normal, with* $\text{cov}(\mu, \varepsilon_i) = 0$. (μ, X_1, X_2) *is multivariate normal, with* $\text{cov}(\varepsilon_1, \varepsilon_2) = \rho \in (0, \sigma_\varepsilon)$.

By Assumption A2, the signals available to the retailers are correlated. This is reasonable in today's business environment. In the retailing industry, for instance, store salesare linked to the general economic

Figure 1 Supply Chain Structures



Notes. In Figure 1, w_1 and w_2 are wholesale prices; q_1 and q_2 are order quantities; x, x_1, and x_2 are signals. Two products are managed in all the systems.

condition reflected by home price and consumption indices. This practically correlates the sales data as the signals received by the retailers. Over the past years, Americans have been cutting back on their spending in the face of an uncertain economy. This has hit major retailers such as WalMart and Target, whose sales patterns display a strong correlation. Under these assumptions about signal structure, we can derive the conditional expectations as follows:

$$E(\mu \mid X=x)=\frac{\sigma_\mu}{\sigma_\mu+\sigma_\varepsilon}x,\quad E(\mu \mid X_i=x_i)=\frac{\sigma_\mu}{\sigma_\mu+\sigma_\varepsilon}x_i,$$

$$E(\mu \mid X_1=x_1, X_2=x_2)=\frac{\sigma_\mu}{2\sigma_\mu+\sigma_\varepsilon+\rho}(x_1+x_2),\quad \text{and}$$

$$E(X_j \mid X_i=x_i)=\frac{\sigma_\mu+\rho}{\sigma_\mu+\sigma_\varepsilon}x_i.$$

$$E(X_j \mid X_i=x_i)\to\frac{\sigma_\mu}{\sigma_\mu+\sigma_\varepsilon}x_i \quad \text{as } \rho\to 0.$$

This is consistent with the existing literature (see, for instance, Li 2002, Ha et al. 2011).

Information flow can take place in two forms. Horizontally, the retailers can exchange signals as a means of cooperation (horizontal information sharing) provided that they each will earn a profit gain that is the rationality requirement to sustain cooperation. Vertically, the suppliers can offer the retailers payments to acquire their signals (vertical information acquisition). Among the four representative two-tier supply chain structures, vertical information acquisition is the only feasible form of information flow in systems B and SC, whereas horizontal information sharing is a strategic option for the retailers in systems RC and SRC. With horizontal competition in both tiers in system SRC, information sharing will interplay with information acquisition in the two competing chains to move the retailers' signals. A comparative analysis of the information structures sustainable in the four structures can shed light on the effects of various factors on establishing information flow.

Price-only contracts govern vertical interactions. The suppliers and retailers utilize the available signals in making respective decisions. We assume their decision policies take linear additive forms. Let $\Omega_S=(x_s^1, x_s^2, \ldots)$ and $\Omega_R=(x_R^1, x_R^2, \ldots)$ be the signals available to a supplier and a retailer, respectively. The supplier's wholesale price takes the form of $w(\Omega_S)=w_0+\sum w_i x_s^i$, and the retailer's order takes the form of $q(\Omega_R)=q_0+\sum q_i x_R^i$, where w_0, q_0, $\{w_i, i=1,2,\ldots\}$, and $\{q_i, i=1,2,\ldots\}$ are the parameters to be determined. Radner (1962) claims that it is sufficient to consider linear decision rules for linear demand functions. The policy structures are common knowledge. The retailers' quantities affect market price and consumer utility. We define consumer utility as follows:

$$CS=\sum_{i=1}^{2}E[U(q_i)-p_iq_i],\quad \text{where,}$$
$$U(q_i)=(a+\mu)q_i-\frac{q_i^2}{2},\quad i=1,2. \tag{2}$$

As illustrated in Figure 2, our decision framework consists of an information subgame and an operations subgame, with the two subgames separated by the receipt and communication of signals. In the information subgame, which occurs before the signals are received, the retailers and suppliers sign information agreements to establish an information structure. Once the signals are received, they are communicated as per the agreements. In the operations subgame, by utilizing the signals available to them, the suppliers offer wholesale prices and the retailers make order decisions. Finally, full market uncertainty is revealed, market price is cleared, and all parties accrue revenue.

We assume the retailers will truthfully disclose signals according to the information agreements, and reflect them in order decisions; otherwise the agreements will be nullified. Li (1985), Zhang (2002), and Ha et al. (2011) explicitly make this assumption in their investigations, whereas Vives (1984) and Li (2002) implicitly use the same assumption. Li and Zhang (2008) show that the retailers in an oligopoly have no incentive to distort signals. For our model setting, we can verify that retailers' untruthful signal revelation is not credibly sustainable. As a related issue, Lee and Whang (2000) comment that it is lack of confidentiality that obstructs information transmission. Li and Zhang (2008) argue that confidentiality must be ensured at the early stage of a partnership and an information strategy must be adopted before any operational activities take place. In practice, an increasing number of firms outsource IT services to external providers, such as IBM and SAP, which build infrastructure, manage data collection, storage, and offer business advice. Data transmission by these independent service providers is secure and can greatly prevent intentional leakage.

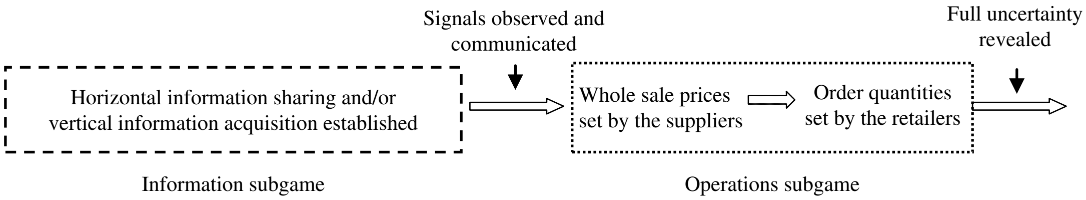
3. Information Flow in Supply Chains

We next analyze the information structures that are sustainable in the four typical two-tier supply chain structures, and explore the impacts of information flow on the performance of the individual parties and the system, as well as the implications for the customers.

Bilateral Monopoly (Setting B)

In a bilateral monopoly, information flow can only occur vertically. In the information subgame, the supplier offers a payment m to the retailer for signal access. The retailer's decision is $n\in\{0,1\}$: $n=0$ indicates that it does not disclose the signal, whereas $n=1$ indicates that it does. Upon receiving the signal, the

Figure 2 **Decision Framework**



retailer discloses it according to the agreement. In the operations subgame, given wholesale prices $w=(w_1, w_2)$ and signal x, the retailer orders $q=(q_1, q_2)$ to maximize its profit of

$$\pi_R(q\mid x,w)=\mathrm{E}\left[\sum_{i=1}^{2}(a_i+\mu-q_i-\beta q_{3-i}-w_i)q_i\mid X=x\right]. \quad (3)$$

Let its order be $q(w\mid x)=(q_1(w\mid x), q_2(w\mid x))$. Without vertical information acquisition ($n=0$), the supplier anticipates the retailer's signal-based order quantities and sets wholesale prices to maximize its profit of $\pi_S^{(0)}=\mathrm{E}[\sum_{i=1}^{2}(w_i-c_i)q_i(w\mid x)]$. With vertical information acquisition ($n=1$), the supplier maximizes its profit, conditional on the received signal x, of $\pi_S^{(1)}(x)=\mathrm{E}[\sum_{i=1}^{2}(w_i-c_i)q_i(w\mid x)\mid x]$. The equilibrium outcomes are shown in Table 2.

The supplier will utilize the signal, available from information acquisition, to make responsive wholesale price decisions. We can show that the variances of the retailer's order quantities will reduce and such reductions will decrease as market competition intensifies (β increases). Vertical information acquisition has its direct effect of improving the supplier's responsiveness in wholesale pricing but restricting the retailer's ordering responsiveness. Total profit of the supplier and retailer will decrease. The supplier will then be unable to offer a payment that is sufficient to incentivize the retailer to disclose its signal. This precludes vertical information acquisition as a sustainable strategic move.

Upstream Supplier Competition (System SC)

In system SC, two suppliers sell products through a retailer in the market. In the information subgame, the two suppliers unilaterally offer $m=(m_1, m_2)$ to the retailer for signal access. The retailer decides on $n=(n_1, n_2)$, where $n_i\in\{0,1\}$ and $n_i=0$ ($n_i=1$, resp.) indicates that it does not (does, resp.) disclose its signal to supplier i. In the operations subgame, given the wholesale prices offered by the suppliers, the retailer maximizes its profit, as given in (3), by choosing order quantities $q(w\mid x)$. When $n=(0,0)$, each supplier i, with no signal access, anticipates the retailer's signal-based order to maximize its profit of

$$\pi_{Si}^{(0,0)}(w)=\mathrm{E}[(w_i-c_i)q_i(w\mid x)], \quad i=1,2. \quad (4)$$

When $n=(1,1)$, each supplier i maximizes its profit, conditional on the received signal x, of

$$\pi_{Si}^{(1,1)}(w\mid x)=\mathrm{E}[(w_i-c_i)q_i(w\mid x)\mid X=x], \quad i=1,2. \quad (5)$$

When $n=(1,0)$, supplier 1 gains signal access but supplier 2 does not. They choose the wholesale prices to maximize their profits given in (5) and (4), respectively. The setting when $n=(0,1)$ is symmetric, with the roles of the two suppliers switched.

Table 3 groups the subgame operation outcomes and the corresponding expected ex-ante profits (including incentive payments) of the retailer and suppliers in system SC. The detailed derivation process is presented in the online appendix.

By only granting supplier i access to its signal, the retailer will rely less (more, resp.) on its signal in ordering from supplier i (supplier $3-i$, resp.). This is attributed to the direct (indirect, resp.) effect of information acquisition by a supplier on the retailer in ordering from this particular supplier (the other supplier, resp.). Although the direct effect limits the retailer's responsive ordering, the indirect effect plays the opposite role.

Table 2 **Operations Equilibria in System B**

n	Decision policy	Ex-ante system profit
0	$w_i^{(0)}=\dfrac{a_i+c_i}{2}$ $q_i^{(0)}(x)=\dfrac{a_i-c_i-\beta(a_{3-i}-c_{3-i})}{4(1-\beta^2)}+\dfrac{\sigma_\mu}{2(1+\beta)(\sigma_\mu+\sigma_\varepsilon)}x$	$\pi_T^{(0)}=\dfrac{3[(a_1-c_1)^2+(a_2-c_2)^2-2\beta(a_1-c_1)(a_2-c_2)]}{16(1-\beta^2)}+\dfrac{\sigma_\mu^2}{2(1+\beta)(\sigma_\mu+\sigma_\varepsilon)}$
1	$w_i^{(1)}(x)=w_i^0+\dfrac{\sigma_\mu}{2(\sigma_\mu+\sigma_\varepsilon)}x$ $q_i^{(1)}(x)=q_i^0(x)-\dfrac{\sigma_\mu}{4(1+\beta)(\sigma_\mu+\sigma_\varepsilon)}x$	$\pi_T^{(1)}=\pi_T^{(0)}-\dfrac{\sigma_\mu^2}{8(1+\beta)(\sigma_\mu+\sigma_\varepsilon)}$

Table 3 Operations Subgame Equilibria in System SC

$n=(n_1,n_2)$	Decision policy	Ex-ante profit
(0, 0)	$w_i^{(0,0)}=w_i^0$	$\pi_R^{(0,0)}=\pi_R^0+\dfrac{\sigma_u^2}{2(1+\beta)(\sigma_\varepsilon+\sigma_\mu)}$
	$q_i^{(0,0)}(x)=q_i^0+\dfrac{1}{2(1+\beta)}Ax$	$\pi_{Si}^{(0,0)}=(w_i^0-c_i)q_i^0$
(1, 1)	$w_i^{(1,1)}(x)=w_i^0+\dfrac{1-\beta}{2-\beta}Ax$	$\pi_R^{(1,1)}=\pi_R^0+\dfrac{(1-4\beta^2)\sigma_u^2}{2(2-\beta)^2(1+\beta)(\sigma_\varepsilon+\sigma_\mu)}+m_1+m_2$
	$q_i^{(1,1)}(x)=q_i^0+\dfrac{1-2\beta}{2(1+\beta)(2-\beta)}Ax$	$\pi_{Si}^{(1,1)}=\pi_{Si}^{(0,0)}+\dfrac{(1-\beta)(1-2\beta)\sigma_u^2}{2(2-\beta)^2(1+\beta)(\sigma_\varepsilon+\sigma_\mu)}-m_i$
(1, 0)	$w_1^{(1,0)}(x)=w_1^0+\dfrac{1-\beta}{2}Ax$	$\pi_R^{(1,0)}=\pi_R^0+\dfrac{(5+3\beta)\sigma_u^2}{16(1+\beta)(\sigma_\varepsilon+\sigma_\mu)}+m_1$
	$w_2^{(1,0)}=w_2^0$	$\pi_{S1}^{(1,0)}=\pi_{S1}^{(0,0)}+\dfrac{(1-\beta)\sigma_u^2}{8(1+\beta)(\sigma_\varepsilon+\sigma_\mu)}-m_1$
	$q_1^{(1,0)}(x)=q_1^0+\dfrac{1}{4(1+\beta)}Ax$	$\pi_{S2}^{(1,0)}=\pi_{S2}^{(0,0)}$
	$q_2^{(1,0)}(x)=q_1^0+\dfrac{1}{4(1+\beta)}Ax$	
(0, 1)	$w_1^{(0,1)}=w_1^0$	$\pi_R^{(0,1)}=\pi_R^0+\dfrac{(5+3\beta)\sigma_u^2}{16(1+\beta)(\sigma_\varepsilon+\sigma_\mu)}+m_2$
	$w_2^{(0,1)}(x)=w_2^0+\dfrac{1-\beta}{2}Ax$	$\pi_{S1}^{(0,1)}=\pi_{S1}^{(0,0)}$
	$q_1^{(0,1)}(x)=q_1^0+\dfrac{2+\beta}{4(1+\beta)}Ax$	$\pi_{S2}^{(0,1)}=\pi_{S2}^{(0,0)}+\dfrac{(1-\beta)\sigma_u^2}{8(1+\beta)(\sigma_\varepsilon+\sigma_\mu)}-m_2$
	$q_2^{(0,1)}(x)=q_2^0+\dfrac{1}{4(1+\beta)}Ax$	

Notes.

$$w_i^0=\frac{(2-\beta^2)a_i-\beta a_{3-i}+2c_i+\beta c_{3-i}}{4-\beta^2},\qquad q_i^0=\frac{(2-\beta^2)(a_i-c_i)-\beta(a_{3-i}-c_{3-i})}{2(1-\beta^2)(4-\beta^2)},$$

$$A=\frac{\sigma_\mu}{\sigma_\mu+\sigma_\varepsilon},\qquad \pi_R^0=\sum_{i=1}^{2}(a_i-q_i^0-\beta q_{3-i}^0-w_i^0)q_i^0.$$

$\dfrac{A}{2(1+\beta)}$ captures the retailer's signal reliance when ordering from supplier i without information flow.

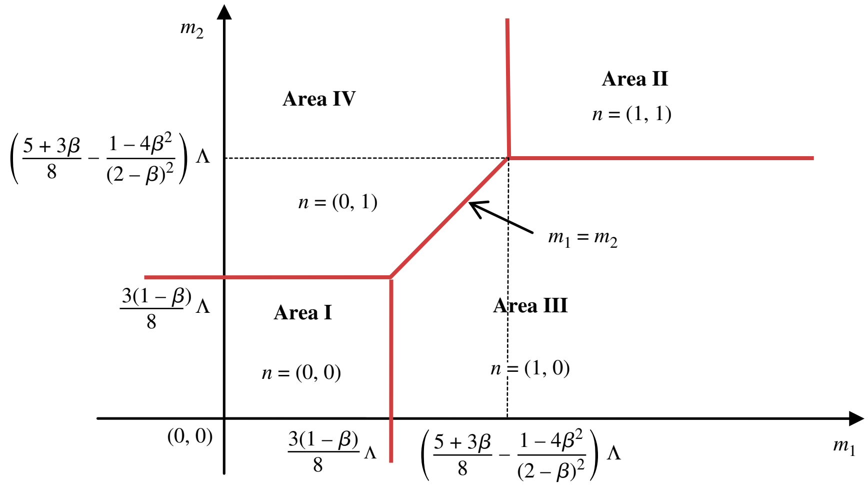
As competition intensifies (β increases), the retailer will make a smaller (larger, resp.) adjustment to its order from supplier i (supplier $3-i$, resp.), i.e., the direct effect will weaken but the indirect effect will strengthen with market competition. By granting both suppliers access to its signal, the retailer will lower signal reliance in ordering from them both and the reductions will increase with competition. Thus, the direct effect of signal disclosure to a supplier on the retailer is stronger than the indirect effect of signal disclosure to the other supplier. A supplier's signal reliance in wholesale pricing will be greater when the signal is available to the other supplier as well. As competition intensifies ($\beta\to 1$), signal availability will have a negligible effect on the suppliers' wholesale prices though the retailer will continue to adjust orders.

The retailer chooses to disclose its signal to the two suppliers given their offered payments. As illustrated in Figure 3, vertical information acquisition will not occur if the suppliers' offered payments are low (Area I). The retailer will disclose its signal to both suppliers if they offer large payments (Area II), but will only disclose its signal to the supplier who offers a larger payment in other situations (Areas III and IV). Anticipating these, the suppliers will choose to offer the payments $m=(m_1,m_2)$.

Proposition 1. *In system SC where two suppliers sell to a retailer, neither supplier will gain access to the retailer's signal. With $n=(n_1,n_2)=(0,0)$, vertical information acquisition is not sustainable.*

Proposition 1 shows that neither supplier has an incentive to acquire the signal at the monopolist retailer

Figure 3 (Color online) Equilibrium Transaction Decision in System SC, Given (m_1, m_2), $\Lambda = \sigma_u^2/(2(1+\beta)(\sigma_\varepsilon+\sigma_\mu))$



in system SC. Vertical information acquisition by a supplier from the retailer will have a direct effect of limiting the retailer's responsiveness in ordering from this particular supplier but an indirect effect of strengthening the retailer's signal reliance in ordering from the other supplier. The direct effect will always dominate the indirect effect to make the retailer suffer a profit loss by disclosing its signal to a supplier, and this profit loss will be more than what the supplier can compensate with its profit gain from responsive wholesale pricing. This is irrespective of the status of information acquisition by the other supplier. Hence, it is the dominant strategy for each supplier not to acquire signal from the retailer.

Downstream Retailer Competition (System RC)
In system RC, a monopolist supplier sells to two competing retailers. Because both retailers have access to signals, it is pertinent for them to consider exchanging signals so as to build a cohesive force into their competitive relationship. In the information subgame, we assume that the retailers first make a decision to exchange signals and the supplier then offers them payments as incentives to disclose their signals. Once the retailers exchange signals, their horizontal information links are publically known, for which the CVS–Kmart–WalMart alliance on store sales sharing provides a canonical example. Under retailer-direct mode of data communication, the supplier reaches out to negotiate with individual retailers for signal acquisition. The signals available to the retailers substantially influence the supplier's decisions about which retailers to approach, which signals to acquire, as well as the incentive payments it has to offer. It is plausible that the supplier makes signal-acquisition decisions after learning the status of signal exchange between the retailers. As we will comment later, the information structure that is sustainable in system RC is robust with respect to the information decision sequence.

The supplier offers possibly different payments $m = (m_1, m_2)$ to the retailers for signal access. Let the retailers' decisions be $n = (n_1, n_2)$, where $n_i = 1$ ($n_i = 0$, resp.) indicates that retailer i discloses (does not disclose, resp.) its signal. In the operations subgame, given wholesale prices $w = (w_1, w_2)$ and signals $x = (x_1, x_2)$, the retailers choose order quantities to maximize their respective profits of

$$\pi_{Ri}^N(q_i \mid w_i, x_i) = E[(a_i+\mu-q_i-\beta q_{3-i}-w_i)q_i \mid X_i = x_i], \quad i=1,2, \tag{6}$$

when they forfeit horizontal information sharing, or

$$\pi_{Ri}^S(q_i \mid w_i, x) = E\big[(a_i+\mu-q_i-\beta q_{3-i}-w_i)q_i \mid X_1 = x_1, X_2 = x_2\big], \quad i=1,2, \tag{7}$$

when they engage in information sharing. The supplier, anticipating the retailers' signal-based order decision, chooses wholesale prices. Its profit function depends on the information structure. In particular,

$$\pi_S^n = \begin{cases} \pi_S^{(0,0)} = E\left[\sum_{i=1}^{2}(w_i-c_i)q_i\right] & n=(0,0), \\ \pi_S^{(1,1)}(x) = E\left[\sum_{i=1}^{2}(w_i-c_i)q_i \,\middle|\, (X_1=x_1, X_2=x_2)\right] & n=(1,1), \\ \pi_S^{(1,0)}(x_1) = E\left[\sum_{i=1}^{2}(w_i-c_i)q_i \,\middle|\, X_1=x_1\right] & n=(1,0), \\ \pi_S^{(0,1)}(x_2) = E\left[\sum_{i=1}^{2}(w_i-c_i)q_i \,\middle|\, X_2=x_2\right] & n=(0,1). \end{cases} \tag{8}$$

Table 4 Operations Subgame Equilibria in System RC, Without Horizontal Information Sharing

(n_1, n_2)	Decision policy	Ex-ante profit
(0, 0)	$w_i^{(0,0)} = w_i^0$	$\pi_{Ri}^{(0,0)} = \pi_{Ri}^0 + \dfrac{\sigma_u^2(\sigma_\varepsilon+\sigma_\mu)}{[\beta(\rho+\sigma_\mu)+2(\sigma_\varepsilon+\sigma_\mu)]^2}$
	$q_i^{(0,0)} = q_i^0 + Bx_i$	$\pi_S^{(0,0)} = \sum_{i=1}^{2}(w_i^0 - c_i)q_i^0$
(1, 1)	$w_i^{(1,1)} = w_i^0 + Bx_i + \dfrac{\beta}{2}Bx_{3-i}$	$\pi_{Ri}^{(1,1)} = \pi_{Ri}^0 + \dfrac{\sigma_u^2(\sigma_\varepsilon+\sigma_\mu)}{4[\beta(\rho+\sigma_\mu)+2(\sigma_\varepsilon+\sigma_\mu)]^2} + m_i$
	$q_i^{(1,1)} = q_i^0 + \dfrac{B}{2}x_i$	$\pi_S^{(1,1)} = \pi_S^{(0,0)} + \dfrac{\sigma_u^2}{2[\beta(\rho+\sigma_\mu)+2(\sigma_\varepsilon+\sigma_\mu)]} - m_1 - m_2$
(1, 0)	$w_1^{(1,0)} = w_1^0 + \left(1+\dfrac{\beta k}{2}\right)Bx_1$	$\pi_{R1}^{(1,0)} = \pi_{R1}^0 + \dfrac{\sigma_u^2(\sigma_\varepsilon+\sigma_\mu)}{4[\beta(\rho+\sigma_\mu)+2(\sigma_\varepsilon+\sigma_\mu)]^2} + m_1$
	$w_2^{(1,0)} = w_2^0 + \left(k+\dfrac{\beta}{2}\right)Bx_1$	$\pi_{R2}^{(1,0)} = \pi_{R2}^0 + \dfrac{\sigma_u^2[(1-2\beta)\rho^2+4\sigma_\varepsilon^2+2(2+\beta)\sigma_\varepsilon\sigma_\mu+\sigma_u^2-2\rho((2-\beta)\sigma_\varepsilon+(1+\beta)\sigma_\mu)]}{4(\sigma_\varepsilon+\sigma_\mu)[\beta(\rho+\sigma_\mu)+2(\sigma_\varepsilon+\sigma_\mu)]^2}$
	$q_1^{(1,0)} = q_1^0 + \dfrac{B}{2}x_1$	$\pi_S^{(1,0)} = \pi_S^{(0,0)} + \dfrac{\sigma_u^2[\rho^2+\sigma_\varepsilon^2+(2+\beta)\sigma_\varepsilon\sigma_\mu+(2+\beta)\sigma_u^2+\rho(\beta\sigma_\varepsilon+(2+\beta)\sigma_\mu)]}{2(\sigma_\varepsilon+\sigma_\mu)[\beta(\rho+\sigma_\mu)+2(\sigma_\varepsilon+\sigma_\mu)]^2} - m_1$
	$q_2^{(1,0)} = q_2^0 + Bx_2 - \dfrac{k}{2}Bx_1$	
(0, 1)	$w_1^{(0,1)} = w_1^0 + \left(k+\dfrac{\beta}{2}\right)Bx_2$	$\pi_{R1}^{(0,1)} = \pi_{R1}^0 + \dfrac{\sigma_u^2[(1-2\beta)\rho^2+4\sigma_\varepsilon^2+2(2+\beta)\sigma_\varepsilon\sigma_\mu+\sigma_u^2-2\rho((2-\beta)\sigma_\varepsilon+(1+\beta)\sigma_\mu)]}{4(\sigma_\varepsilon+\sigma_\mu)[\beta(\rho+\sigma_\mu)+2(\sigma_\varepsilon+\sigma_\mu)]^2}$
	$w_2^{(0,1)} = w_2^0 + \left(1+\dfrac{\beta k}{2}\right)Bx_2$	$\pi_{R2}^{(0,1)} = \pi_{R2}^0 + \dfrac{\sigma_u^2(\sigma_\varepsilon+\sigma_\mu)}{4[\beta(\rho+\sigma_\mu)+2(\sigma_\varepsilon+\sigma_\mu)]^2} + m_2$
	$q_1^{(0,1)}(x) = q_1^0 + Bx_1 - \dfrac{k}{2}Bx_2$	$\pi_S^{(0,1)} = \pi_S^{(0,0)} + \dfrac{\sigma_u^2[\rho^2+\sigma_\varepsilon^2+(2+\beta)\sigma_\varepsilon\sigma_\mu+(2+\beta)\sigma_u^2+\rho(\beta\sigma_\varepsilon+(2+\beta)\sigma_\mu)]}{2(\sigma_\varepsilon+\sigma_\mu)[\beta(\rho+\sigma_\mu)+2(\sigma_\varepsilon+\sigma_\mu)]^2} - m_2$
	$q_2^{(0,1)}(x) = q_2^0 + \dfrac{B}{2}x_2$	

Notes.

$$w_i^0 = \frac{a_i+c_i}{2}\; q_i^0 = \frac{2(a_i-c_i)-\beta(a_{3-i}-c_{3-i})}{2(4-\beta^2)}, \qquad B = \frac{\sigma_\mu}{(2+\beta)\sigma_\mu+2\sigma_\varepsilon+\beta\rho}, \qquad k = \frac{\sigma_\mu+\rho}{\sigma_\mu+\sigma_\varepsilon}, \qquad \pi_{Ri}^0 = \left(\frac{2(a_i-c_i)-\beta(a_{3-i}-c_{3-i})}{2(4-\beta^2)}\right)^2.$$

B captures a retailer's reliance on its own signal when ordering from the supplier, without any information flow.

We group the subgame equilibrium operation outcomes and the corresponding expected ex-ante profits of the supply chain parties when the retailers forfeit horizontal information sharing in Table 4.

Having access to retailer i's signal x_i only, the supplier will adjust wholesale price w_i by $B(1+\beta k/2)x_i$, which is independent of market competition and signal correlation, and w_{3-i} by $B(k+\beta/2)x_i$, which increases as competition intensifies or signal correlation strengthens. As $1+\beta k/2 > k+\beta/2$, w_i is more responsive to x_i than w_{3-i}. Retailer i will halve its reliance on x_i when ordering from the supplier, whereas retailer $3-i$ will lower its order by $(k\beta/2)x_i$, which decreases in β but increases in ρ. Vertical signal acquisition by the supplier from a retailer limits responsive ordering by both retailers, though to different extents. After gaining access to both signals, i.e., $n=(1,1)$, the supplier will rely more on x_i than x_{3-i} when adjusting w_i, and the two retailers will be mainly under the direct effect of information acquisition to halve their reliance on respective signals in ordering. The supplier's adjusted wholesale prices will decrease as signal correlation strengthens (ρ increases). As competition intensifies (β increases), the supplier will rely less on x_i but more on x_{3-i} when setting w_i.

Lemma 1. *In system RC where a supplier sells to two retailers, if the retailers do not share signals, let*

$$p_N^L = \frac{(\sigma_\varepsilon-\rho)\sigma_u^2(3\sigma_\varepsilon+2\sigma_\mu+2\beta\sigma_\mu-(1-2\beta)\rho)}{4(\sigma_\varepsilon+\sigma_\mu)(\beta(\rho+\sigma_\mu)+2(\sigma_\varepsilon+\sigma_\mu))^2} \quad \textit{and}$$

$$p_N^H = \frac{3\sigma_u^2(\sigma_\varepsilon+\sigma_\mu)}{4(\beta(\rho+\sigma_\mu)+2(\sigma_\varepsilon+\sigma_\mu))^2},$$

then $0 < p_N^L < p_N^H$, p_N^L *and* p_N^H *decrease in* β *and* ρ:

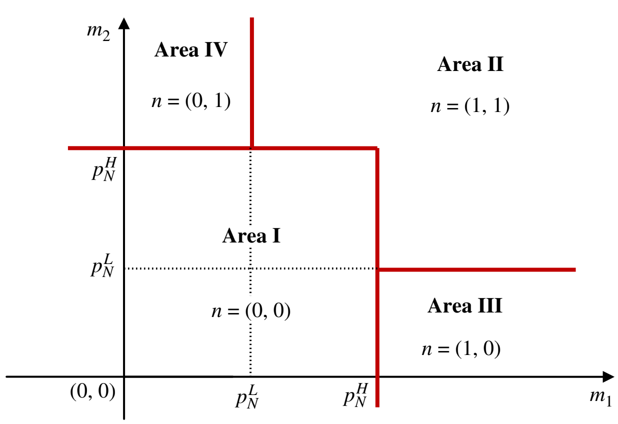
(1) $\pi_{R1}^{(0,0)} > \pi_{R1}^{(1,0)}$ *iff* $0 \le m_1 < p_N^H$; *and* $\pi_{R1}^{(0,1)} > \pi_{R1}^{(1,1)}$ *iff* $0 \le m_1 < p_N^L$.

(2) $\pi_{R2}^{(0,0)} > \pi_{R2}^{(0,1)}$ *iff* $0 \le m_2 < p_N^H$, *and* $\pi_{R2}^{(1,0)} > \pi_{R2}^{(1,1)}$ *iff* $0 \le m_2 < p_N^L$.

Lemma 1 states that without horizontal information sharing, if a retailer does not (does, resp.) disclose its signal to the supplier, the other retailer will disclose its signal only if the offered payment is higher than p_N^H (p_N^L, resp.). As $p_N^H > p_N^L > 0$, a retailer will suffer a profit loss after disclosing its signal to the supplier (direct effect), but its profit loss will reduce as the other retailer has disclosed its signal as well (carryover effect). $p_N^L \to 0$ as $\rho \to \sigma_\varepsilon$. That is, when the retailers' signals are sufficiently correlated, the supplier, already having access to a signal, can induce the other retailer to disclose its signal almost for free. In this case, additional signal availability to the supplier will trigger incremental effects on the profit of the retailer who discloses its signal. Both p_N^H and p_N^L decrease with β and ρ. More intense competition boosts the retailers' orders to reduce the pressure from the supplier's responsive wholesale pricing and signal-triggered adjustments will taper off as signal correlation strengthens. In these cases, the retailers' profit losses as a result of signal disclosure will reduce, making vertical information links more affordable for the supplier.

The retailers' signal-disclosure decisions given $m = (m_1, m_2)$ are illustrated in Figure 4. In each area of Figure 4, the equilibrium status of signal disclosure by the retailers is unique. Neither retailer will disclose its signal when the offered payments are low (Area I), only one retailer will disclose its signal if the offered payment is sufficiently higher than that offered to the other retailer (Areas III and IV) and both retailers will disclose signals otherwise (Area II). Note that if the supplier has to offer the same payments to the retailers as incentives, then either both retailers disclose their signals (at high payments) or neither of them does (at low payments). This is consistent with the finding in Ha et al. (2011). Differential payments are effective for the supplier to manipulate the retailers' incentives to disclose their signals and profit from their competitive relationship.

Figure 4 (Color online) Information Acquisition in System RC, Without Horizontal Information Sharing



Lemma 2. *In system RC where a supplier sells to two retailers, if the retailers do not exchange signals, let*

$$\beta_{RC}^{N1} = \frac{-2\rho^2 + \sigma_\varepsilon^2 - 4\rho\sigma_\mu + 2\sigma_\varepsilon\sigma_\mu - \sigma_u^2}{2(\sigma_\varepsilon + \sigma_\mu)(\rho + \sigma_\mu)},$$

$$\beta_{RC}^{N2} = \frac{\rho^2 - 4\rho\sigma_\varepsilon + 2\sigma_\varepsilon^2 - 2\rho\sigma_\mu - \sigma_u^2}{2(\rho + \sigma_\mu)^2}, \quad \text{and}$$

$$\beta_{RC}^{N3} = \frac{3\rho - \sigma_\varepsilon + 2\sigma_\mu}{2(\rho + \sigma_\mu)}, \quad \text{then:}$$

(1) *When* $\rho \ge (\sigma_\varepsilon - \sigma_\mu)^+/2$, *no information acquisition will occur if* $0 \le \beta \le \beta_{RC}^{N2}$; *bilateral information acquisition will occur, with payments* $m^* = (p_N^H, p_N^L)$ *or* $m^* = (p_N^L, p_N^H)$, *if* $\beta_{RC}^{N2} < \beta \le \beta_{RC}^{N3}$; *unilateral information acquisition will occur, with the supplier offering* p_N^H *to a retailer, if* $\beta_{RC}^{N3} < \beta < 1$.

(2) *When* $0 \le \rho < (\sigma_\varepsilon - \sigma_\mu)^+/2$, *no information acquisition will occur if* $0 \le \beta \le \beta_{RC}^{N1}$, *but unilateral information acquisition will occur, with the supplier offering* p_N^H *to a retailer, otherwise.*

If the retailers forfeit signal exchange, the supplier will have an incentive to acquire signals unless $\beta \le \beta_{RC}^{N1}$ when ρ is low or $\beta \le \beta_{RC}^{N2}$ when ρ is high. Both β_{RC}^{N1} and β_{RC}^{N2} decrease in ρ but increase in σ_ε. This implies that weaker signal correlation or lower signal accuracy can weaken the supplier's incentive to acquire signals. Only Case 1 in Lemma 2 applies when the signals are accurate enough ($0 \le \sigma_\varepsilon < \sigma_\mu$). In the case of weak competition with $0 < \beta \le \beta_{RC}^{N2}$, vertical acquisition will hurt the retailers' profits and make the supplier unable to afford the incentives required for signal solicitation. In the case of moderate competition with $\beta_{RC}^{N2} < \beta \le \beta_{RC}^{N3}$, the supplier will solicit both signals (bilateral information acquisition) by offering them differential payments. When there is intense competition with $\beta > \beta_{RC}^{N3}$, the supplier will be content by having access to one signal (unilateral information acquisition) as its profit gain from acquiring an additional signal will not be enough for it to afford the incentive. Although β_{RC}^{N3} increases, β_{RC}^{N2} decreases in ρ. Hence, the supplier will have a stronger incentive to acquire both signals as they become more indicative of each other. Case 2 of Lemma 2 will apply when the signal accuracy is weak ($\sigma_\varepsilon \ge \sigma_\mu$) and signal correlation is weak ($0 \le \rho < (\sigma_\varepsilon - \sigma_\mu)/2$); in this case, the supplier will not have much interest in gaining signal access and will acquire at most one signal when market competition is intense.

Suppose the retailers exchange signals. Their leveled signal availability correlates their decisions that rely on

Table 5 Operations Subgame Equilibria in System RC, with Horizontal Information Sharing

(n_1, n_2)	Decision policy	Ex-ante profit
(0, 0)	$w_i^{(0,0)} = w_i^0$	$\pi_{Ri}^{(0,0)} = \pi_{Ri}^0 + \dfrac{2\sigma_\mu^2}{(2+\beta)^2(\rho+\sigma_\varepsilon+2\sigma_\mu)}$
	$q_i^{(0,0)} = q_i^0 + C(x_1+x_2)$	$\pi_S^{(0,0)} = \sum_{i=1}^{2}(w_i^0 - c_i)q_i^0$
(1, 1)	$w_i^{(1,1)} = w_i^0 + \left(1+\dfrac{\beta}{2}\right)C(x_1+x_2)$	$\pi_{Ri}^{(1,1)} = \pi_{Ri}^0 + \dfrac{\sigma_\mu^2}{2(2+\beta)^2(\rho+\sigma_\varepsilon+2\sigma_\mu)} + m_i$
	$q_i^{(1,1)} = q_i^0 + \dfrac{C}{2}(x_1+x_2)$	$\pi_S^{(1,1)} = \pi_S^{(0,0)} + \dfrac{\sigma_\mu^2}{(2+\beta)(\rho+\sigma_\varepsilon+2\sigma_\mu)} - m_1 - m_2$
(1, 0)	$w_1^{(1,0)} = w_1^0 + \left(1+\dfrac{\beta}{2}\right)(1+k)Cx_1$	$\pi_{R1}^{(1,0)} = \pi_{R1}^0 + \dfrac{\sigma_\mu^2(2\sigma_\mu+5\sigma_\varepsilon-3\rho)}{4(2+\beta)^2(\sigma_\varepsilon+\sigma_\mu)(\rho+\sigma_\varepsilon+2\sigma_\mu)} + m_1$
	$w_2^{(1,0)} = w_2^0 + \left(1+\dfrac{\beta}{2}\right)(1+k)Cx_1$	$\pi_{R2}^{(1,0)} = \pi_{R2}^0 + \dfrac{\sigma_\mu^2(2\sigma_\mu+5\sigma_\varepsilon-3\rho)}{4(2+\beta)^2(\sigma_\varepsilon+\sigma_\mu)(\rho+\sigma_\varepsilon+2\sigma_\mu)}$
	$q_1^{(1,0)} = q_1^0 + \dfrac{1-k}{2}Cx_1 + Cx_2$	$\pi_S^{(1,0)} = \pi_S^{(0,0)} + \dfrac{\sigma_\mu^2}{2(2+\beta)(\sigma_\varepsilon+\sigma_\mu)} - m_1$
	$q_2^{(1,0)} = q_2^0 + \dfrac{1-k}{2}Cx_1 + Cx_2$	
(0, 1)	$w_1^{(0,1)} = w_1^0 + \left(1+\dfrac{\beta}{2}\right)(1+k)Cx_2$	$\pi_{R1}^{(0,1)} = \pi_{R1}^0 + \dfrac{\sigma_\mu^2(2\sigma_\mu+5\sigma_\varepsilon-3\rho)}{4(2+\beta)^2(\sigma_\varepsilon+\sigma_\mu)(\rho+\sigma_\varepsilon+2\sigma_\mu)}$
	$w_2^{(0,1)} = w_2^0 + \left(1+\dfrac{\beta}{2}\right)(1+k)Cx_2$	$\pi_{R2}^{(0,1)} = \pi_{R2}^0 + \dfrac{\sigma_\mu^2(2\sigma_\mu+5\sigma_\varepsilon-3\rho)}{4(2+\beta)^2(\sigma_\varepsilon+\sigma_\mu)(\rho+\sigma_\varepsilon+2\sigma_\mu)} + m_2$
	$q_1^{(0,1)}(x) = q_1^0 + \dfrac{1-k}{2}Cx_2 + Cx_1$	$\pi_S^{(0,1)} = \pi_S^{(0,0)} + \dfrac{\sigma_\mu^2}{2(2+\beta)(\sigma_\varepsilon+\sigma_\mu)} - m_2$
	$q_2^{(0,1)}(x) = q_2^0 + \dfrac{1-k}{2}Cx_2 + Cx_1$	

Notes.

$$w_i^0 = \frac{a_i+c_i}{2}, \qquad q_i^0 = \frac{2(a_i-c_i)-\beta(a_{3-i}-c_{3-i})}{2(4-\beta^2)}, \qquad C = \frac{\sigma_\mu}{(2+\beta)(2\sigma_\mu+\sigma_\varepsilon+\rho)},$$

$$k = \frac{\sigma_\mu+\rho}{\sigma_\mu+\sigma_\varepsilon}, \qquad \pi_{Ri}^0 = \left(\frac{2(a_i-c_i)-\beta(a_{3-i}-c_{3-i})}{2(4-\beta^2)}\right)^2.$$

$C(x_1+x_2)$ captures how a retailer utilized both signals when making order decisions, without any information flow.

the aggregated realized signal values. The operations subgame outcomes are grouped in Table 5. The supplier will now utilize the signals available from acquisition to make the same adjustment to the wholesale prices to the two retailers: $\sigma_\mu(x_1+x_2)/(2(2\sigma_\mu+\sigma_\varepsilon+\rho))$ once it has access to both signals and $\sigma_\mu(1+k)x_i/(2(2\sigma_\mu+\sigma_\varepsilon+\rho))$ once it has access to signal x_i. In the case when only retailer i discloses its signal, the direct effect of information acquisition will have retailer i rely less on x_i, whereas the carryover effect will cause retailer $3-i$ to rely less on x_i as well in ordering from the supplier. As retailer $3-i$ discloses signal x_{3-i} as well, it will halve its reliance on x_{3-i} but rely more on x_i. More intense competition or stronger signal correlation will weaken the signal reliance by the retailers and supplier in making responsive decisions.

Based on these subgame outcomes, we analyze the retailers' incentive to disclose signals and the supplier's decisions about signal prices. Lemma 3 characterizes the subgame equilibrium outcomes when the retailers share signals.

Lemma 3. *In system RC where a supplier sells to two retailers, if the retailers exchange signals, the supplier will offer $m^* = (p_S^L, p_S^H)$ or $m^* = (p_S^H, p_S^L)$ to gain access to the signals at both retailers, where,*

$$p_S^H = \frac{3\sigma_u^2}{4(2+\beta)^2(\sigma_\varepsilon+\sigma_\mu)} \quad \textit{and}$$

$$p_S^L = \frac{3\sigma_u^2(\sigma_\varepsilon-\rho)}{4(2+\beta)^2(\sigma_\varepsilon+\sigma_\mu)(\rho+\sigma_\varepsilon+2\sigma_\mu)}.$$

$p_S^H > p_S^L > 0$, $p_S^H < p_N^H$ and $p_S^L < p_N^L$, p_S^L decreases in β and ρ, p_S^H decreases in β.

Lemma 3 states that once the retailers exchange signals, the supplier will always acquire signals from them both by offering them differential payments as incentives. The payments p_S^H and p_S^L are the counterparts to p_N^H and p_N^L when the retailers forfeit signal exchange. Although p_S^H is insensitive to ρ, p_S^L decreases in ρ. This implies that signal correlation is not weighed by the supplier in its decision to initiate vertical information acquisition but, once having access to a signal, it will have a stronger incentive to set up an additional vertical information link as signal correlation strengthens. Since $p_S^H < p_N^H$ and $p_S^L < p_N^L$, signal exchange between the retailers, by leveling their signal availability, will reduce their profit losses from signal disclosure by mitigating the scales of the arising direct effects. This enables the supplier to acquire more signals. We can show that $p_N^H \to p_S^H$ and $p_S^L, p_N^L \to 0$, as $\rho \to \sigma_\varepsilon$. Hence, as the signals become more indicative of each other, the status of horizontal information sharing will have a less influence on the supplier's incentive in signal acquisition.

Knowing the pattern of the supplier's signal acquisition, the retailers make a cooperative decision on horizontal information sharing by weighing their profits from exchanging signals, in which case the supplier will always acquire their signals, against forfeiting this option, in which case the supplier's signal acquisition depends on signal structure and market competition. Proposition 2, assisted by Figure 5, reveals the information structure sustainable in system RC.

Proposition 2. *In system RC where a supplier sells to two retailers, the information structure is as shown in Figure 5:*

(1) *In Area* I, *neither horizontal information sharing nor vertical information acquisition will occur.*

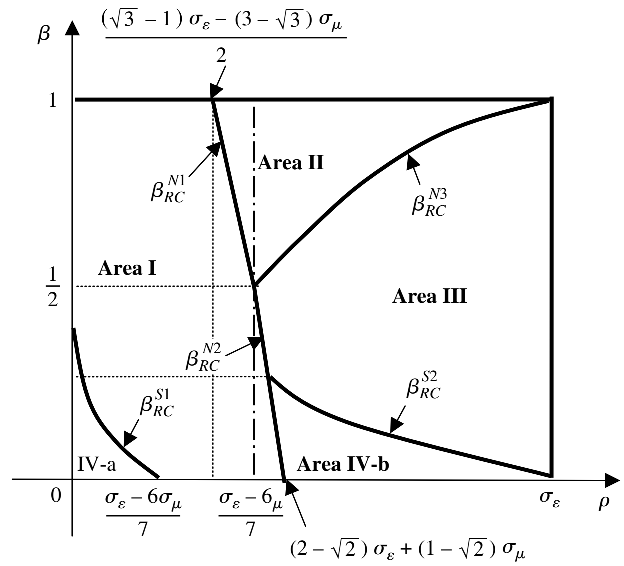
(2) *In Area* II, *no horizontal information sharing, but unilateral information acquisition will occur.*

(3) *In Area* III, *no horizontal information sharing, but bilateral information acquisition will occur.*

(4) *In Area* IV, *horizontal information sharing and bilateral information acquisition will both occur.*

Figure 5 illustrates the partitioning of (ρ, β) on $(0, \sigma_\varepsilon) \times (0, 1)$ to sustain information flow in system RC. Horizontal information sharing grants each retailer access to an additional signal and has a pooling effect. When competition is weak, the retailers do not face much pressure in making respective quantity decisions, so that enhanced signal availability endows them with more flexibility in ordering. When competition is intense, however, the retailers are under the high pressure of quantity competition and turn to be cautious in ordering from the supplier. Signal exchange causes each retailer to be cautious in signal utilization. As a result, the pooling effect is beneficial to the retailers by enhancing their flexibility in responsive ordering when competition is less intense, which provides a necessary condition to sustain horizontal information sharing.

Figure 5 **Information Structure Sustainable in System RC**



Notes. The partitioning is applicable when $\sigma_\varepsilon \geq 6\sigma_u$. The partitioning for other $(\sigma_\varepsilon \sigma_u)$ can be inferred. β_{RC}^{N1}, β_{RC}^{N2}, and β_{RC}^{N3} are as defined in Lemma 2. The expressions for the threshold levels of β_{RC}^{S1} and β_{RC}^{S2} can be found in the online appendix. The properties of all the threshold levels can be obtained upon request.

To effectively sustain signal exchange, the retailers each have to earn a higher profit by making this strategic move than by forfeiting this option, taking into consideration the supplier's signal acquisition. Note that the supplier will solicit signals from both retailers once they exchange signals. The retailers will then be exposed to the various effects of information acquisition and the pooling effect of information sharing. If the retailers forfeit signal exchange, market competition and signal correlation will jointly influence the supplier's decision on signal solicitation. As shown in Figure 5, the retailers are better off with signal exchange in Area IV-a and Area IV-b. Recall that the supplier forfeits signal acquisition (acquire both signals, resp.) if the retailers forfeit signal exchange in Area IV-a (Area IV-b, resp.). Weakened competition (β decreases) strengthens the retailers' incentive to exchange signals, whereas strengthened signal correlation (ρ increases) plays an opposite role. This can be observed in Figure 5, where the region to sustain both horizontal information sharing and bilateral vertical signal acquisition (Areas IV.a and IV.b) expands as β decreases but shrinks as ρ increases.

When horizontal signal exchange is not sustainable by the retailers, vertical signal acquisition by the supplier remains a feasible strategic move. By Figure 5, this form of information flow will occur when ρ is large or σ_ε is small. A strong signal correlation allows the supplier, with access to a signal, to infer with sufficient confidence the other signal for use in decision making and thus encourages it to establish vertical information links. The supplier is also drawn by high signal accuracy to acquiring signals and having its decisions aligned with those by the retailers. Note that when signal accuracy is high ($0 \le \sigma_\varepsilon < \sigma_u$), the supplier will acquire signals in most circumstances. Through acquisition, it gains access to one signal if β is sufficiently large (Area II) but both signals otherwise (Area III), and has a stronger tendency to acquire both signals as ρ increases (Area III expands with ρ). This is because as competition pressure on the retailers is relieved or the signals become more indicative of one another, given the supplier has access to one signal, additional signal availability to it will trigger only marginal effects in reshaping the interactions among channel parties. The retailers' profit losses as a result of signal disclosure will reduce. This will enable the supplier to afford enhanced signal availability.

Proposition 3. *In system RC where a supplier sells to two retailers, under incentive-driven information flow, the supplier will earn a higher profit, the customers will be worse off, and the retailers, while suffering profit losses in general, can be better off when signal correlation is weak.*

Proposition 3 states that the supplier always benefits from incentive-driven information flow. As demand signals are passed upstream, the direct effect of information acquisition will make the supplier better off with responsive wholesale pricing, limit the retailers' responsive ordering, and ultimately hurt customers. When only unilateral information acquisition is sustained (Area II in Figure 5), the supplier's payment (p_N^H) can compensate the signal-disclosing retailer just enough for its profit loss, whereas the carryover effect will make the other retailer suffer a profit loss. To build bilateral information acquisition, the supplier offers the retailers differential payments to manipulate their incentives in signal disclosure. Specifically, it can design payments such that both retailers dominantly prefer to disclose their signals, though they may earn higher profits by keeping signals to themselves. When the retailers forfeit signal exchange, bilateral information acquisition confers an information advantage to the supplier (Area III in Figure 5).

Horizontal information sharing between the retailers stimulates bilateral information acquisition by the supplier to realize information transparency. Under this circumstance, when signal correlation is weak (Area IV-a in Figure 5, existing when signal accuracy is low), the streamlined system-wide decision making resulting from information transparency will play a dominant role in improving system profit and the retailers will share part of the system profit gain. Otherwise (Area IV-b in Figure 5), the retailers will suffer profit losses under incentive-driven information flow. What drives them to exchange signals is that they will be even worse off if they forfeit this option as a result of signal solicitation by the supplier.

Chain-to-Chain Competition (System SRC)

In system SRC, two chains carry products and compete in selling in the market. Once a retailer commits to signal disclosure, it will disclose all the signals it has access to. In particular, a retailer will disclose the signals at both retailers when they are under horizontal information sharing but disclose its own signal otherwise. This assumption does not apply to system RC, where the monopolist supplier can directly gain access to the signal at each retailer. In the operations subgame after signals are observed and transmitted, the suppliers simultaneously offer wholesale prices to their retailers who choose order quantities to maximize their expected profits, as given in (6) and (7). When $n = (n_1, n_2) = (0, 0)$, each supplier i sets wholesale price, based on prior belief, to maximize its profit of $\pi_{Si}^{(0,0)} = E[(w_i - c_i)q_i]$.

When $n = (1, 1)$, vertical signal acquisition occurs in each chain. If the retailers forfeit signal exchange, supplier i will gain access to signal x_i only, and its profit function will be $\pi_{Si}^{(1,1)}(x_i) = \mathrm{E}[(w_i - c_i)q_i \mid X_i = x_i]$. If the retailers exchange signals, supplier i will gain access to both signals and its profit function will be $\pi_{Si}^{(1,1)}(x_1, x_2) = \mathrm{E}[(w_i - c_i)q_i \mid (X_1 = x_1, X_2 = x_2)]$. When $n = (1, 0)$, only supplier 1 has access to retailer 1's signal, and it will maximize its profit conditional on x_1 if the retailers forfeit signal exchange or conditional on (x_1, x_2) if the retailers exchange signals. The situation with $n = (0, 1)$ follows by symmetry, with the roles of the two suppliers swapped.

The subgame equilibrium outcomes and the corresponding profits when the retailers forfeit signal exchange are grouped in Table 6, and those when the retailers exchange signals are grouped in Table 7. Note that without information flow, the retailers in system SRC will use the signals available to them in the same way as when they order from a monopolist supplier in system RC. This is intuitive as the signals are not passed upstream so that the suppliers are unable to utilize them in wholesale pricing, and supplier competition does not affect how the retailers use their signals in decision making. Under information acquisition, however, upstream channel structure affects the retailers' signal utilization. Suppose that the retailers forfeit signal exchange. When the supplier acquires signal x_1 from retailer 1, i.e., $n = (1, 0)$, this retailer will halve its signal reliance in responsive ordering in both systems RC and SRC, whereas retailer 2 will strengthen its signal reliance in system SRC but weaken

Table 6 Operations Subgame Equilibria in System SRC, Without Horizontal Information Sharing

(n_1, n_2)	Decision policy	Ex-ante profit
(0, 0)	$w_i^{(0,0)} = w_i^0$	$\pi_{Ri}^{(0,0)} = \pi_{Ri}^0 + \dfrac{\sigma_\mu^2(\sigma_\epsilon+\sigma_\mu)}{(\beta\rho+2\sigma_\epsilon+(2+\beta)\sigma_\mu)^2}$
	$q_i^{(0,0)} = q_i^0 + Bx_i.$	$\pi_{Si}^{(0,0)} = (w_i^0 - c_i)q_i^0$
(1, 1)	$w_i^{(1,1)} = w_i^0 + Dx_i$	$\pi_{Ri}^{(1,1)} = \pi_{Ri}^0 + \dfrac{\sigma_\mu^2(\sigma_\varepsilon+\sigma_\mu)[(1-\beta)\beta^2\rho^2+(4+8\beta-3\beta^2)\sigma_\varepsilon^2-\beta(8-4\beta+\beta^2)\rho\sigma_\mu + 4\sigma_\mu^2-\sigma_\varepsilon(\beta(8-2\beta-\beta^2)\rho-(8+8\beta-4\beta^2+\beta^3)\sigma_\mu)]}{[-\beta\rho+4\sigma_\varepsilon+(4-\beta)\sigma_\mu]^2[\beta\rho+2\sigma_\varepsilon+(2+\beta)\sigma_\mu]^2} + m_i$
	$q_i^{(1,1)} = q_i^0 + Gx_i + Hx_{3-i}$	$\pi_{Si}^{(1,1)} = \pi_{Si}^{(0,0)} + \dfrac{2(4-\beta^2)\sigma_\mu^2(\sigma_\varepsilon+\sigma_\mu)^2}{[-\beta\rho+4\sigma_\varepsilon+(4-\beta)\sigma_\mu]^2[\beta\rho+2\sigma_\varepsilon+(2+\beta)\sigma_\mu]^2} - m_i$
(1, 0)	$w_1^{(1,0)} = w_1^0 + \dfrac{4-\beta^2}{4}Bx_1$	$\pi_{R1}^{(1,0)} = \pi_{R1}^0 + \dfrac{\sigma_\mu^2(\sigma_\varepsilon+\sigma_\mu)}{4[\beta\rho+2\sigma_\varepsilon+(2+\beta)\sigma_\mu]^2} + m_1$
	$w_2^{(1,0)} = w_2^0$	$\pi_{R2}^{(1,0)} = \pi_{R2}^0 + \dfrac{\sigma_\mu^2[4\beta^2\rho+(16+8\beta-3\beta^2)\sigma_\varepsilon+(4+\beta)^2\sigma_\mu]}{16[\beta\rho+2\sigma_\varepsilon+(2+\beta)\sigma_\mu]^2}$
	$q_1^{(1,0)} = q_1^0 + \dfrac{B}{2}x_1$	$\pi_{S1}^{(1,0)} = \pi_{S1}^{(0,0)} + \dfrac{(4-\beta^2)\sigma_\mu^2(\sigma_\varepsilon+\sigma_\mu)}{8[\beta\rho+2\sigma_\varepsilon+(2+\beta)\sigma_\mu]^2} - m_1$
	$q_2^{(1,0)} = q_2^0 + Bx_2 + \dfrac{\beta}{4}Bx_1$	$\pi_{S2}^{(1,0)} = \pi_{S2}^{(0,0)}$
(0, 1)	$w_1^{(0,1)} = w_1^0$	$\pi_{R1}^{(0,1)} = \pi_{R1}^0 + \dfrac{\sigma_\mu^2[4\beta^2\rho+(16+8\beta-3\beta^2)\sigma_\varepsilon+(4+\beta)^2\sigma_\mu]}{16[\beta\rho+2\sigma_\varepsilon+(2+\beta)\sigma_\mu]^2}$
	$w_2^{(0,1)} = w_2^0 + \dfrac{4-\beta^2}{4}Bx_2$	$\pi_{R2}^{(0,1)} = \pi_{R2}^0 + \dfrac{\sigma_\mu^2(\sigma_\varepsilon+\sigma_\mu)}{4[\beta\rho+2\sigma_\varepsilon+(2+\beta)\sigma_\mu]^2} + m_2.$
	$q_1^{(0,1)}(x) = q_1^0 + Bx_1 + \dfrac{\beta}{4}Bx_2.$	$\pi_{S1}^{(0,1)} = \pi_{S1}^{(0,0)}$
	$q_2^{(0,1)}(x) = q_2^0 + \dfrac{B}{2}x_2$	$\pi_{S2}^{(0,1)} = \pi_{S2}^{(0,0)} + \dfrac{(4-\beta^2)\sigma_\mu^2(\sigma_\varepsilon+\sigma_\mu)}{8[\beta\rho+2\sigma_\varepsilon+(2+\beta)\sigma_\mu]^2} - m_2$

Notes.

$$w_i^0 = \frac{(8-\beta^2)a_i - 2\beta a_{3-i} + 8c_i + 2\beta c_{3-i}}{16-\beta^2}, \qquad q_i^0 = \frac{2((8-\beta^2)(a_i-c_i) - 2\beta(a_{3-i}-c_{3-i}))}{64-20\beta^2+\beta^4}, \qquad B = \frac{\sigma_\mu}{(2+\beta)\sigma_\mu + 2\sigma_\varepsilon + \beta\rho},$$

$$D = \frac{\sigma_\mu(4-\beta^2)(\sigma_\varepsilon+\sigma_\mu)}{(4\sigma_\varepsilon+(4-\beta)\sigma_\mu-\beta\rho)((2+\beta)\sigma_\mu+2\sigma_\varepsilon+\beta\rho)}, \qquad G = \frac{\sigma_\mu(2\sigma_\varepsilon+(2-\beta)\sigma_\mu-\beta\rho)}{(4\sigma_\varepsilon+(4-\beta)\sigma_\mu-\beta\rho)((2+\beta)\sigma_\mu+2\sigma_\varepsilon+\beta\rho)},$$

$$H = \frac{\beta\sigma_\mu(\sigma_\varepsilon+\sigma_\mu)}{(4\sigma_\varepsilon+(4-\beta)\sigma_\mu-\beta\rho)((2+\beta)\sigma_\mu+2\sigma_\varepsilon+\beta\rho)}, \qquad \pi_{Ri}^0 = \left(\frac{2((8-\beta^2)(a_i-c_i) - 2\beta(a_{3-i}-c_{3-i}))}{64-20\beta^2+\beta^4}\right)^2.$$

it in system RC. This can be attributed to the carryover effect of signal acquisition from a retailer that exerts different impacts on the other retailer not involved in this acquisition. With $n = (1, 1)$, both retailers will rely on their own signals when ordering from the supplier in system RC, but will utilize both signals in system SRC. The acquired signals will have a less influence on the retailers' order quantities as signal correlation strengthens. That is, signal correlation will force the retailers to limit their utilization of the pooled signals in decision making.

Suppose the retailers exchange signals. After a supplier acquires signal from its exclusive retailer, it will access both signals so that its responsive wholesale price and the retailer's order will depend on the aggregated signal values. This particular supplier's signal utilization in wholesale pricing, however, is influenced by the status of signal acquisition in the competing chain. Particularly, it will rely more on the signals if the other supplier acquires signal than otherwise. This observation can be made by comparing the coefficients of $(x_1 + x_2)$ in $w_1^{(1,1)}$ and $w_1^{(1,0)}$, which gives $((4-\beta^2)/(4-\beta))C > ((4-\beta^2)/4)C$. When only one retailer discloses signals to its supplier, this particular retailer will rely less on the signals in ordering than its counterpart in the competing chain. Take $n = (1, 0)$ for

Table 7 **Operations Subgame Equilibria in System SRC, with Horizontal Information Sharing**

(n_1, n_2)	Decision policy	Ex-ante profit
(0, 0)	$w_i^{(0,0)} = w_i^0$	$\pi_{Ri}^{(0,0)} = \pi_{Ri}^0 + \dfrac{2\sigma_\mu^2}{(2+\beta)^2(\rho+\sigma_\varepsilon+2\sigma_\mu)}$
	$q_i^{(0,0)} = q_i^0 + C(x_1+x_2)$	$\pi_{Si}^{(0,0)} = (w_i^0 - c_i)q_i^0$
(1, 1)	$w_i^{(1,1)} = w_i^0 + \dfrac{4-\beta^2}{4-\beta}C(x_1+x_2)$	$\pi_{Ri}^{(1,1)} = \pi_{Ri}^0 + \dfrac{8\sigma_\mu^2}{(4-\beta)^2(2+\beta)^2(\rho+\sigma_\varepsilon+2\sigma_\mu)} + m_i$
	$q_i^{(1,1)} = q_i^0 + \dfrac{2}{4-\beta}C(x_1+x_2)$	$\pi_{Si}^{(1,1)} = \pi_{Si}^{(0,0)} + \dfrac{4(2-\beta)\sigma_\mu^2}{(4-\beta)^2(2+\beta)(\rho+\sigma_\varepsilon+2\sigma_\mu)} - m_i$
(1, 0)	$w_1^{(1,0)} = w_1^0 + \dfrac{4-\beta^2}{4}C(x_1+x_2)$	$\pi_{R1}^{(1,0)} = \pi_{R1}^0 + \dfrac{\sigma_\mu^2}{2(2+\beta)^2(\rho+\sigma_\varepsilon+2\sigma_\mu)} + m_1$
	$w_2^{(1,0)} = w_2^0.$	$\pi_{R2}^{(1,0)} = \pi_{R2}^0 + \dfrac{(4+\beta)^2\sigma_\mu^2}{8(2+\beta)^2(\rho+\sigma_\varepsilon+2\sigma_\mu)}$
	$q_1^{(1,0)} = q_1^0 + \dfrac{C}{2}(x_1+x_2)$	$\pi_{S1}^{(1,0)} = \pi_{S1}^{(0,0)} + \dfrac{(2-\beta)\sigma_\mu^2}{4(2+\beta)(\rho+\sigma_\varepsilon+2\sigma_\mu)} - m_1$
	$q_2^{(1,0)} = q_2^0 + \left(1+\dfrac{\beta}{4}\right)C(x_1+x_2)$	$\pi_{S2}^{(1,0)} = \pi_{S2}^{(0,0)}$
(0, 1)	$w_1^{(0,1)} = w_1^0$	$\pi_{R1}^{(0,1)} = \pi_{R1}^0 + \dfrac{(4+\beta)^2\sigma_\mu^2}{8(2+\beta)^2(\rho+\sigma_\varepsilon+2\sigma_\mu)}$
	$w_2^{(0,1)} = w_2^0 + \dfrac{4-\beta^2}{4}C(x_1+x_2)$	$\pi_{R2}^{(0,1)} = \pi_{R2}^0 + \dfrac{\sigma_\mu^2}{2(2+\beta)^2(\rho+\sigma_\varepsilon+2\sigma_\mu)} + m_2$
	$q_1^{(0,1)}(x) = q_1^0 + \left(1+\dfrac{\beta}{4}\right)C(x_1+x_2)$	$\pi_{S1}^{(0,1)} = \pi_{S1}^{(0,0)}$
	$q_2^{(0,1)}(x) = q_2^0 + \dfrac{C}{2}(x_1+x_2)$	$\pi_{S2}^{(0,1)} = \pi_{S2}^{(0,0)} + \dfrac{(2-\beta)\sigma_\mu^2}{4(2+\beta)(\rho+\sigma_\varepsilon+2\sigma_\mu)} - m_2$

Notes.

$$w_i^0 = \frac{(8-\beta^2)a_i - 2\beta a_{3-i} + 8c_i + 2\beta c_{3-i}}{16-\beta^2}, \qquad q_i^0 = \frac{2((8-\beta^2)(a_i-c_i) - 2\beta(a_{3-i}-c_{3-i}))}{64-20\beta^2+\beta^4}, \qquad C = \frac{\sigma_\mu}{(2+\beta)(2\sigma_\mu+\sigma_\varepsilon+\rho)},$$

$$\pi_{Ri}^0 = \left(\frac{2((8-\beta^2)(a_i-c_i) - 2\beta(a_{3-i}-c_{3-i}))}{64-20\beta^2+\beta^4}\right)^2.$$

instance. Retailer 1, after disclosing its signals, adjusts its order quantity by $(C/2)(x_1+x_2)$, whereas retailer 2, who does not disclose signals, adjusts its order quantity by $(1+\beta/4)C(x_1+x_2)$, with $1/2 < 1+\beta/4$. This can be attributed to the spillover effect arising from product substitutability.

Based on the subgame equilibrium outcomes, we analyze the suppliers' incentives to build vertical information links.

Lemma 4. *Under chain-to-chain competition in system SRC, irrespective of the status of horizontal information sharing, vertical information acquisition is unsustainable in either chain.*

Vertical information acquisition is unsustainable in the setting of chain-to-chain competition. This echoes the finding in Ha and Tong (2008) that study a similar setting but without the option of horizontal information sharing between the retailers. We complement their finding to show that the suppliers have no incentive to acquire signals when the retailers exchange signals. This is because horizontal competition between the suppliers aggravates the direct effect arising from information acquisition by a supplier from its exclusive retailer to lower the retailer's profit, and unilateral decision making deprives each supplier of the incentive to afford signal acquisition. Compared with system SC, the suppliers in system SRC face more intense horizontal competition by selling to competing retailers. Now that the retailers' signals will not flow upstream, horizontal information sharing is the only feasible form of information flow in system SRC.

PROPOSITION 4. *Under chain-to-chain competition in system SRC, horizontal information sharing will occur if*

$$\beta < \beta_{SRC} \triangleq \frac{2\left[\sqrt{2(\sigma_\mu+\sigma_\varepsilon)(2\sigma_\mu+\sigma_\varepsilon+\rho)}-(\sigma_\mu+\sigma_\varepsilon)\right]}{3\sigma_\mu+\sigma_\varepsilon+2\rho},$$

while information acquisition is unsustainable.

The retailers in system SRC will forfeit signal exchange if market competition is intense ($\beta > \beta_{SRC}$). As β_{SRC} decreases in ρ, information collaboration is more likely to be sustained when the signals are less correlated. That is, a strengthened signal correlation will mitigate the retailers' incentive to share signals. As the signals are more correlated with each other, the retailers, after signal exchange, will limit their signal utilization and hence be less flexible in responsive ordering. This will reduce the benefit they can extract from the pooling effect. Recall that in system RC, the retailers will not share signals when $\beta > \max\{\beta_{RC}^{N2}, \beta_{RC}^{S2}\}$ or $\beta > \beta_{RC}^{S1}$ (see Figure 5). It can be verified that $\beta_{SRC} > \max\{\beta_{RC}^{S1}, \beta_{RC}^{S2}, \beta_{RC}^{N2}\}$. The retailers have a stronger incentive to exchange signals when they each order from an independent supplier than when they order from the same supplier. Recall that signal exchange will stimulate bilateral vertical signal acquisition in system RC, which will have detrimental effects on the retailers, whereas it will not induce the suppliers into establishing any vertical information links in system SRC and thus deliver no impact on the retailers. As a result, compared with system SRC, signal exchange is sustainable in a less competitive market in system RC, for the pooling effect to be sufficiently strong to outweigh the negative direct effect of information acquisition on the retailers.

Remarks and Discussions

We next investigate two issues that are related to our study. One issue is the decision sequence whereby the suppliers and retailers build an information structure. The other is the availability to multiple signals by the retailers, which has not been much tapped in the existing literature.

Information decision sequence. Our investigation when both forms of information flow are valid options is under the sequence where the retailers first make a decision to exchange signals and the suppliers then offer them payments for signal acquisition. We have examined an alternative sequence in which the suppliers make the first move to get signals and the retailers then decide on signal exchange. The operations subgame remains unchanged once an information structure is established. With our assumptions about signal structure, we find that the sustainable information structures are quite robust. In system RC, referring to Figure 5, the area in which both horizontal information sharing and bilateral information acquisition are sustained (Area IV) will expand under the alternative sequence, whereas the other areas will shrink. It is intuitive that with the supplier making the first move for signal acquisition, the retailers will be less concerned about signal exchange because the supplier will be unable to extract their signal-based profit gains as it does under the original decision sequence. In system SRC under the alternative sequence, the suppliers still will not acquire any signals and the retailers' decision regarding horizontal information sharing will be the same as that under the original sequence.

Multiple signals. Under the assumption that each retailer has access to a demand signal, we have shown that the retailers' signals can be passed upstream only in a specific channel structure (system RC). However, vertical data communication often happens in practice. To shed more light on this phenomenon, we extend our model setting to include multiple signal access. A retailer can have access to data from multiple sources. Under the retailer-direct data exchange mode, the supplier can acquire multiple signals in a single transaction and, as anecdotal evidence indicates, simply pay the retailer to "Give me the data on a CD" (Dolley et al. 2009, p. 15). We revisit the bilateral monopoly (system B) by letting the retailer have access to multiple signals and assuming that the signal structure satisfies the following assumptions.

Signal structure I. The full signal set at the retailer $s=(X_1, X_2, \ldots, X_N)$, $N \geq 1$, is multivariate normal.

$X_i = \mu_i + \varepsilon_i$, $i = 1, \ldots N$, *where*

$$\mu_i \sim N(0, \sigma_\mu), \quad \varepsilon_i \sim N(0, \sigma_\varepsilon);$$

$$\operatorname{cov}(\mu_i, \varepsilon_j) = 0; \quad \operatorname{cov}(\mu_i, \mu_j) = h \in (0, \sigma_\mu);$$

$$\operatorname{cov}(\varepsilon_i, \varepsilon_j) = \rho \in (0, \sigma_\varepsilon), \quad i \neq j,$$

$$\mu = \frac{\sum_{i=1}^N \mu_i}{N}.$$

These assumptions are consistent with those in Gal-Or (1985). By the decision sequence in Figure 2, the supplier first offers a signal price m to the retailer who then chooses the number n of signals to disclose. Let $\hat{s} = (x_1, x_2, \ldots, x_n)$, $0 \leq n \leq N$, be the signals acquired by the supplier. In the operations subgame, the supplier and retailer maximize their respective profits of $\pi_S(\hat{s}) = E\{\sum_{i=1}^2 (w_i - c_i)q_i \mid \hat{s}\}$, and $\pi_R(s, \hat{s}) = E[\sum_{i=1}^2 (a_i + \mu - q_i - \beta q_{3-i} - w_i)q_i] \mid (s, \hat{s})$. The outcomes are:

$$w_i(\hat{s}) = \frac{a_i + c_i + \hat{M}(n)}{2}, \quad \text{and}$$
$$q_i(s, \hat{s}) = \frac{a_i - c_i - \beta(a_{3-i} - c_{3-i})}{4(1-\beta^2)} + \frac{2M - \hat{M}(n)}{4(1+\beta)}, \tag{9}$$

where

$$M = \frac{\sigma_\mu}{\sigma_\mu + \sigma_\varepsilon} \cdot \frac{\sum_{i=1}^N x_i}{N} \quad \text{and}$$

$$\hat{M}(n) = \frac{\sigma_\mu}{\sigma_\mu + \sigma_\varepsilon} \cdot \frac{n(\sigma_\mu + \sigma_\varepsilon) + n(N-1)(h+\rho)}{N(\sigma_\mu + \sigma_\varepsilon) + N(n-1)(h+\rho)} \cdot \frac{\sum_{i=1}^n x_i}{n}.$$

These decisions depend on signal values only through their mean. Rather than providing n signals in a package, the retailer can pass their average statistics to the supplier. The expected ex-ante system profit is $\pi_T = \pi_T^0 + \Delta\pi_T(n, N)$, where π_T^0 is the system profit without information flow and $\Delta\pi_T(n, N)$ is attributed to vertical signal flow (the expressions for π_T^0 and $\Delta\pi_T(n, N)$ are available upon request). It can be verified that $\Delta\pi_T > 0$ if

$$h < h_A \triangleq \frac{3\sigma_\mu \rho}{4\sigma_\varepsilon + \sigma_\mu} \quad \text{and}$$

$$N > N_A \triangleq 1 + \frac{\sigma_\mu \sigma_\varepsilon + \sigma_u^2}{3\sigma_\mu \rho - (4\sigma_\varepsilon + \sigma_\mu)h},$$

which we call the *transaction condition*. Given $\Delta\pi_T > 0$, $\Delta\pi_T$ increases with n. That is, the system profit gain from vertical information acquisition will increase as the retailer discloses more signals to the supplier.

In the information subgame, given signal price m, the retailer chooses the number n of signals to disclose by maximizing its expected ex-ante profit of

$$\pi_R(n \mid m) = \mathrm{E} \sum_{i=1}^{2} (a_i + \mu - q_i - \beta q_{3-i} - w_i) q_i + nm, \quad (10)$$

where the expectation is taken with respect to the observed and transacted signals. The supplier chooses signal payment m to maximize its expected ex-ante profit of

$$\pi_S(m) = \mathrm{E} \sum_{i=1}^{2} (w_i(\hat{s}) - c_i) q_i(s, \hat{s}) - nm. \quad (11)$$

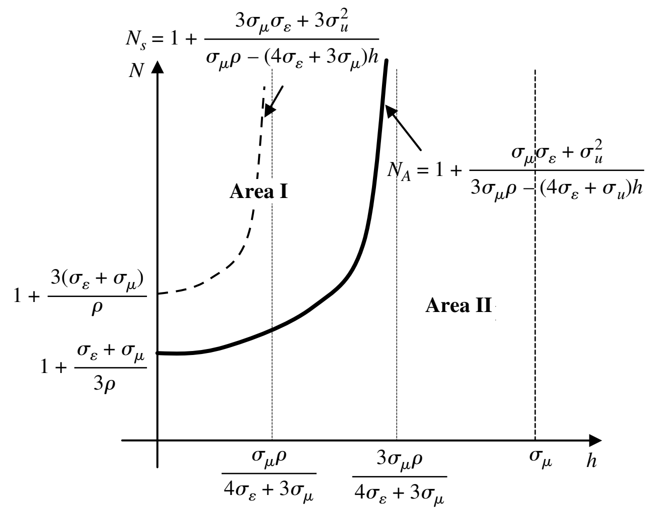
Proposition 5. *In the bilateral monopoly, where a supplier sells to a retailer that has multiple signals, vertical information acquisition will occur under the transaction condition, when the supplier offers*

$$m^* = \frac{3\sigma_u^2(\sigma_u + \sigma_\varepsilon) + (N-1)(3\sigma_u^2 h + 4\sigma_\mu \sigma_\varepsilon h - \sigma_u^2 \rho)}{8(1+\beta)N^2(\sigma_u + \sigma_\varepsilon)^2}$$

to acquire $n^* = N$ signals.

As shown in the transaction condition and illustrated in Figure 6, vertical information acquisition will occur when signal quantity N is large and signal correlation h is weak (Area I). Once it occurs, the supplier and retailer will have the same signal availability. Data communication between the retailer and supplier, with the direct effect thus brought about, improves the supplier's responsiveness but restricts the retailer's ordering responsiveness. With the supplier acquiring all signals, information transparency is realized, the positive influence of which on system performance will strengthen as the number of signals increases or the signals are weakly correlated. Under the transaction condition on signal number and correlation, the streamlined decision making resulting from information transparency will improve system profit, enabling the supplier to afford the incentive required for the retailer to disclose its signals.

Figure 6 Information Acquisition Equilibrium in a Bilateral Monopoly



Signal price is negative when

$$h < h_S \triangleq \frac{\sigma_\mu \rho}{4\sigma_\varepsilon + 3\sigma_\mu} \quad \text{and}$$

$$N > N_S \triangleq 1 + \frac{3\sigma_\mu(\sigma_\varepsilon + \sigma_\mu)}{\sigma_\mu \rho - (4\sigma_\varepsilon + 3\sigma_\mu)h}$$

(the area in Figure 6 between the dashed curve and the vertical axis). In this situation, the retailer can physically benefit from disclosing its signals to the supplier. The retailer is worse off by utilizing all signals, which are weakly correlated, in ordering than when it has no signals, given that the supplier makes wholesale price decisions based on its prior belief about these signals. Vertical information sharing is able to align the supplier's wholesale pricing and the retailer's ordering. This benefits not only the supplier but the retailer as well. It is challenging to investigate incentive-driven information flow in more involved structures in which the retailers have multiple signals because of the substantially expanded problem dimensions. We conjecture that a sufficiently large number of signals with weak correlations at a retailer can facilitate vertical information acquisition.

4. Comparative Analysis and Managerial Insights

The results that we have obtained so far provide sufficient clues for us to investigate the issues that have motivated this study.

Table 8 Information Structures in Two-Tier Supply Chains

Structure	B	SC	RC	SRC
Horizontal supplier competition	No	Yes	No	Yes
Horizontal retailer competition	No	No	Yes	Yes
Horizontal information sharing	NA	NA	Sustainable if β is low	Sustained if β is low
Vertical information acquisition	Unsustainable	Unsustainable	Sustained if ρ is sufficiently high: unilateral if β is high, and bilateral otherwise	Unsustainable
Information sharing and information acquisition	NA	NA	Sustained when β is low and ρ is moderate	Unsustainable

Sustainability of Incentive-Driven Information Flow
Table 8 groups the information structures that are sustainable in the four representative channel structures. Incentive-driven information flow will not occur in a bilateral monopoly (system B). This is because the direct effect of information acquisition will lower system profit, to make the supplier's profit gain not enough to compensate the retailer for its loss. With two independent suppliers providing for a monopolist retailer (system SC), supplier competition will aggravate the direct effect of information acquisition to worsen the retailer's profit and their unilateral decision making will deprive each supplier of its incentive to acquire signal. With retailer competition only (system RC), a necessary condition to sustain horizontal signal exchange is that competition is less intense, when the pooling effect can enhance the retailers' ordering responsiveness. The supplier can be driven by higher signal accuracy and stronger signal correlation to acquire signals, by offering the retailers differential payments to manipulate their incentives in signal disclosure. The conditions for full-scale information flow that involves both horizontal information sharing and bilateral information acquisition are as follows: (1) an asymmetric channel structure with a monopolist upstream supplier and competing downstream retailers; (2) not-too-intense market competition; and (3) reasonably accurate and correlated demand signals available to the retailers. In system SRC, supplier competition precludes information acquisition but the retailers will exchange signals when market competition is less intense.

With retailer competition, elimination of supplier competition is a necessary condition for the retailers' signals to move upstream and this vertical information flow will be more sustainable as signal accuracy improves and signal correlation strengthens. Ample anecdotal evidence indicates that retailers have "boosted the frequency and scope of communication with vendors" (Interbrand Design Forum 2003). Although part of the reason for this boost can be attributed to the increasing popularity of sharing programs between retailers and their upstream partners, we can base on our findings to offer an alternative explanation. After suppliers undergo waves of consolidation through mergers and acquisitions, only few suppliers remain to provide for major competitors in the market. This change in channel structure mitigates the competition pressure on the suppliers who will then have a stronger incentive than ever to acquire signals from the retailers. This incentive will further strengthen as the retailers' signals become more correlated.

Horizontal information sharing can be sustained provided that market competition is less intense, the main driver for which is to enhance the retailers' responsiveness in ordering. An article in Venture Beat on the WalMart–Target initiative for MCX argues that "it is all about customer data" (Carpenter 2012). As two supporters of MCX, WalMart caters to larger families with lower incomes (blue-collar segment) but Target aims at medium-sized families with higher incomes (middle-class segment). The difference in consumer segment makes their product offerings not quite substitutable: Target focuses on more stylish and higher quality products than WalMart. With sophisticated IT systems and correlated sales, MCX may well provide a platform for them to share customer information and strengthen order responsiveness. With a shrinking supply base, such horizontal information sharing can stimulate vertical information acquisition, as exemplified by the joint venture of CVS, Kmart, and WalMart into data sharing that triggered data acquisition by major drug makers. We anticipate that system-wide information transparency will be enhanced as more retailers initiate customer information sharing and the trend of decompetition continues on the supply side.

Profit Implication of Information Flow
The pattern of information flow determines the signals that are available to supply chain parties who will utilize the signals in responsive decision making. This will have a substantial impact on their performance. We use $\Delta\pi_k^m$ to denote the profit gain to member k and ΔCS^m the change in consumer welfare in system m that can be attributed to information flow. Member k can be s for the supplier in system RC, s_i for supplier i in system SC or SRC, R for the retailer in system B or SC, R_i for retailer i in system RC or SRC, and T for total profit. System m can be B, RC, SC, or SRC.

Proposition 6. *Under incentive-driven information flow we have the following*:

(1) $\Delta\pi_S^{RC} \geq \sum_i \Delta\pi_{Si}^{SRC}$, $\sum_i \Delta\pi_{Ri}^{RC} \leq \sum_i \Delta\pi_{Ri}^{SRC}$, $\Delta\pi_T^{RC} \leq \Delta\pi_T^{SRC}$, $\Delta CS^{RC} \leq \Delta CS^{SRC}$.

(2) $\sum_i \Delta\pi_{Si}^{SC} = \sum_i \Delta\pi_{Si}^{SRC} = 0$; $\Delta\pi_R^{SC} > \sum_i \Delta\pi_{Ri}^{SRC}$; $\Delta\pi_T^{SC} > \Delta\pi_T^{SRC}$; $\Delta CS^{SRC} > \Delta CS^{SC}$ if $\beta < \beta_{SRC}$.

(3) $\Delta\pi_R^B = \Delta\pi_R^{SC}$, $\Delta\pi_S^B = 0 = \Delta\pi_S^{SC}$, $\Delta\pi_T^B = \Delta\pi_T^{SC}$, $\Delta CS^B = \Delta CS^{SC}$.

(4) $\Delta\pi_R^B > \Delta\pi_R^{RC}$, $\Delta\pi_S^B = 0 \leq \Delta\pi_S^{RC}$, $\Delta\pi_T^B > \Delta\pi_T^{RC}$, $\Delta CS^B > \Delta CS^{RC}$.

With retailer competition, elimination of upstream competition strengthens the suppliers' power in vertical interaction. Information-wise, this structural change encourages the suppliers to acquire signals but discourages the retailers from exchanging signals. By part (1) of Proposition 6, compared with system SRC, the retailers in system RC earn less signal-based profits but the suppliers profit from the enhanced signal availability in responsiveness wholesale pricing. The system will suffer a profit loss and the customers will be worse off. Circumstances exist in which the retailers exchange signals and the suppliers forfeit signal acquisition in system SRC, but the retailers forfeit signal exchange and the supplier acquires signals in system RC. Even so, however, the direct effect of information acquisition will be strong enough to take away the benefit from the pooling effect of signal exchange and cause the retailers to suffer profit losses. Under horizontal competition, the suppliers have no incentive to acquire signals. This is because of their unilateral decision making that makes it the dominant strategy for each supplier not to acquire signals. By part (2) of Proposition 6, compared with competing retailers, a monopolist retailer can make better use of the signals in responsive ordering. This, together with a strengthened channel position, allows the retailer to extract a larger profit gain. The entire system profits less from incentive-driven information flow with retailer competition than without. However, the customers can benefit from retailer competition. This occurs when competition is weak ($\beta < \beta_{SRC}$), in which case the competing retailers will exchange signals and the increased product availability will benefit the customers. The information structures sustained in system SC and system B are identical. By part (3), with the supplier(s) having no signal availability, the monopolist retailer makes the same signal utilization in ordering and the signal-based system profit and consumer welfare are the same in the two systems. Part (4) states that with a monopolist supplier, retailer competition can drive the supplier to establish vertical information links. The direct effect that arises from vertical information acquisition will make the retailers lose profits. System profit and consumer welfare will be worse off as well.

5. Concluding Remarks

We have investigated incentive-driven information flow in two-tier supply chains, where retailers order from suppliers and sell substitutable products in a market with uncertain demand. The retailers each have access to a demand signal and their signals are correlated. They can exchange signals with each other to engage in horizontal information sharing, whereas the suppliers can offer them differential payments as incentives to disclose their signals through vertical information acquisition. Information acquisition by a supplier from a retailer has several effects on channel parties. The direct effect benefits the supplier with enhanced responsiveness in wholesale pricing, but hurts the retailer by limiting its responsive ordering. The indirect effect, which is present when the retailer orders from independent suppliers, makes the retailer enhance its signal utilization to be more flexible in ordering from the supplier not involved in signal acquisition. The carryover effect is present with retailer competition and has mixed influences on the retailer not involved in signal acquisition. Horizontal information sharing between the retailers results in a pooling effect that can strengthen their ordering responsiveness when market is less competitive. Channel structure, signal structure, and market competition jointly affect the interactions among these effects to influence the profit performance of and hence the incentives for the suppliers and retailers to engage in information communication.

Our results indicate that retailer competition is necessary for information flow of any form to be sustained, while supplier competition precludes vertical information acquisition. Horizontal information sharing can stimulate vertical information acquisition when competing retailers order from a monopolist supplier, who solicits signals by offering the retailers differential payments to manipulate their incentives in signal disclosure. As signal correlation strengthens, the suppliers will have a stronger incentive to acquire signals, whereas the retailers will have a weaker incentive to exchange signals. It can be incentive compatible for the retailers' signals to be made available to all channel parties through incentive-driven information flow. Under this circumstance, the supplier will profit from information flow and the retailers can be better off as well, but the customers will experience higher prices and lower product availability.

Our work paves the way to investigate incentive-driven information flow in more general supply chains that involve more than two tiers. A network approach needs to be developed to tackle the myriad layers of competitive and cooperative forces that can exist. In this paper, the relationships in the vertical channel are governed by price-only contracts. Given the intricate interplay between information sharing by retailers and information acquisition by suppliers, it is worth the effort to examine the robustness of our findings with respect to contract format through an examination of commonly used contracts such as revenue sharing contract and two-part tariff contract. Moreover, in reality, the suppliers' costs can be privately known. Such knowledge, together with the exclusive demand information access to the retailers, produces a setting with two-sided information asymmetry. It will be an important extension to extend the scope of the investigation to include both demand and cost information sharing in supply chains.

Supplemental Material

Supplemental material to this paper is available at http://dx.doi.org/10.1287/msom.2016.0575.

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